BOTTOM-UP MODEL FOR INTERCONNECTION

DESCRIPTION OF THE METHODOLOGY

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1. INTRODUCTION

This document is intended to describe the methodology and principles behind the Bottom Up Total Element Long Run Average Incremental Cost Model (BU-TELRAIC), which was developed by the Belgian Regulatory Body for Postal Services and Telecommunication (BIPT) assisted by Bureau van Dijk Management Consultants (BvD) and in close collaboration with the Belgian telecommunications sector.

It however cannot be the aim of this document to provide a complete and detailed description of every single aspect of the bottom-up (BU) model. It is therefore regarded as a simplified description of the BU model and not an exhaustive description.

1.1. *STRUCTURE OF THIS DOCUMENT*

Chapter 2 lays out the basic concepts; the methodological approach followed and clarifies both financial and technological assumptions.

Chapter 3 provides an overview of the simplified network architecture used to develop the model and shortly describes the different traffic types, cost pools and routing factors and how they interact. *Chapter 4* elaborates on the identification and the calculations concerning cost pools, up to the resulting cost per minute for each identified communication type. *Chapter 5*, of a more technical nature, describes the derivation of the routing factors used in the previous chapters.

1.2. *SCOPE OF THE MODELING PROCESS*

Each organization with a strong position on the fixed public telephone network, leased lines or voice telephone market is obliged by law to publish a *reference offer*, containing tariffs for the different *interconnection services* (e.g. Belgacom's Reference Interconnect Offer, BRIO). Since the interconnection communication tariffs have a significant impact on the liberalization of the telecommunications market, the BIPT has been given the authority to verify that the interconnection charges are set on the basis of objective criteria and follow the principles of *transparency* and *cost orientation*. The BU-TELRAIC model was developed for this purpose.

When developing a bottom-up (BU) model, one has to decide upon the definition of the *increment*, i.e. the group of telecommunication services that tariffs will be determined for. After consultation of the sector, it was decided that the increment will consist of all PSTN/ISDN services (or 'switched services') that are offered by the incumbent operator by means of its national network. The definition of this increment fully complies with the European Commission's Recommendation C(98)960 and ensures that a certain part of the incumbent's shared and common costs can be recovered, which tends to encourage network investments and reflect the real costs of new market entrants. Leased lines and data services are not included in this increment. It was also decided that a first version of the model would focus on traffic dependent interconnection services, and more precisely on the *terminating* and *collecting* services. Other interconnection services such as the *access to an access point* (ATAP) or *interconnect link services* are not modeled.

Apart from the development of the BU-TELRAIC model, BIPT also developed a *top-down (TD) model*. Later on the BU and TD models will be compared and the differences between them will be identified in a process named the *reconciliation process*. This paper however will focus only on the BU model development.

Consultations with the Belgian telecommunications industry have been conducted at different stages of the process and opportunities have been given to provide input on the BU model structures, data and formulae.

2. BASIC CONCEPTS, PRINCIPLES AND ASSUMPTIONS

2.1. *PROBLEM DESCRIPTION AND DIVISION INTO SUB-PROBLEM STATEMENTS*

As indicated in paragraph 1.2 the results from the BU model should be appropriate input for the reconciliation process and ideally give an in-depth (technical) view on the different *costs pools*[1].

As different communications types will consume to a different extent different resources, the total cost per minute will differ for these communication types. Figure 1 represents the process flow followed in order to obtain such communication tariffs.

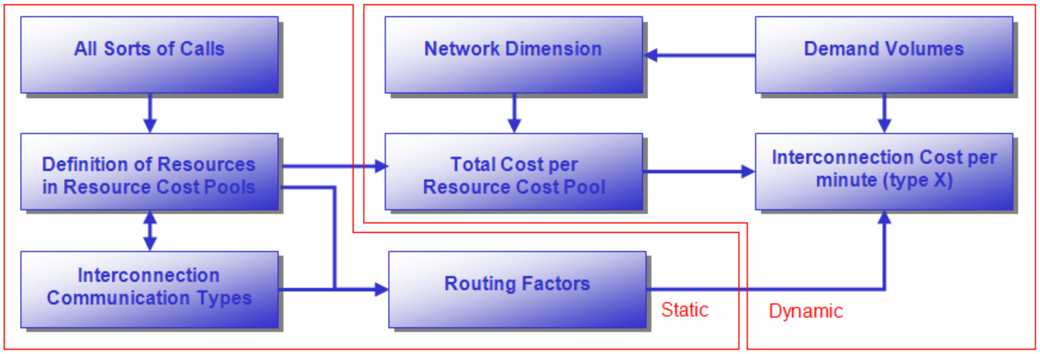

Figure 1. Approach for Interconnection Tariff Problem

As can be seen from this figure, all sorts of calls in a network use resources from this network. Studying this usage allows to identify the resource cost pools[1] for a relevant number of types of communication traffic. These traffic types use the resource cost pools as defined by the *routing factors*, alternatively a routing factor indicates in which amount an communication of a certain type consumes a resource (or resource cost pool).

Adding the input demand data to the process, the BU model dimensions the network and can thus calculate the total cost of the different resource cost pools. From this total cost, a unit cost per resource cost pool can be derived, based on the routing factors and the volumes of all sorts of calls that make use of that resource pool.

Subsequently, the cost for an specific communication type is calculated based on the unit cost per resource cost pool, the routing factors for that communication type and the demand volume.

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[1] A logical grouping of resources aggregated to simplify the assignment of these resources to cost objects.

Since the definition of the resource pools, the communication types and their routing factors only depend on the architecture and not on the dimension of the network, they can be considered static and will not easily change after been decided upon by the involved parties. Figure 1 represents this by grouping elements in the *static* set. In contrast, *network dimension*, *total cost pools* and *interconnection cost per minute*, grouped in the *Dynamic* set in Figure 1, still need to be calculated in the BU model as these elements do depend on the network dimension. We will further elaborate the calculation of these elements in the next section.

2.2. *COST MODELING METHODOLOGY*

This paragraph focuses on the *dynamic* element set in Figure 1, which groups the network dimension dependant elements. The calculation of the per minute interconnection cost for a certain communication type is performed through *cost modeling*, described as the process of building costs of components and aggregates through a granular approach. The final cost for a good or service is calculated in function of multiple input variables.

Some of these input variables are *cost drivers*, which means they have a direct cause-effect relationship to a cost. Figure 2 represents a simplified cost modeling process. The cost drivers, e.g. *number of lines* and *amount of minutes called*, are indicated by the ovals.

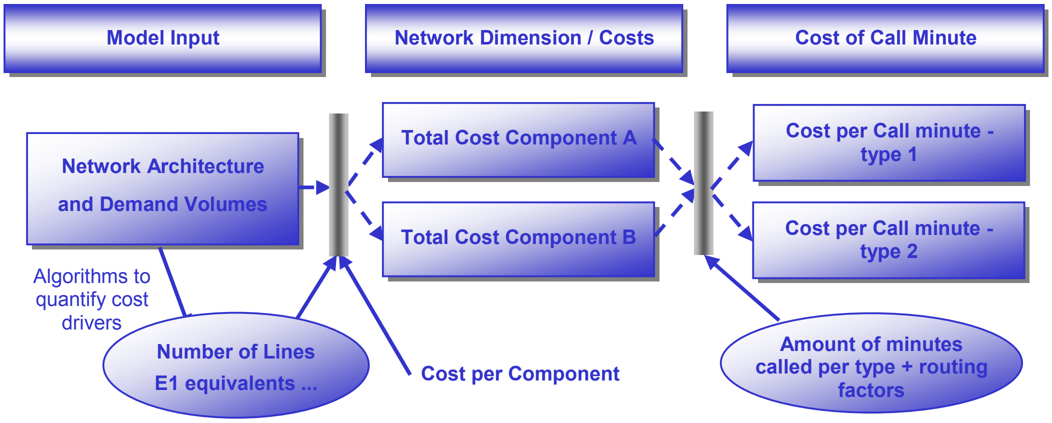

Figure 2. Simplified example for cost modelling process

In Figure 2 the model input (*network architecture* and *demand volumes*) are used to calculate the level of the cost drivers, e.g. *E1 equivalents*, these amounts are then used to derive the quantity of components needed in order to guarantee the required network capacity. From this the total cost of a component can be obtained by multiplication with the cost of that component. Eventually, the total cost of a component is allocated to all *communication types* that make use of the component pro rata the routing factors and the amounts of minutes called per type of communication. A change in model input, e.g. number of installed lines on a BU, can for instance result in an increase in the needed number of *component A*, but not of *component B*. The increase of the total cost of *component A* could cause an increase of the calculated interconnection cost of the *interconnection type 1*, if the routing factor for *component A* and *interconnection type 1* is not zero, meaning in order to obtain an *interconnection of type 1* at least one *component A* is required.

The BU model is a more complex, but very alike structure. The model input is detailed data gained from different sources, including the incumbent's data, e.g. location of the nodes, subscribers per node. From this data a certain amount of cost drivers are then calculated, which in turn are used to dimension all needed network components, e.g. switching matrices, km of cable, amount of TMUX, etc…

It is worth mentioning that in order to obtain the level of a cost driver, that cost driver is calculated for each different network node, and subsequently summed to a resulting total amount for that cost driver. This total cost driver level thus accounts for the granularity of the equipment. In other words, the investment in equipment associated with specific requirements stipulated in every distinct node will exceed the investment in equipment associated with the sum of the requirements as a whole.

After having obtained the total cost for each of network component by multiplication with the cost per component, these cost are allocated to different communication types, e.g. *Collecting Intra Access Area (IAA) communication type*, *Terminating Local communication type*. For this purpose specific cost drivers are used, on the one hand the amount of call minutes per call type, obtained via the incumbent and regarded as input data, on the other hand the routing factors. After all, some communication types use the components (or resource pools) more than once per call minute, e.g. the *Terminating Local communication type* uses the resource pool BUs (Base Units) once, but the VAS[2] communication type uses it two times. These factors also need to be considered when allocating the costs to the different communication types.

In Figure 3, representing a conceptual view of the information flow in the BU model, the equipment components are divided into three different categories, namely *switching*, the *transmission* and the *transmission infrastructure (or 'outside plant')*. This figure can be seen as a more complete higher-level overview of the process.

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[2] VAS = Value Added Service

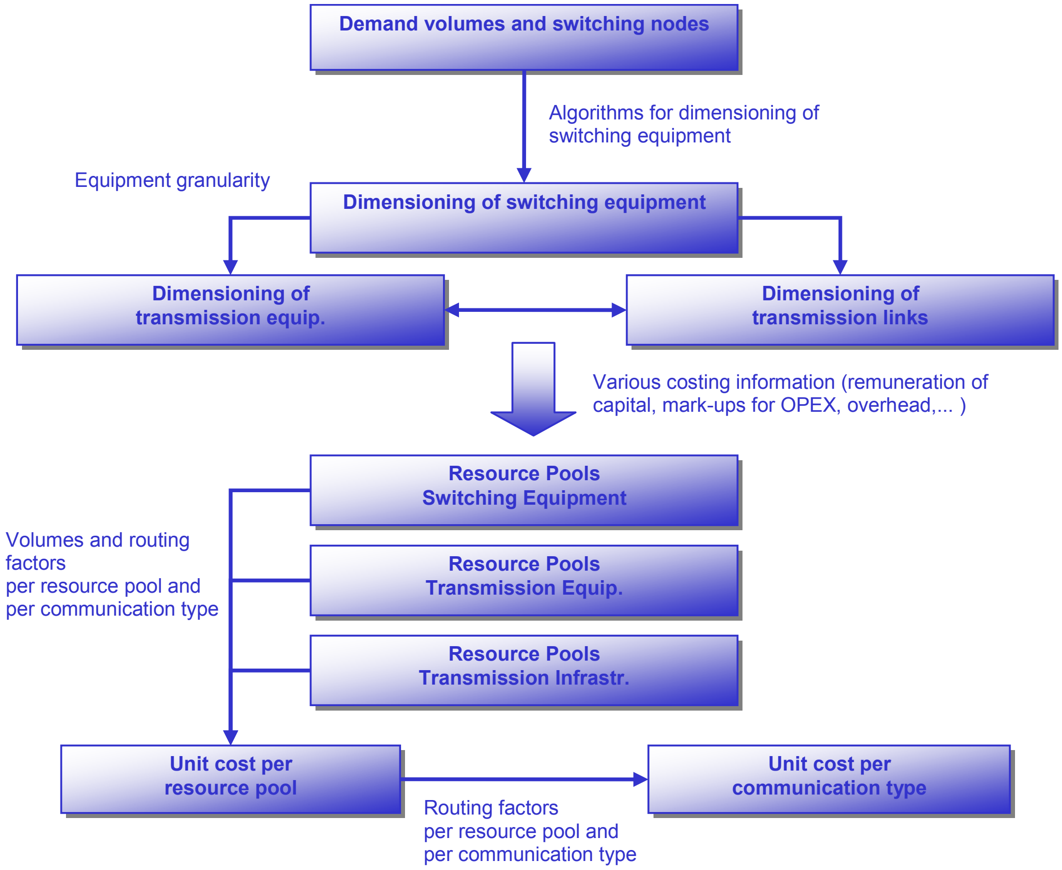

Figure 3. Top level overview of the information flow

Having explained the general concepts of the BU model, following chapters detail this methodology. Chapter 3 elaborates on the network architecture, traffic types and dimensioning of the network. Chapter 4 gives a more detailed and complete overview of the different cost pools and cost calculation in general, while chapter 5 examines the routing factors used. The remainder of this chapter clarifies some of the concepts needed to fully comprehend these chapters.

2.3. *METHODOLOGICAL CHOICES AND ASSUMPTIONS*

This section explains the choices, assumptions and general concepts used throughout this document, and is divided into two parts, one detailing on the *financial* and *economic* and one on the *technological* choices, concepts and assumptions.

Most often these choices and assumptions are based on European Directives; best practices and are in line with the BU models developed in other European countries. The European Regulators Group (ERG)[3] and Independent Regulators Group (IRG)[4] are two organizations that release best practices based on sector consultations, aiming for a consistent and harmonized approach. As described by the best practices, different consultation rounds with

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[3] ERG Consultation Document – Proposed ERG common position regarding FL-LRIC cost modelling. 30 July 2003.

[4] Principles of implementation regarding FL-LRIC cost modelling, as decided by the Independent Regulators Group, 24 November 2000, http://irgis.icp.pt/admin/attachs/78.pdf.

the Belgian telecommunication sector have been conducted and opportunities have been given to provide input to the technological and financial choices and assumptions.

2.3.1 FINANCIAL AND ECONOMIC CHOICES, CONCEPTS AND ASSUMPTIONS

This section describes the methodology for estimating the cost of a service and the depreciation method used.

LONG RUN AVERAGE INCREMENTAL COST (LRAIC)

LRAIC, as practiced in the telecommunications sector, is a methodology for estimating the cost of a total service increment based on a model of the actual, or slightly modified, network. The basic idea is to calculate the interconnection prices based on the cost to produce these interconnect products/services in a modern telecommunication network, which does not bear the burden of inefficiencies. LRAIC was recommended as the most appropriate approach to set cost-based interconnection prices by the European Commission's recommendations on interconnection in a liberalized telecommunications market (98/195EC and 97/33EC).

> "*The principle behind using the LRAIC approach is to base the interconnection charges on what the cost of an interconnect product would be, if provided by the most efficient network operator and not on the current cost of production.*"

The more recent European Access and Interconnection Directive of 7 March 2002 does not specify LRAIC and simply states:

> *"National regulatory authorities shall ensure that any cost recovery mechanism or pricing methodology that is mandated serves to promote efficiency and sustainable competition and maximize consumer benefits."*

LRAIC is however still the standard approach followed by European countries. A common position on the different LRIC flavors is in the process of being synthesized by the European Regulator's Group (ERG)[5].

In the Belgian BU model the **Total Element Based Forward Looking Long Run Average Incremental Costing (TELRAIC)** approach was pursued. Hereunder, the concepts of this costing methodology are expound.

Element Based In an "Element Based" model, the network is considered as a collection of elements comprising switching and transmission equipment that constitute the switching and transmission nodes, as well as the transmission links. The BU model allows the calculation of the total cost of the provision of a given PSTN/ISDN-service as the sum of the costs of the network elements that are used by this service. Moreover, an 'element based' approach promotes the transparency of the cost structure and allows to acquire a profound insight in the impact of technical optimization on the cost structure.

Long Run "Long run" refers to the time horizon within which all costs become variable and the firm can undertake all capital investments or disinvestments that it desires in order to increase or decrease the capacity of its different network service offerings. The long run horizon implies that the entire investment cost caused by the increment can be avoided.

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[5] ERG Consultation Document – Proposed ERG common position regarding FL-LRIC cost modelling. 30 July 2003.

Forward Looking In the bottom-up model, the cost base will be forward looking. Forward-looking costs aim to look ahead and consider the costs that would be applicable when one would build a network, featuring the same functionality as the existing one, at present. This reasoning implies that for modeling purposes, some older technologies are replaced by newer equivalents, e.g. PDH[6] is replaced by SDH[7], in other words SDH is used as the modern equivalent asset (MEA) for PDH. This implies that the historical costs of the assets cannot be used for the valuation of the operator's assets, since they do not reflect the current situation; as a consequence, application of a *Current Cost Accounting* (CCA) methodology, i.e. the valuation at current prices of the assets modeled is required.

Incremental Costing The increment is defined as "all PSTN/ISDN-services", which implies that the network modeled in the BU model will be the efficient equivalent of the incumbent's PSTN/ISDN-network. The choice of the increment has a direct influence on the dimensioning of the network and on the sharing of costs between various services. The section hereunder titled "*The increment and network elements to be modeled*" comments on how the choice of the increment influences the determination of the direct investment in network components in the BU model.

DEPRECIATION METHOD

As explained in a previous section covering the LRAIC approach, the costs considered are those applicable when one would build a network, featuring the same functionality as the existing one, at present. Consequently, depreciations taken from the *financial accounts*, which simply allocate the historic cost of assets over the financial depreciation periods, are not to be used.

Actually, depreciation in *forward-looking* cost models, as the Belgian BU model, should ideally reflect the change in the value of an asset during a given year, taking into account the expected technical life of the asset, a concept known as *economic depreciation*.

The Belgian BU model utilizes the *tilted annuity formula*; this formula calculates an *annuity cost* that varies from year to year, taking into account the fact that the price of the asset is expected to vary. This results in a falling annual cost if the price is expected to fall over time.

The tilted annuity results in costs that, after discounting, cover the purchase price and financing costs of the asset. In the telecommunications sector competition and short duration contracts imply that the profile of depreciation is critical to remain competitive and recover capital costs. The tilted annuity brings forward this issue of cost recovery and enables the incumbent to recover its costs whilst competing with future new entrants.

The annuity cost is estimated by the following formula:

$$ACC_0 = GRC_0\left(1+P\right)^{1/2} * \left(1+W\right)^{1/2} * \frac{1-\dfrac{1+P}{1+W}}{1-\left(\dfrac{1+P}{1+W}\right)^{L}}$$

With:

ACC_0 = Annuity Cost (year 0)
P = Price Change

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[6] PDH stands for Plesiochronous Digital Hierarchy (PDH)

[7] SDH stands for Synchronous Digital Hierarchy (SDH)

L = Economic Asset Life
GRC_0 = Gross Replacement Cost (year 0)
W = Weighted Average Cost of Capital.

The calculation methodology, and with it, the exact value of the *Weighted Average Cost of Capital* (*WACC*) is the same for both the BU Model and the top-down model[8]. This calculation is, furthermore, in conformance with The European Commission Recommendation 98/960/EC[9].

2.3.2 TECHNOLOGICAL CHOICES AND ASSUMPTIONS

This section elaborates on the technological choices made in the BU model. These choices are often based on European Directives, best practices and are in line with the BU models developed in other European countries.

SCORCHED NODE APPROACH VERSUS SCORCHED EARTH APPROACH

A LRAIC cost model calculates the cost of offering services by an operator that exploits an efficient network. However, with respect to the efficiency of the network, different approaches can be taken in a BU model (e.g. *scorched earth approach*, *scorched node approach*).

In a **scorched earth** model, first the amount and the localization of the nodes are optimized, in consequence, transmission routes in the model may not correspond with existing routes.

In a **scorched node** model, the existing nodes and links are assumed to already be optimized, and remain unaltered, but all other elements can be optimized.

Since the topology and nodes of an incumbent's network cannot be altered readily, and since the incumbent has been through a switching node consolidation process up till 2002, the BIPT decided to apply a *scorched node approach*. Indeed, it would be difficult and time consuming to specify an optimal network and it could take an incumbent several years to achieve such an efficient design - by which time what was considered to be efficient may itself have changed. Moreover, it is questionable whether interconnection tariffs, based on a network of which the topology and nodes differs too much from the actual network, do promote sustainable competition and by consequence maximize consumer benefits[10]. Furthermore, ERG affirms that there is a general preference for the scorched node approach[11].

BORDER WITH THE LOCAL ACCESS NETWORK

One should decide which parts of the incumbent's network will be modeled. As the increment purely consists of PSTN/ISDN-services, it is clear that solely the PSTN/ISDN-network qualifies to be modeled and that e.g. the data network is not relevant.

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[8] Further information can be found on the websote of the BIPT (www.bipt.be) under the titles: "Beschrijving van het top-down model BRIO 2004" (Dutch) / "Description du modèle des coûts top-down de l'IBPT pour le calcul des tarifs d'interconnexion du BRIO 2004" (French)

[9] COMMISSION RECOMMENDATION C(1998) 960 final of 8 April 1998 on interconnection in a liberalized telecommunications market

[10] Cf. Objectives of regulation, as stated in the "European Access and Interconnection Directive" of 7 March 2002.

[11] ERG Summary of the Consultation on FL-LRIC Principles of Implementation and Best Practice (PIB), February 2004.

Subsequently, one has to decide which parts of the PSTN/ISDN-network will be included. In that perspective, it was decided in the first consultation document that solely the core PSTN/ISDN-network will be modeled, which implies that the local access network will not be included in this first version of the BU model. After all, since the costs of the local access network should be reflected in a specific subscription fee, they cannot have an impact on the interconnection tariffs.

As a consequence, a distinction has to be made between the local access and core PSTN/ISDN-network. In accordance with the European Commission's Recommendation C(98)960 and with other BU models, network components that are not traffic sensitive and that are dedicated to a particular customer, are said to be part of the local access network. In the BU model, these are assumed to be all network components from the customer termination point (or *customer premises*), up to and including the line card. Network components that are traffic-sensitive on the other hand, belong to the core network.

THE INCREMENT AND NETWORK ELEMENTS TO BE MODELED

The choice of the increment, i.e. the group of telecommunication services that tariffs will be determined for, has a direct influence on the dimensioning of the network and on the sharing of costs between various services. This section comments on how the choice of the increment influences the determination of the investment in network components in the bottom-up model.

Direct investment in switching equipment Since all PSTN/ISDN-services (or *switched services*) are part of the increment, a complete switching network will be dimensioned and taken into account when determining the cost of the PSTN/ISDN-network. After all, no other services than those included in the increment make use of this switching equipment. It should be noted however that the part of the switching capacity used for the connection towards other national or international operators has not been modeled, as these are irrelevant in the setting of tariffs for traffic dependent interconnection services.

Direct investment in transmission equipment Unlike the switching components, transmission equipment (TMUX, ADM,..) is not exclusively used by PSTN/ISDN-services, but also e.g. by leased lines. Some of these components will always be dedicated to PSTN/ISDN services (e.g. tributary cards), whereas other components (e.g. investments in the fixed parts of an ADM) could be shared with other services (e.g. leased lines). The algorithms for the dimensioning of the transmission equipment in the BU model only take into account the volumes of the services included in the increment (i.e. ISDN/PSTN traffic). This implies first of all that the BU model will model a smaller amount of *service-dedicated* equipment than the amount that would be required for offering a complete range of telecommunications services. However, part of the required transmission equipment is determined by the transmission links on which the transmission nodes are located (e.g. fixed investment in ADMs). These part will be modeled completely, but the cost of these shared transmission components will be shared between PSTN/ISDN-services and other services. This approach is consistent with the one taken regarding the sharing of direct investment in transmission links in the section hereunder.

Direct investment in transmission links The physical structure of each ring and point-to-point connection is based on the incumbent's network. For each *LDC Link* and for each *Regional Ring*, the capacity modeled is based on the installed capacity in the incumbent's network. For the Core Links, the modeled capacity is based on the capacity used[12]. No

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[12] Definitions of 'LDC Link', 'Regional Ring' and 'Core Link' can be found in paragraph 3.3

sufficiently detailed information was available that allows the application of detailed algorithms for the dimensioning of the transmission links on the individual link or ring-basis. However, in the BU model the choice of the cable type, as well as the sharing of cables, ducts and trenches between different transmission layers is optimized. The part of the costs allocated to the core network, has also been shared between PSTN/ISDN and other services, based on the reality within the incumbent. This is consistent with approaches taken in other BU models throughout Europe.

USE OF DETAILED NETWORK INFORMATION TO MODEL THE NETWORK

Looking at the different possible options to model the network, the BIPT has chosen to use detailed node information provided by the incumbent as a starting point for the BU model. Other options as the use of general aggregated data, with or without the use of specific geographic characteristics, were considered inadequate, as the results of such models are highly criticizable given the large number of assumptions taken and the poor concordance with the actual network of the operator.

The main disadvantage of a model that uses detailed node and transmission information is often the difficulty to obtain the high quality information needed to feed the model. Moreover, a model that contains confidential information of the incumbent's network, especially with regard to demand in every node, requires special attention to separate the confidential from the non-confidential information, increasing the complexity of the BU model.

3. NETWORK ARCHITECTURE, TRAFFIC TYPES AND DIMENSIONING

The first two paragraphs of this chapter describe the modeled network and explain the different communication types. The following two paragraphs clarify how traffic is conveyed over the network using network resources and how this routing of traffic defines resource pools.

3.1. *OVERVIEW OF THE NETWORK ARCHITECTURE*

3.1.1 SWITCHING NETWORK ARCHITECTURE

The switching network (or logical network) modeled can be decomposed into three hierarchical levels. The lower level will be constituted of remote concentrator units, also called *Remote Units* (RUs), these elements do not exhibit switching capabilities and logically depend on the second level *Base Units* (BUs). Base Units do have switching capabilities and they can be logically interconnected to other BUs if this is justified by the traffic amount between them. On the physical level however, this interconnection will be made using the existing transmission paths. The third level will be the transit level, which is constituted of *Covering Area Exchanges* (CAEs). If the amount of traffic vindicates it, a direct connection between a BU and a CAE of a different access area can be installed (on the logical level).

The BIPT has opted for this network structure since it reflects best the current situation at Belgacom, after the implementation of the switching consolidation process. Figure 4 schematically illustrates the modeled network for one access area. In this figure, full lines represent the logical routing paths followed in a *normal switching hierarchy.* The additional logical interconnections, installed if the traffic amounts justify these, are indicated by dashed lines and are not part of the *normal switching hierarchy.*

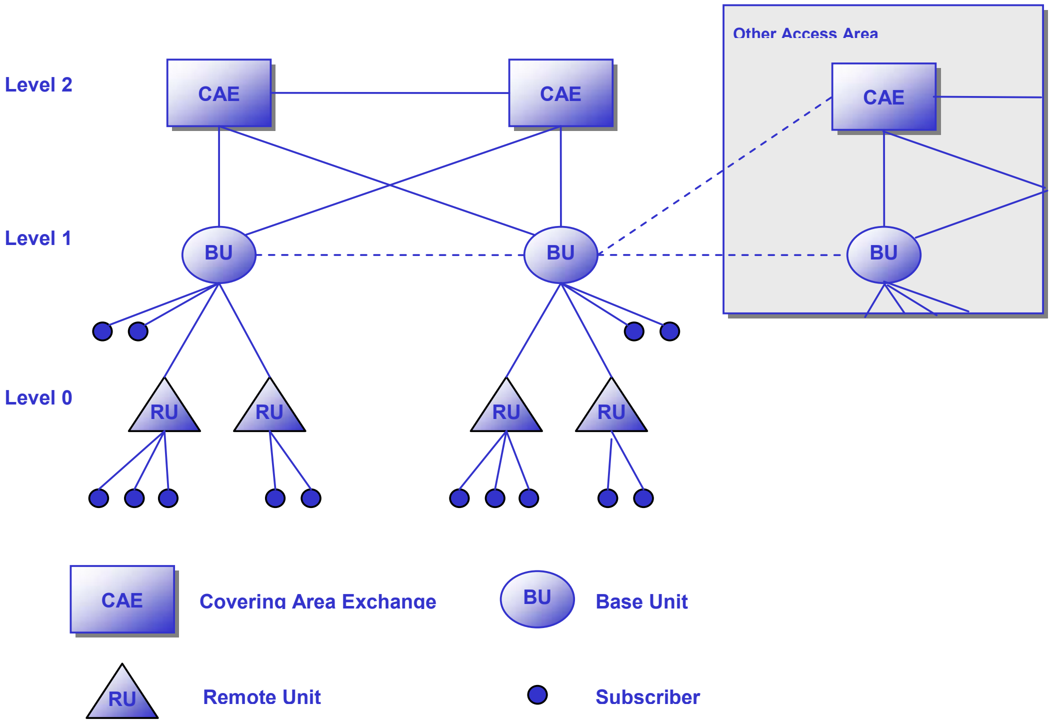

Figure 4. Switching Network Structure Modeled

3.1.2 TRANSMISSION NETWORK ARCHITECTURE

As illustrated by Figure 5 the physical transmission network is divided into the *regional transmission network* and the *core transmission network*[13]. The regional transmission network is constructed by means of *LDC links*, as well as SDH-rings[14], which will be called *regional rings* hereafter. The core network links join the *zonal transmission centers* (ZTCs). Its transmission paths may be partly collocated with the physical rings of the regional network. A part of SDH connections in the core transmission network are point-to-point, but regularly the larger ZTCs are connected with SDH rings.

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[13] The regional and core transmission network are often also indicated as '*the core network'* as opposed to the *local access* network.

[14] SDH (Synchronous Digital Hierarchy) is a standard technology for synchronous data transmission on optical media.

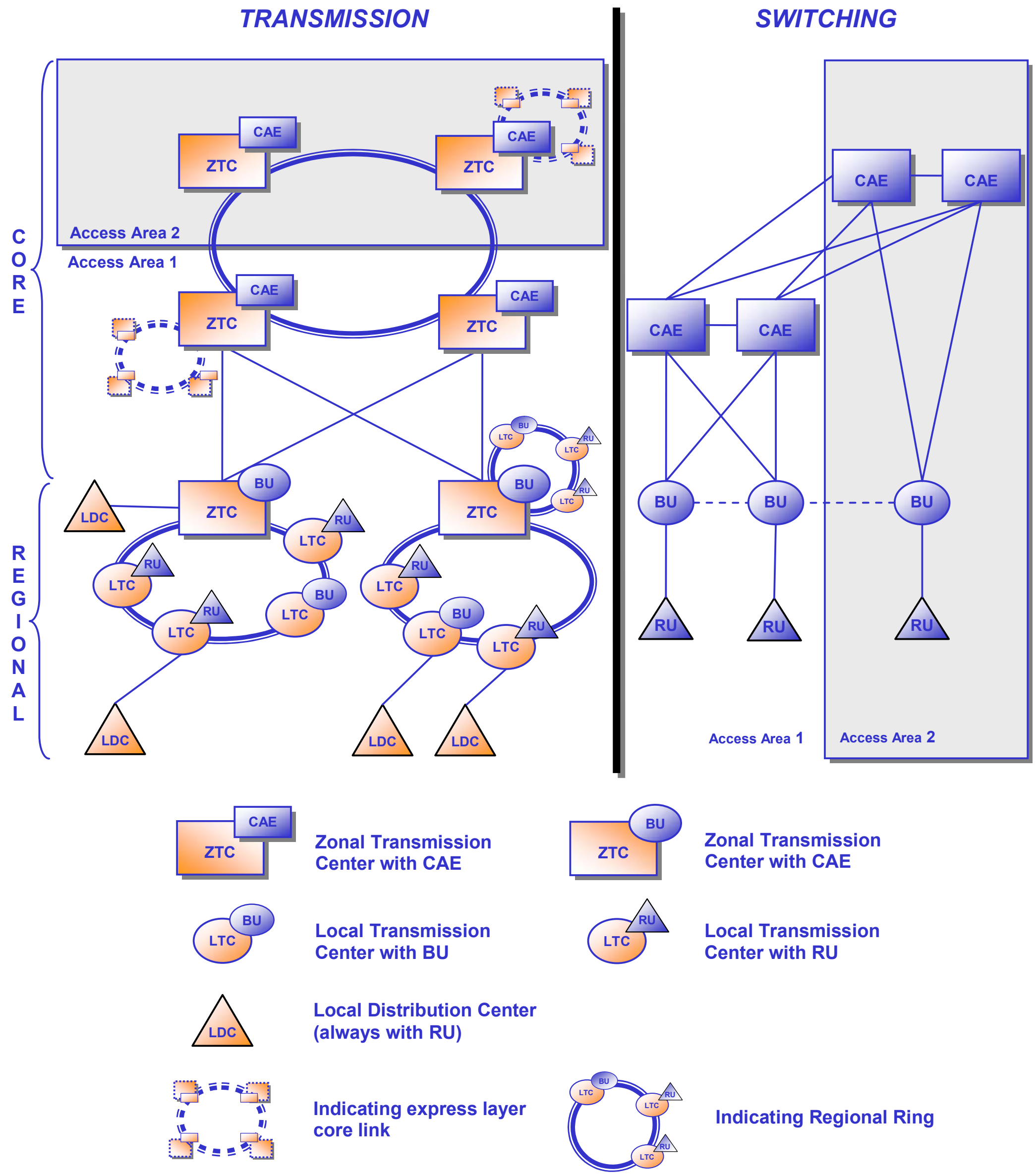

Figure 5. Transmission Network Structure Modeled

Two kinds of transmission centers are located on the regional rings: the *zonal transmission centers* (ZTCs) and the *local transmission centers* (LTCs). The ZTCs provide connections between regional rings, between the regional and the core transmission network and between rings in the core transmission network. *Local Distribution Center* (LDC) are not located on a regional ring and connected to a LTC or a ZTC by means of a point-to-point fiber connection. The LTC or ZTC to which the LDC physically is connected, is not necessarily collocated with the host BU to which the RU in the LDC is connected.

On top of this transmission function, a ZTC is collocated with a switching element, mostly BUs or CAEs. In fact, all CAEs are collocated with a ZTC. The BUs can be collocated with a ZTC or a LTC, while RUs are collocated with a LTC or a LDC.

As can be depicted from Figure 5 all transmission centers are collocated with switching nodes (BUs or CAEs) or concentration nodes (RUs). This figure however does not illustrate the transmission infrastructure sharing. The sharing assumptions, modeled in the BU model, are outlined in more detail in paragraph 4.4.3.

3.1.3 SIGNALING NETWORK ARCHITECTURE

The signaling system transfers dialing information between the different exchanges. It initiates the *charging systems* and *processes call control information*. The switching system facilitates thus the connection and disconnection of the 64 kbit/s user-information channels. The signaling information uses separate channels for its transmission.

On average, several hundred user-information channels can be transmitted on a single 64 kbit/s-signaling channel. The signaling network is logically an independent network with its own nodes. Because of the limited effect of the cost of the signaling network, this version of the BU model does not encompass this network separately.

3.2. *COMMUNICATION TYPES*

This paragraph covers the PSTN/ISDN communication types that are defined in the bottom-up model. These communication types differ from the types defined in the context of the top-down model, as, although the regulated interconnection services are the same, some communication types differ (e.g. *Belgacom-to-Belgacom traffic*, being traffic from a Belgacom subscriber to another Belgacom subscriber). This is due to the fact that the top-down model communication types are often defined from a (historical) commercial perspective (e.g. distinction between *zonal* and *inter-zonal calls*) and the fact that the definition of the BU communication types is more strongly inspired by the network architecture (e.g. distinction between *inter-ring* and *intra-ring traffic*).

3.2.1 BOTTOM-UP COMMUNICATION TYPES

This section defines the different bottom-up communication types, which are easily divided into two groups, namely the *Belgacom to Belgacom traffic* and *traffic between Belgacom and other operators* (national OLOs[15] or international operators).

BELGACOM TO BELGACOM TRAFFIC TYPES

- **Local Traffic**: traffic between two users, connected to the same base unit (BU) or to remote units (RUs) dependent of the same BU.
- **IAA Traffic**: non-local traffic between two users connected to the same access area. Within the IAA traffic type there exist two possibilities:
  - IAA Intra-Ring Traffic: non-local traffic between two users connected to nodes (BUs or RUs) on the same regional ring.
  - IAA Inter-Ring Traffic: non-local traffic between two users connected to nodes (BUs or RUs) on different regional rings, but within one access area.
- **EAA Traffic**: traffic between two users connected to nodes (BUs or RUs) belonging to different access areas.
- **Internet Traffic** (BGC to BGC): traffic type comprising the internet traffic switched on the incumbent's PSTN/ISDN network.

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[15] OLO: Other Licensed Operator

- **VAS Traffic**: traffic type comprising all VAS traffic switched on the incumbent's PSTN/ISDN network.

TRAFFIC TYPES FOR TRAFFIC BETWEEN BELGACOM AND OTHER OLOS

- **National Transit** (IAA and EAA): traffic from OLO1[16], to OLO2, transiting the Belgacom network. In case OLO1 and OLO2 have access to a Belgacom access point in the same Access Area, this is *IAA National Transit traffic*. If not, the call is transited from one Access Area to another, and becomes *EAA National Transit traffic.*
- **Terminating** (Local, IAA and EAA): The types IAA and EAA are identical to the ones defined in the BRIO. Local terminating traffic is traffic coming from an OLO and terminated at a BU on the Belgacom network, destined for a Belgacom customer, connected to that same BU or to a RU dependent of the same BU. IAA terminating traffic is terminated at the CAE level and is destined for a Belgacom customer, connected to a BU or RU in the Access Area (AA) to which the CAE belongs. In the case of EAA, the Belgacom customer for which the call is destined, is connected to a BU or RU in another AA than the one the CAE, on which the call is terminated, belongs to.
- **Collecting**: **Local & IAA Interconnection**: This traffic type is identical to the one defined in the BRIO. Local collecting traffic is traffic collected by an OLO at a BU on the Belgacom network, coming from a Belgacom customer, connected to that BU or to a RU dependent of the BU. IAA collecting traffic is collected at the CAE level and is coming from a Belgacom customer, connected to a BU or RU in the AA to which the CAE belongs.
- **Interconnection: BGC to Fixed (non-collecting part):** traffic originating at the Belgacom network and terminated on the network of other fixed operators.
- **Interconnection: BGC to Mobile:** traffic originating at the Belgacom network and terminated on the network of mobile operators..
- **International Traffic**: (**Incoming, Outgoing and Transit**): Traffic entering or leaving the Belgacom network at the international exchanges. This traffic can be entering the Belgacom network as it is destined for a Belgacom end-user (*incoming international traffic*) or as it is destined for an end-user in another foreign country, which means the call will be transited to a third country (*international transit traffic*). Another sort of call is a call leaving the Belgacom network, destined for a foreign receiver (*outgoing international traffic).*

3.3. *RESOURCE POOLS*

This paragraph clarifies how resource pools are defined by the conveyance of traffic over the local, access area and national network. The concepts of local, access area and national network try to indicate the logical hierarchies in the networks, according to the level of switches they are related to.

There respective definitions are:

- **Local Network**: network that connects all subscribers connected to the same BU, which can be located in an LTC or a ZTC.

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[16] OLO: Other Licensed Operator

- **Access Area Network**: network that connects all subscribers connected to RUs and BUs, located in the same *access area* (i.e. having the same two CAEs as host). A CAE is always located in a ZTC.
- **National Network**: network that connects all subscribers connected to the incumbent's network, independent of the RU and BU they are connected to.

3.3.1 LOCAL NETWORK

This section explains how the traffic is conveyed over the *local network* and how this defines resource pools. As explained in paragraph 3.1 covering the switching network architecture, RUs have switching equipment, but do not exhibit intelligent switching capabilities, they are logically dependent on a host BU. Therefore subscribers are connected to a host BU directly or indirectly via a RU and calls originating from these subscribers must be conveyed exactly once by their host BU. BUs can be collocated with LTCs in nodes denoted as LTC-BUs, or with ZTCs in nodes denoted as ZTC-BUs. ZTC-BUs can be connected to multiple regional rings, in contrast to LTC-BUs, which can only be connected to one ring. The shorthand notation, indicating the transmission and switching equipment in a certain node e.g. ZTC-BU, will be consistently used hereafter. It is noteworthy that LDCs can only be collocated with RUs.

The host BU can be directly or indirectly connected with a number of logically dependent LDC-RUs. In case of indirect connection the LDC-RU is connected with the host BU through a LTC-RU. The link between a LDC and a LTC is called a *LDC Link*, while the part of the regional transmission network directly connecting the host BU with its logically dependent LTC-RUs is called a *Regional Ring.* A Regional Ring can contain multiple host BUs and their directly connected dependent RUs.

Figure 6 below shows the architecture of a local network of subscribers that have the same ZTC-BU as host. The architecture of a local network of subscribers that have the same LTC-BU as host is identical, except for the fact that the host is a LTC-BU.

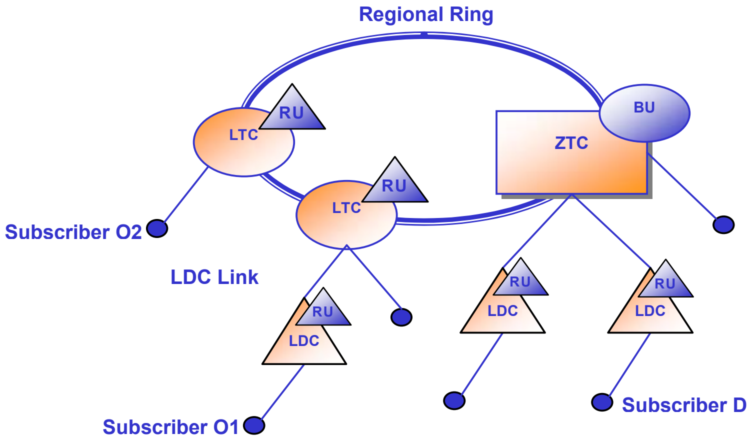

Figure 6. Example model of a Local Network

Studying the conveyance of local calls over the network in Figure 6, and more specifically a call between the originating subscriber O1 and a destination subscriber D, the following routing is observed between that subscriber O1 and its host BU:

Routing between subscriber O1 and host BU

- Dedicated link from subscriber O1 to the LDC-RU
- LDC-RU
- LDC Link
- LTC-RU
- Regional Ring
- Host BU

Core network elements used between subscriber O1 and host BU[17]

- LDC-RU switching equipment
- LDC-RU transmission equipment
- LDC Link
- LTC-RU transmission equipment
- Regional Ring
- ZTC-BU transmission equipment
- ZTC-BU switching equipment

Only the first half of the connection, i.e. up to the BU, is to be considered, since the second half from the BU to the destination subscriber is dependent on the location of the destination subscriber and can be considered entirely analogous to the route from the originating subscriber to the host BU.

Another call from subscriber O2 to a destination subscriber D, results in the following routing from subscriber O2 to its host BU.

Routing between subscriber O2 and host BU

- Dedicated link from subscriber O2 to the LTC-RU
- Concentration in the LDC-RU
- Regional Ring
- Host BU

Core network elements used between subscriber O1 and host BU[18]

- LTC-RU switching equipment
- LTC-RU transmission equipment
- Regional Ring
- ZTC-BU transmission equipment
- ZTC-BU switching equipment

Having detailed the two most complicated calls, all other calls between subscribers use the same list of elements or a subset from the list.

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[17] The dedicated link from subscriber O1 to the LDC-RU is not considered, as this connection is part of the *local access network* as opposed to the *core network*, cfr. paragraph 2.3.2 under the heading *Border with the Local Access network*

[18] The dedicated link from subscriber O1 to the LDC-RU is not considered, as this connection is part of the *local access network* as opposed to the *core network*, cfr. paragraph 2.3.2 under the heading *Border with the Local Access network*

The network elements used in the conveyance of calls over the network, can be grouped in the following switching and transmission resource pools according to their function:

Switching resource pools

- RUs, comprising both LDC-RUs and LTC-RUs
- BUs, comprising both LTC-BUs and ZTC-BUs

Transmission resource pools

- Transmission Equipment:
    - Regional Ring Transmission Equipment
    - LDC Link Transmission Equipment

- Transmission Infrastructure (or *Outside plant*):
    - LDC Links
    - Regional Rings

The resource pool *Regional Ring Transmission Equipment* contains the transmission equipment, located in a LTC or ZTC, needed to put traffic on a regional ring, and completely analogous to this. The transmission resource pool *LDC Link Transmission Equipment* contains the transmission equipment, located in a LDC, needed to put traffic on a LDC Link.

For every usage of a LDC Link, the resource pool *LDC Link Transmission Equipment* is used exactly once. For every usage of a Regional Ring, the resource pool *Regional Ring Transmission Equipment* is used exactly twice (at both ends of the Regional Ring). In fact, these numbers representing the usage of resource pools are called *routing factors* and were first explained in paragraph 2.1, giving an overview of the problem definition, and are examined in greater detail in chapter 5.

3.3.2 ACCESS AREA NETWORK

This section explains how the traffic is conveyed over the *Access Area network* and defines the resource pools. The line of reasoning is the same as in the previous paragraph, concerning the local network. The access area network conveys all calls between subscribers belonging to the same access area and it's architecture is shown in Figure 7, where it is combined with the local access area network architecture in order to more easily comprehend the routing of the calls between subscribers. This figure however does not show all possible elements on each of the rings, since each ring can connect multiple ZTC-BUs, LTC-BUs and LTC-RUs. The latter LTC-RUs on the ring have one of the BUs on the ring as host.

Transmission between regional rings is possible via *Core Links*, or even more easily achieved if the rings share a ZTC. CAEs are used to convey calls between two different BUs and are always collocated with a ZTC. Next to using the normal switching hierarchy, calls can be directly conveyed between BUs using direct transmission links between the BUs.

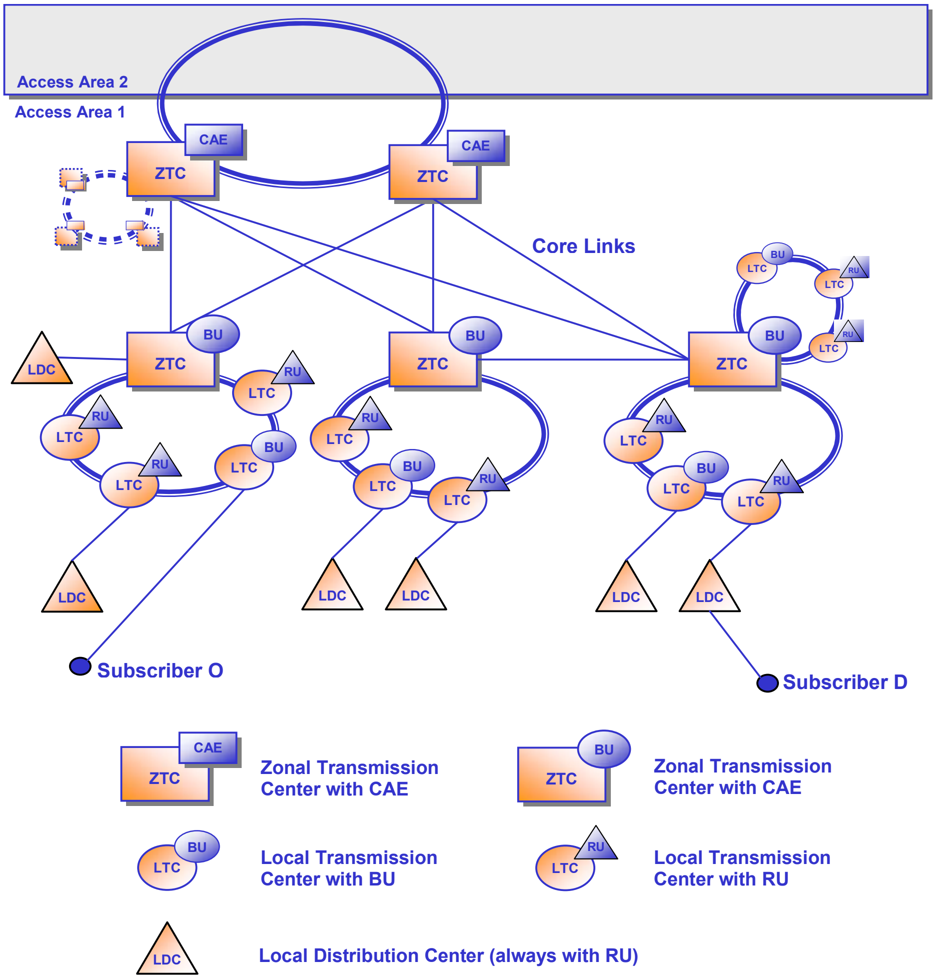

Figure 7. Example Model of the Access Area Network

Studying the conveyance of calls over the network in Figure 7, and more specifically a call between the originating subscriber O and the destination subscriber D, the following routing is observed between subscriber O and CAE:

<u>Routing between subscriber O and CAE</u>

- Dedicated link from subscriber O to the LTC-BU
- LTC-BU
- Regional Ring
- ZTC-BU
- ZTC-ZTC
- CAE

Only the first half of the connection up to the CAE is to be considered, since the second half from the CAE to the destination subscriber is dependent on the location of the destination subscriber and can be considered entirely analogous to the route from the originating subscriber to the CAE.

Network elements used between subscriber O and CAE

- LTC-BU switching equipment
- LTC-BU transmission equipment
- Regional Ring
- ZTC-BU transmission equipment
- Core Link
- ZTC-CAE transmission equipment
- ZTC-CAE switching equipment

Having detailed the most complicated call, all other calls between two subscribers use the same list of elements or a subset from this list, combined with elements discussed in previous section, concerning the local access network.

Similar to the discussion for the local network, the conveyance of calls in the access area network identifies the following resource pools:

Switching resource pools

- BUs (comprising of LTC-BUs and ZTC-BUs)
- CAEs (comprising of ZTC-CAEs)

Transmission resource pools

- Transmission Equipment:
  - Regional Ring Transmission Equipment
  - Core Link Transmission Equipment

- Transmission Infrastructure (or *Outside plant*):
  - Regional Rings
  - Core Links

The resource pool *Regional Ring Transmission Equipment* comprises the transmission equipment, located in a ZTC or LTC, needed to put traffic on a regional ring. Analogous, the resource pool *Core Link Transmission Equipment* groups transmission equipment, located in a ZTC, needed to put traffic on a Core Link.

As already explained in the previous section, concerning the local network, every usage of the *Regional Ring* resource pool implies that the resource pool *Regional Ring Transmission Equipment* is used exactly twice. Such a relationship cannot be derived for the resource pools *Core Link Transmission Equipment* and *Core Links*. Indeed, in the case rings are adjacent, traffic can be conveyed between the regional rings without using a Core Link. However, since *Core Link Transmission Equipment* is used to put traffic from a ZTC onto a regional ring, every usage of a *Core Link* implies that *Core Link Transmission Equipment* is used twice (at both ends of the link). The usage of *Core Link Transmission Equipment* will in general be at least twice the usage of *Core Links*.

3.3.3 NATIONAL NETWORK

This paragraph explains how the access areas, of which the architecture was detailed in the previous paragraph, are interconnected to build up the national network. Each of the eight access areas of the nation network contains exactly 1 pair of CAEs and in each access area this pair of CAEs is interconnected for redundancy purposes. In order to realize calls between subscribers in different access areas, denoted *Extra Access Area traffic* (EAA), some ZTC-CAEs located in different access areas are interconnected in a meshed topology built from *ZTC-ZTC Links*, as can be seen in Figure 8. In some cases, multiple ZTC-ZTC Links constitute SDH rings.

Apart from this meshed topology at the transmission level, the CAEs are logically connected to each other in a fully-meshed topology. In other words, all CAEs can directly switch traffic to other CAEs, on the physical level however, this interconnection will be made using the existing transmission paths.

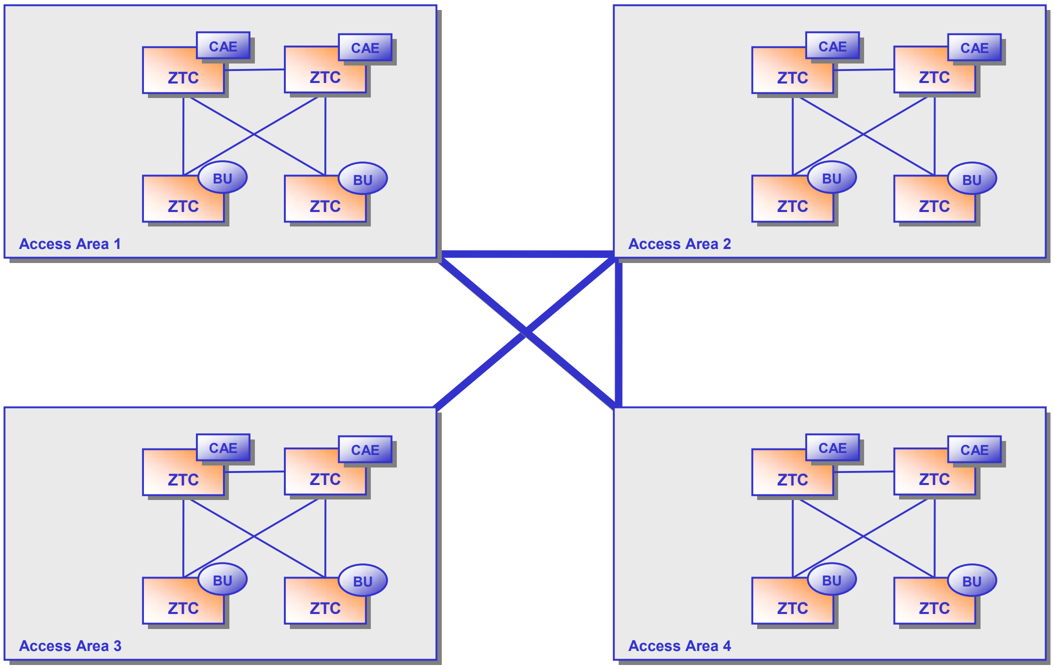

Figure 8. Example Model of National Network with connections on transmission level

This architecture allows the conveyance of calls between access areas through either:

- Switching by the CAE of the originating access area to the CAE of the destination access area. This involves the usage of two *CAEs* and one or more *Core Links*.
- Direct switching by the host BU in the originating access area to the host BU in the destination access area. This requires a direct logical link between the two host BUs, that boils down to the usage of *Regional Rings, Core Links*, *Regional Ring Transmission Equipment* and *Core Link Transmission Equipment*.
- Switching by the CAE of the originating access area directly to the host BU in the destination access area. This involves the usage of one CAE and the usage of *Regional Rings, Core Links*, *Regional Ring Transmission Equipment* and *Core Link Transmission Equipment*.
- Switching by the host BU of the originating access area directly to the CAE in the destination access area. This involves the usage of one CAE and the usage of *Regional Ring, Core Links*, *Regional Ring Transmission Equipment* and *Core Link Transmission Equipment*.

For all these cases, the resource pools used were previously identified while examining local traffic and traffic in an access area.

3.4. *Introducing Routing Factors*

The following table enumerates the resource pools identified in the previous paragraphs.

Table 1. Overview Resource Pools

Resource pool	Type	Index i
LDC Links	Outside Plant	1
Regional Rings	Outside Plant	2
Core Links	Outside Plant	3
LDC Link Transmission Equipment	Transmission Equipment	4
Regional Ring Transmission Equipment	Transmission Equipment	5
Core Link Transmission Equipment	Transmission Equipment	6
RUs	Switching Equipment	7
BUs	Switching Equipment	8
CAEs	Switching Equipment	9

These resource pools are such that they are used zero, one or multiple times in the conveyance of individual calls from the different communication types.

The BU model is conceived to calculate tariffs for the communication types specified in Table 2. In order to obtain these tariffs the cost of the resource pools are to be calculated and allocated to the different communication types based on the routing factors $RF_{i,j}$ in this table.

All values for $RF_{8,j}$ in Table 2, excepting $RF_{8,6}$, are clear from the definition of the communication type. The routing factor $RF_{8,6}$ is in fact calculated as a weighted average due to the fact that the *internet communication type traffic* consists of classical routed traffic and off-load traffic, which is diverted from the PSTN/ISDN network to an access server directly after a BU or CAE[19].

Table 2. Routing factors for communication type-resource pool pairs

Routing factors $RF_{i,j}$		**Resource pool**								
	i →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Communication type	*j*	Links LDC	Regional Rings	Core Links	LDC Links Trans. Equip	Reg. Ring Trans. Equip	Core Links Trans. Equip	RUs	BUs	CAEs
Local Traffic	*1*	$RF_{1,1}$	$RF_{2,1}$	$RF_{3,1}$	$RF_{4,1}$	$RF_{5,1}$	$RF_{6,1}$	$RF_{7,1}$	**1**	$RF_{9,1}$
IAA Intra-Ring Traffic	*2*	$RF_{1,2}$	$RF_{2,2}$	$RF_{3,2}$	$RF_{4,2}$	$RF_{5,2}$	$RF_{6,2}$	$RF_{7,2}$	**2**	$RF_{9,2}$
IAA Inter-Ring Traffic	*3*	$RF_{1,3}$	$RF_{2,3}$	$RF_{3,3}$	$RF_{4,3}$	$RF_{5,3}$	$RF_{6,3}$	$RF_{7,3}$	**2**	$RF_{9,3}$
EAA Traffic	*4*	$RF_{1,4}$	$RF_{2,4}$	$RF_{3,4}$	$RF_{4,4}$	$RF_{5,4}$	$RF_{6,4}$	$RF_{7,4}$	**2**	$RF_{9,4}$
VAS	*5*	$RF_{1,5}$	$RF_{2,5}$	$RF_{3,5}$	$RF_{4,5}$	$RF_{5,5}$	$RF_{6,5}$	$RF_{7,5}$	**2**	$RF_{9,5}$
Internet	*6*	$RF_{1,6}$	$RF_{2,6}$	$RF_{3,6}$	$RF_{4,6}$	$RF_{5,6}$	$RF_{6,6}$	$RF_{7,6}$	$RF_{8,6}$	$RF_{9,6}$
Terminating Local	*7*	$RF_{1,7}$	$RF_{2,7}$	$RF_{3,7}$	$RF_{4,7}$	$RF_{5,7}$	$RF_{6,7}$	$RF_{7,7}$	**1**	$RF_{9,7}$
Terminating IAA	*8*	$RF_{1,8}$	$RF_{2,8}$	$RF_{3,8}$	$RF_{4,8}$	$RF_{5,8}$	$RF_{6,8}$	$RF_{7,8}$	**1**	$RF_{9,8}$
Terminating EAA	*9*	$RF_{1,9}$	$RF_{2,9}$	$RF_{3,9}$	$RF_{4,9}$	$RF_{5,9}$	$RF_{6,9}$	$RF_{7,9}$	**1**	$RF_{9,9}$
Collecting Local	*10*	$RF_{1,10}$	$RF_{2,10}$	$RF_{3,10}$	$RF_{4,10}$	$RF_{5,10}$	$RF_{6,10}$	$RF_{7,10}$	**1**	$RF_{9,10}$
Collecting IAA	*11*	$RF_{1,11}$	$RF_{2,11}$	$RF_{3,11}$	$RF_{4,11}$	$RF_{5,11}$	$RF_{6,11}$	$RF_{7,11}$	**1**	$RF_{9,11}$
Transit IAA	*12*	$RF_{1,12}$	$RF_{2,12}$	$RF_{3,12}$	$RF_{4,12}$	$RF_{5,12}$	$RF_{6,12}$	$RF_{7,12}$	**0**	$RF_{9,12}$

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[19] This reasoning is further detailed in paragraph 5.5.6.

Transit EAA	*13*	$RF_{1,13}$	$RF_{2,13}$	$RF_{3,13}$	$RF_{4,13}$	$RF_{5,13}$	$RF_{6,13}$	$RF_{7,13}$	**0**	$RF_{9,13}$
International In & Out	*14*	$RF_{1,14}$	$RF_{2,14}$	$RF_{3,14}$	$RF_{4,14}$	$RF_{5,14}$	$RF_{6,14}$	$RF_{7,14}$	**1**	$RF_{9,14}$
International Transit	*15*	$RF_{1,15}$	$RF_{2,15}$	$RF_{3,15}$	$RF_{4,15}$	$RF_{5,15}$	$RF_{6,15}$	$RF_{7,15}$	**0**	$RF_{9,15}$
IC Others: BGC to FOLO	*16*	$RF_{1,16}$	$RF_{2,16}$	$RF_{3,16}$	$RF_{4,16}$	$RF_{5,16}$	$RF_{6,16}$	$RF_{7,16}$	**1**	$RF_{9,16}$
IC Others: BGC to MOLO	*17*	$RF_{1,17}$	$RF_{2,17}$	$RF_{3,17}$	$RF_{4,17}$	$RF_{5,17}$	$RF_{6,17}$	$RF_{7,17}$	**1**	$RF_{9,17}$

The detailed calculation of the routing factors for each of the communication types and for each of the resource pools is outlined in Chapter 5.

The communication types j = 1, 2, 3, 4 correspond with the Belgacom to Belgacom traffic types between geographical numbers for voice-services (cf. paragraph 3.2) and have been discussed in the previous paragraphs of this chapter. In fact, all the communication types in Table 2 use the same PSTN/ISDN network and the same routing principles as these types.

For types j = 7, 8, 9, 10, 11, 12, 13, corresponding to the traffic types between Belgacom and the other national operators (OLOs), the interconnection link, being the link providing the connection between the incumbent's network and OLO, and the elements on the switch dedicated to this interconnection link are not considered a part of the PSTN/ISDN increment and for this reason they are not included in the BU model.

For types j = 14, 15, 16, 17, corresponding to the traffic types between Belgacom and other operators abroad, the cost of the switching components, dedicated for international calls and the international connections (e.g. submarine cables) are not included in the BU model.

The types j = 5, 6 correspond to the VAS[20] and Internet traffic, both Belgacom to Belgacom services which have a more or less specific routing as has also described within the framework of the top-down model[21].

4. COST CALCULATION

This paragraph gives an overview on the cost calculation methodology and consequently goes into detail on the various components, e.g. *remuneration of capital*, *mark-ups for OPEX*, *overhead*. It also further defines the resource pools and elaborates on their contents, e.g. documenting the formulae used to calculate investments in direct CAPEX.

4.1. *OVERVIEW COST CALCULATION*

As clarified by the previous paragraph, the routing of traffic for different communication types defines the resource cost pools[22], and a routing factor indicates in which amount a communication of a certain type consumes a *resource* (or *resource cost pool*).

These resource pools are a logical grouping of resources. For each of the resource pools, costs will be calculated. These consist of both CAPEX and OPEX. The CAPEX are determined as investment costs, which are to be depreciated by the *Tilted Annuity Formula* presented in paragraph 2.3.1. Since CAPEX, belonging to a certain resource pool, do not necessary have the same expected *asset life* or *annual price change*, they need to be depreciated separately.

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[20] Value-Added Services VAS

[21] Cf. Description of theoretical routing factors for the top-down model 2003: http://www.bipt.be/Actualites/Communications/routingfactortheorie-presentatie%20nl.pdf

[22] A logical grouping of resources aggregated to simplify the assignment of these resources to cost objects.

Figure 9 presents an overview of the total yearly cost calculation of a resource pool and its allocation to all sorts of traffic types.

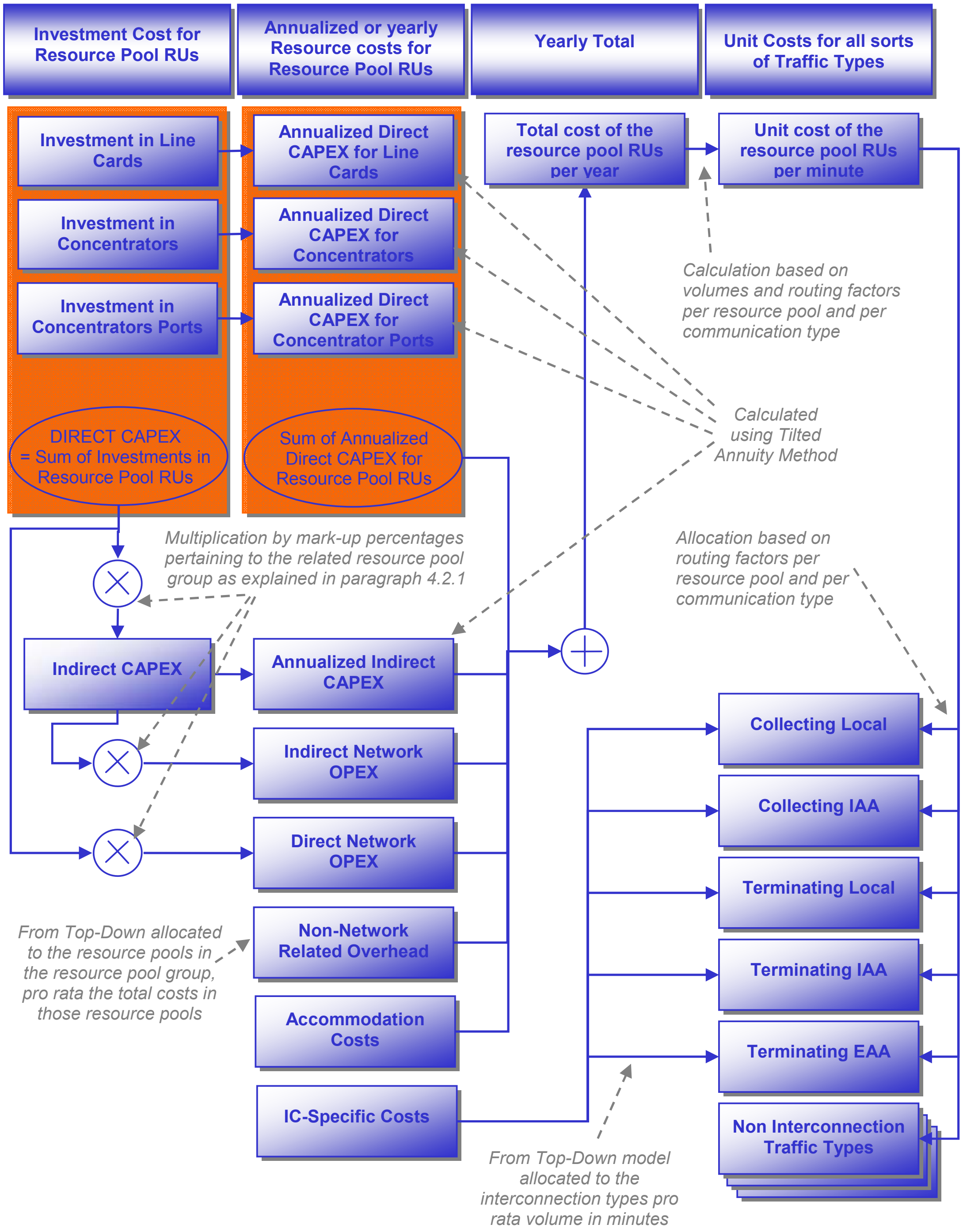

Figure 9. Simplified example for cost calculation and allocation of the resource pool RUs

Figure 9 also shows the methodology involving the allocation of the *Non-network Related Overhead* and *IC-Specific Costs*. Furthermore, it shows that the *Indirect CAPEX* and *Direct Network OPEX* are calculated by multiplication of the *Direct CAPEX* with a certain mark-up percentage and that the *Indirect Network OPEX* is derived from the *Indirect CAPEX.* All these notions are further defined and described in the following section 4.2.

As can be depicted from Figure 9 the unit costs for all sort of communication types can be derived from the *IC-specific costs* and the *unit costs per resource pool*. The latter can in turn be derived from the *total (annual) cost per resource pool*.

4.2. *NETWORK MARK-UP COSTS, NON-NETWORK RELATED OVERHEAD COSTS AND IC-SPECIFIC COSTS.*

This section discusses the various costing information regarding *network mark-up costs* and *non-network related overhead costs*.

4.2.1 OVERVIEW

As illustrated by Figure 9 and Table 3, the following cost categories are defined:

- Indirect Network Support CAPEX
- Direct Network OPEX
- Indirect Network OPEX
- Non-network related overhead.

Table 3. Network mark-up costs and non-network overhead costs

	Switching		*Transmission*	
	Local	*Transit*	*Equipment*	*Infrastructure*
Total Network OPEX				
Direct Network OPEX	... (in %)	... (in %)	... (in %)	... (in %)
Indirect Network OPEX	... (in %)	... (in %)	... (in %)	... (in %)
Indirect Network Support CAPEX	... (in %)	... (in %)	... (in %)	... (in %)
Non-Network Related Overhead	... (in €)	... (in €)	... (in €)	... (in €)

For all of these cost categories, an appropriate value will be determined for the following groups of resource pools:

- Local switching (gathering the resource pools *RUs* and *BUs*);
- Transit switching (resource pool *CAEs*);
- Transmission equipment (gathering the resource pools *LDC Link Transmission Equipment*, *Regional Ring Transmission Equipment* and *Core Link Transmission Equipment*);
- Transmission infrastructure (gathering the resource pools *LDC Links*, *Regional Rings* and *Core Links*).

The grouping of these resource pools has been decided upon, based on the format of the information obtained from multiple sources (incumbent, OLOs and other bottom-up models).

For the mark-ups, this implies that uniform percentages will be applied to the resource pools belonging to the same group (e.g. the mark-up for Indirect Network Support CAPEX will be the same for the Resource pools *LDC Link Transmission Equipment*, *Regional Ring Transmission Equipment* and *Core Link Transmission Equipment*).

This table also contains the mark-up percentages to be applied to the resource pool *RUs* in Figure 9 and in accordance to the above reasoning, they can be found in the *Switching Local* column. This table also contains the *Non-Network Related Overhead* borrowed from the top-down model and allocated to the resource pools in the resource pool group, pro rata the total costs in those resource pools.

4.2.2 DEFINITION AND CALCULATION

In the following sections, the different network mark-up costs and non-network related overhead cost categories will be defined and it will be explained how they are calculated.

INDIRECT NETWORK SUPPORT CAPEX

The *Indirect network support CAPEX* is the total of all capital expenditure costs that cannot be directly attributed to specific network components that are dimensioned in paragraph 4.3, but that are indispensable for providing PSTN/ISDN-services, e.g. CAPEX costs for network management systems.

As a consequence, this cost category contains all CAPEX costs relevant for PSTN/ISDN-services, excluding *Direct investment CAPEX* (i.e. all direct investments in switching equipment, transmission equipment, transmission infrastructure), *accommodation costs* and *Non-network related overhead CAPEX* (e.g. building costs for the corporate headquarters).

The investment in indirect network support CAPEX is included in the bottom-up model by means of a mark-up percentage, namely as a percentage of the direct network investments:

$$mark-up_{Indirect\ CAPEX} = \frac{GRC\ Indirect\ CAPEX_{Top-Down}}{GRC\ Direct\ CAPEX_{Top-Down}}$$

The percentage is mainly determined based on input information from the top-down model for interconnection, as well as on more detailed cost accounting information from the incumbent operator. However, the fact that other sources on similar mark-ups are available for the determination of the indirect network costs, allows the BIPT to verify the reasonableness of its results.

The percentage derived from top-down information related to the incumbent, will then be applied to the direct investment in switching and transmission equipment and transmission links, as illustrated in Figure 9. This provides us the total investment in indirect network support CAPEX. This absolute amount will subsequently be depreciated and, per resource pool, added to the annualized direct CAPEX.

The Indirect network support CAPEX is depreciated by means of the same methodology as the direct network CAPEX, i.e. the *Tilted Annuity Method* as illustrated in paragraph 2.3.1. Note however that in the applied *Tilted Annuity Formula*, the parameters *economic asset life* (L) and *price change* (P) differ from the direct network CAPEX.

DIRECT NETWORK OPEX

The *Direct network OPEX* is the total of all direct operational expenditure costs that are required to guarantee the continuity of the network components' functioning, such as maintenance costs.

As a consequence, this cost category contains all OPEX costs relevant for PSTN/ISDN-services, excluding *Non-network related overhead OPEX* and *Indirect Network OPEX*, which is defined hereafter.

The *Direct Network OPEX* is calculated by means of a mark-up percentage, namely the percentage of the direct network investments:

$$mark-up_{Direct\ Network\ OPEX} = \frac{annual\ direct\ network\ OPEX_{Top-Down}}{GRC\ Direct\ CAPEX_{Top-Down}}$$

Analogous to the *Indirect network support CAPEX*, the percentage derived from top-down information related to the incumbent, will then be applied to the direct investment in switching and transmission equipment and transmission links, as calculated in paragraph 4.4. This provides us the annual direct network OPEX, which can directly be added to the annualized direct and indirect CAPEX per resource pool.

INDIRECT NETWORK OPEX

The *Indirect network OPEX* is the total of all indirect operational expenditure costs that are required to guarantee the continuity of the indirect network investments' functioning, such as maintenance costs of the performance management systems.

As a consequence, this cost category contains all OPEX costs relevant for PSTN/ISDN-services, excluding *Non-network related overhead OPEX* and *Direct Network OPEX*.

The direct network OPEX is also calculated by means of a mark-up percentage, namely the percentage of the indirect network investments:

$$mark-up_{Indirect\ Network\ OPEX} = \frac{annual\ indirect\ network\ OPEX_{Top-Down}}{GRC\ Indirect\ CAPEX_{Top-Down}}$$

The percentage derived from top-down information related to the incumbent, will now be applied to the indirect investment in switching and transmission equipment and transmission links, as calculated in paragraph 4.4. This provides us the annual indirect network OPEX, which can directly be added to the annualized direct and indirect CAPEX and network OPEX per resource pool.

NON-NETWORK RELATED OVERHEAD COSTS

The *Non-network related overhead costs* can be defined as the total of all costs related to general support services, that cannot be directly attributed to the exploitation of the network. Typical examples are the costs of the human resources, finance and legal department.

Non-network related overhead costs are borrowed from the top-down model for interconnection and allocated to the resource pools in the resource pool group, pro rata the total costs in those resource pools. Please note however that specific costs, e.g. costs related to restructuring plans, are eliminated from the non-network related overhead costs coming from the top-down model, as the inputs for the bottom-up model should reflect as close as possible the costs of an efficient operator.

IC-SPECIFIC COSTS

The *Interconnection-Specific costs* (*IC-specific costs*) are defined as these costs that are caused directly and only by the interconnection services. They can relate to both traffic dependent and traffic independent interconnection services. However, as the scope of this bottom-up model is limited to the basic traffic dependent interconnection services (cf. paragraph 1.2), only the interconnection specific costs related to terminating and collecting services will need to be added to the total cost base.

The IC-specific costs for the traffic dependent interconnection services are borrowed from the top-down model for interconnection and allocated to the interconnection communication types pro rata the volume in minutes *Collecting IAA*, *Collecting Local*, *Terminating EAA*, *Terminating IAA*, *Terminating Local*.

These costs mainly relate to part of the cost of the carrier division, in which the costs can be found of the contact persons with OLOs at the incumbent operator as well as part of the costs of staff at the regulatory department, which deal with interconnection issues.

4.3. *OVERVIEW RESOURCE POOLS*

As clarified by the previous paragraph, the routing of traffic for different communication types defines the resource cost pools[23], and a routing factor indicates in which amount an communication of a certain type consumes a resource (or resource cost pool). These resource cost pools comprise of both CAPEX[24] and OPEX[25] costs, relating to a certain network functionality and grouped in switching and transmission resource pools.

As explained BIPT has chosen for a modeling approach based on detailed network information, allowing to calculate the costs based on a per node basis, and thus accounting for the specific spread of demand, as well as the granularity of certain equipment in the network dimensioning.

4.3.1 OVERVIEW SWITCHING RESOURCE POOLS

- **Resource Pool RUs** containing all costs associated with RUs (Remote Units), such as line cards for PSTN, line cards for ISDN, concentrators, E1 ports, costs for accommodation, ...
- **Resource pool BUs** containing all costs associated with BUs (Base Units), such as line cards for PSTN, line cards for ISDN, concentrators, E1 ports, switching matrices, processors, costs for accommodation, ...
- **Resource Pool CAEs** containing all costs associated with CAEs (Covering Area Exchanges), such as ports, switching matrices, processors, costs for accommodation, ...

As noted, these switching resources pools contain the direct CAPEX and OPEX, they however also comprises of the *indirect network support CAPEX costs*.

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[23] A logical grouping of resources aggregated to simplify the assignment of these resources to cost objects.

[24] CAPEX, short for capital expenditures, described as the amount used during a particular period to acquire or improve long-term assets such as property, plant, or equipment.

[25] OPEX, short for operating expenses, described as the expenses incurred in conducting normal business operations. Or with other words, the amount paid for asset maintenance or the cost of doing business, excluding interest, depreciation, and taxes.

4.3.2 OVERVIEW TRANSMISSION RESOURCE POOLS

The transmission resource pools are divided into two groups, based on the network functionality, namely *Equipment* and *Links.*

EQUIPMENT

- **LDC Link Transmission Equipment** describes the costs associated with the transmission equipment with LDC functionality and comprising of tributary cards in LDC, TMUX, tributary cards in LTC, ...
- **Regional Ring Transmission Equipment** describes the costs associated with the transmission equipment with LTC functionality[26] (a LTC, or a ZTC with LTC functionality) and comprising of ADM, tributary cards, TMUX, ...
- **Core Link Transmission Equipment** describes the costs associated with the transmitting traffic to another ring or to another ZTC, and comprising of cross-connects, line termination equipment for p2p connections, ...

LINKS

- **LDC Links** describes the costs associated with the point-to-point[27] (p2p) link for the connection LDC-LTC.
- **Regional Rings** describes the costs associated with the connection between a LTC-LTC or LTC-ZTC over the regional rings network.
- **ZTC-ZTC Links** describes the costs associated with the connection between two ZTCs located on the same ring network, or connected through a p2p connection.

4.4. *RESOURCE COST POOL CALCULATIONS*

This section provides detailed information on the determination of the investments in the switching equipment, transmission equipment and transmission links. Separate subsections 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.

The remainder of this paragraph represents schemas of the equipment and documents the formulae used to calculate investments. The figures, schematically represent the equipment, use a color code, in which orange and blue colored components respectively identify switching components and transmission components.

4.4.1 SWITCHING RESOURCE POOLS

RESOURCE POOL RUS

The resource pool RUs comprises of the switching equipment used in the LDC-RU and in the LTC-RU. However, it follows from the fact that the dimensioning of the switching equipment is independent from transmission equipment, that the same dimensioning rules apply to both LDC-RU and LTC-RU switching equipment.

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[26] In this model, costs associated with a ZTC are split, according to their functionality, into a part providing the LTC functionality and a part providing the cross-connect functionality.

[27] A point-to-point link (or shorthand notation: p2p) directly connects two points, or nodes.

The LDC-RU equipment is schematically represented in Figure 10, in which orange and blue colored components respectively identify switching components and transmission components.

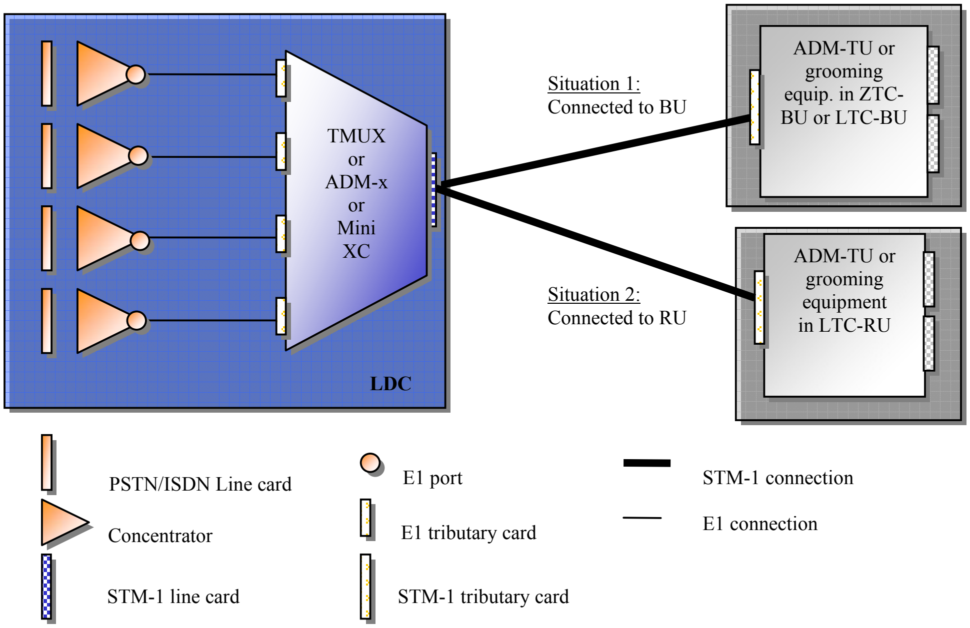

Figure 10. Simplified schematic representation of the LDC-RU equipment

The LDC-RU switching equipment thus comprises of PSTN/ISDN line cards, concentrator and concentrator ports (or E1 ports).

PSTN/ISDN line cards

Line cards are the termination point of the subscriber lines from the customer's premises, therefore the number of line cards depends on the number of lines. The cost of a line card is attributed to the core network only for a certain percentage, since it defines the border between the core and access networks. (cfr. paragraph 2.3.2, subsection *Border With Local Access Network*).

$$\mathit{Investment\ in\ line\ cards\ in\ a\ specific\ RU} = \frac{\#PSTN * Inv\_PSTN\_RU + \#ISDNBA * Inv\_ISDNBA\_RU + \#ISDNPRA * Inv\_ISDNPRA\_RU}{U_{lc\_RU}} * Perc\_core$$

With:

#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[28]
U_{lc_RU}: *Utilisation factor (in %) for the line cards in RU*

Inv_PSTN_RU: Investment cost in PSTN line cards in RU for 1 PSTN user
Inv_ISDNBA_RU: Investment cost in ISDN-BA line cards in RU for 1 ISDN-BA user
Inv_ISDNPRA_RU: Investment cost in ISDN-PRA line cards in RU for 1 ISDN-PRA user
Perc_core: % of the line card attributable to the core network

Concentrators

A concentrator is best described as equipment capable of concentrating the traffic, in other words it reduces the number of subscriber lines from the access network to a lower number of E1s towards the TMUX.

$$\textit{Investment in concentrators in a specific RU} =$$

$$\textit{number of concentrators (E1) * investment cost per concentrator (E1)} =$$

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

With:

Roundup: Rounds the result upwards to the nearest integer

#PSTN: Number of PSTN subscribers in a specific node

#ISDNBA: Number of ISDN-BA subscribers in a specific node[28]

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

U_{c_RU}: *Utilisation factor (in %) for the concentrator in RU*

U_{pc}: *Number of line equivalents in a concentrator per E1*

Inv_conc_RU: Investment cost for a concentrator per E1

G_c: *Granularity of concentrator (e.g. multiple of 4 E1s required)*

Concentrator ports

The concentrator ports are used to connect the concentrator to the equipment following the concentrator (e.g. TMUX) on E1 level.

$$\textit{Investment in concentrator related ports in a specific RU} =$$

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

With:

Roundup: Rounds the result upwards to the nearest integer

#PSTN: Number of PSTN subscribers in a specific node

#ISDNBA: Number of ISDN-BA subscribers in a specific node[28]

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

U_{cp_RU}: *Utilisation factor (in %) for concentrator ports in RU*

U_{pc}: *Number of line equivalents in a concentrator per E1*

Inv_portc_RU: Investment cost for a E1 port

G_c: *Granularity of concentrator (e.g. multiple of 4 E1s required)*

Please note that the number of ports equals the number of concentrators when utilization 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.

Accommodation

The accommodation costs of all nodes in the network modeled consist of an annualized cost (CAPEX and OPEX) per m² and of a fixed yearly cost (OPEX) per node. However, since all switching and transmission nodes are collocated, the fixed yearly cost (OPEX) per node needs

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[28] In the modeled network, no ISDN-PRA lines are installed in the RUs. Nevertheless, the formulae applied in the bottom-up model allow the possibility of taking PRAs into account in the RUs.

to be split between the switching and transmission nodes. Arbitrary, it is fully accounted for in the formulae for determining the yearly accommodation cost of the switching nodes and therefore does not reoccur in the formulae for the investments in transmission nodes.

$$\text{Yearly accommodation cost in a specific RU} =$$

$$Acc_{fix\_RU} + Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * 30}{U_{lc\_RU} * G_{RU\_acc}}\right) * Footprint\_RU_{G\_acc}$$

$$* Acc_{var\_RU} * Corr_{lc\_RU} * (1 + Corr_{oh\_RU})$$

With:

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_{fix_RU}: Fixed yearly OPEX (fixed per node)
U_{lc_RU}: Utilisation factor (in %) for line cards in RU
G_{RU_acc}: Granularity of RU equipment (in a number of equivalent lines)
$Footprint\_RU_{G\_acc}$: Footprint of RU equipment for number of equivalent lines equal to granularity
Acc_{fix_RU}: Fixed yearly OPEX (fixed per node)
Acc_{var_RU}: Variable annualised OPEX and CAPEX (variable per m²)
$Corr_{lc\_RU}$: Correction factor for the elimination of the footprint requirements for the line cards
$Corr_{oh-RU}$: Correction factor for the addition of the overhead surface (for extra corridors etc)

RESOURCE POOL BUs

The resource pool BUs comprises of the switching equipment used in the LTC-BU and in the ZTC-BU. However, it follows from the fact that the dimensioning of the switching equipment is independent from transmission equipment, that the same dimensioning rules apply to both LTC-BU and ZTC-BU switching equipment.

The LTC-BU equipment is schematically represented in Figure 11, in which orange and blue colored components respectively identify switching components and transmission components.

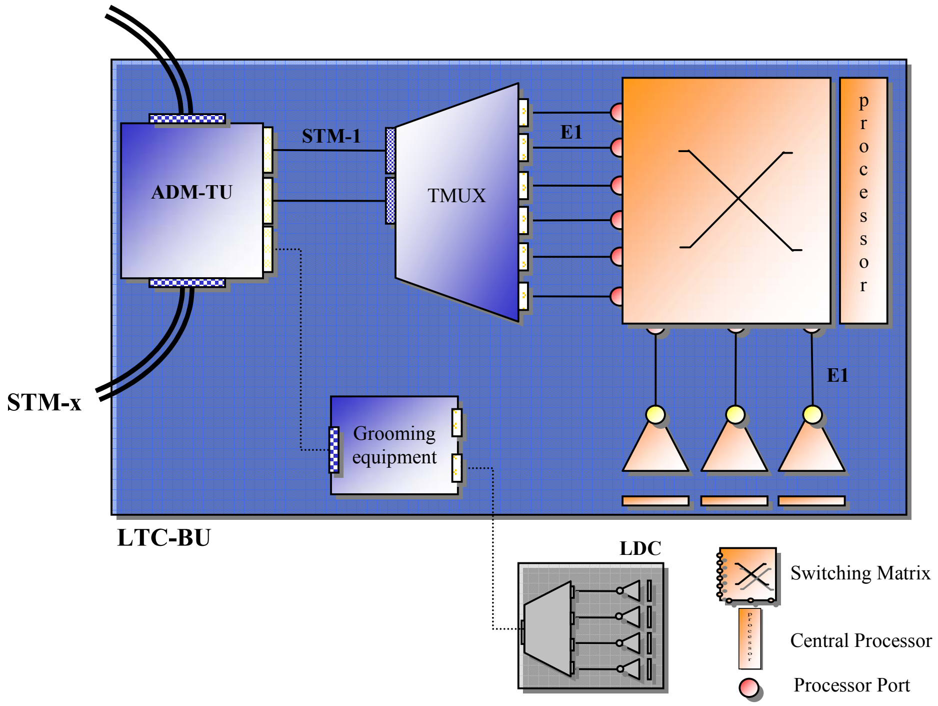

Figure 11. Simplified schematic representation of the LTC-BU equipment

The LTC-BU switching equipment thus comprises of PSTN/ISDN line cards, concentrator and concentrator ports (or E1 ports), switching matrix, switching matrix ports and central processor.

PSTN/ISDN line cards

Line cards are the termination point of the subscriber lines from the customer's premises, therefore the number of line cards depends on the number of lines. The cost of a line card is attributed to the core network only for a certain percentage, since it defines the border between the core and access networks. (cfr. paragraph 2.3.2, subsection *Border With Local Access Network*).

$$\text{Investment in line cards in a specific BU} =$$

$$\frac{\#PSTN * Inv\_PSTN\_BU + \#ISDNBA * Inv\_ISDNBA\_BU + \#ISDNPRA * Inv\_ISDNPRA\_BU}{U_{lc\_BU}} * Perc\_core$$

With:

#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_BU: Investment cost in PSTN line cards in a BU for 1 PSTN user

Inv_ISDNBA_BU: Investment cost in ISDN-BA line cards in a BU for 1 ISDN-BA user

Inv_ISDNPRA_BU: Investment cost in ISDN-PRA line cards in a BU for 1 ISDN-PRA user

U_{lc_BU}: *Utilisation factor (in %) for the line cards*

Perc_core: Percentage of the line card attributable to the core network

Concentrators

A concentrator is best described as equipment capable of concentrating the traffic, in other words it reduces the number of subscriber lines from the access network to a lower number of E1s towards the TMUX.

$$\text{Investment in concentrators in a specific BU} =$$

$$\text{number of concentrators (E1)} * \text{investment cost per concentrator (E1)} =$$

$$Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}}{U_{c\_BU} * U_{pc} * G_{c}}\right) * G_{c} * Inv\_conc\_BU$$

With:

Roundup: Rounds the result upwards to the nearest integer
#PSTN: Number of PSTN subscribers in a specific node
#ISDNBA: Number of ISDN-BA subscribers in a specific node[29]
 # ISDNPRA: Number of ISDN-PRA subscribers in a specific node

U_{c_BU}: *Utilisation factor (in %) for the concentrator in BU*
U_{pc}: *Number of line equivalents per E1*
Inv_conc_BU: Investment cost for a concentrator (per E1) in a BU
G_{c}: *Granularity of concentrator (e.g. multiple of 4 E1s required)*

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.

$$\text{Investment in concentrator related ports in a specific BU} =$$

$$Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}}{U_{cp\_BU} * U_{pc} * G_{c}}\right) * G_{c} * inv\_portc\_BU$$

With:

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_{cp_BU}: *Utilisation factor (in %) for concentrator ports in BU*
U_{pc}: *Number of line equivalents per E1*
Inv_portc_BU: Investment cost for a E1 port in a BU
G_{c}: *Granularity of concentrator (e.g. multiple of 4 E1s required)*

Switching Matrix Ports

The number of ports on the switching matrix is the sum of the number of ports facing the concentrators in the BU and RUs and the number of ports for intended for traffic switching in the BU. The number of ports facing the concentrators equals the number of ports on the concentrator itself, while the number of ports intended for the traffic switching is computed by applying the Erlang B-formula to the BHE of the BU, taking into account the number of directions D.

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[29] In the modeled network, no ISDN-PRA lines are installed in the RUs. Nevertheless, the formulae applied in the bottom-up model allow the possibility of taking PRAs into account in the RUs.

$$\begin{aligned}
&\textit{Investment in switching matrix ports in a specific BU} = \\
&\textit{investment in ports facing the concentrator in BU} + \textit{investment in ports for the switching matrix} + \\
&\textit{investment in ports facing the RU concentrators} = \\
&Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}}{U_{cp\_BU} * U_{pc} * G_c}\right) * G_c * Inv\_portm\_BU + \\
&Roundup\left(\frac{D * ErlangB(BHE/D, P_b)}{U_{mp\_BU} * C_i}\right) * Inv\_portm\_BU + \\
&\textit{number of concentrator ports RU} * Inv\_portm\_BU
\end{aligned}$$

With:

Roundup: Rounds the result to the nearest integer
ErlangB(x,y): ErlangB function[30]
BHE: BHE per node
C_i: Number of 64 Kbps channels per E1
D: Number of directions in which BHE are measured
P_b: Blocking ratio
U_{cp_BU}: Utilisation factor for ports on the concentrator in a BU
U_{pc}: Number of line equivalents per E1
Inv_portm_BU: Investment in port (per E1) on the switching matrix in a BU
G_c: Granularity of concentrator (e.g. multiple of 4 E1s required)
U_{mp_BU}: Utilisation factor for the ports (%) on the switching matrix in a BU

Switching Matrix

The switching matrix is controlled by the processor and able to interconnect lines and trunks.

$$\begin{aligned}
&\textit{Investment in switching matrix in a specific BU} = \\
&\textit{investment in switching matrix related to ports facing the concentrator in BU} + \\
&\textit{investment in switching matrix related to traffic measured in switch} + \\
&\textit{investment in switching matrix related to ports facing the RU concentrators} = \\
&Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}}{U_{cp\_BU} * U_{pc} * G_c}\right) * G_c * Inv\_switch\_BU + \\
&Roundup\left(\frac{D * ErlangB(BHE/D, P_b)}{U_{m\_BU} * C_i}\right) * Inv\_switch\_BU + \\
&\textit{number of concentrator ports RU} * Inv\_switch\_BU
\end{aligned}$$

With:

Roundup: Rounds the result to the nearest integer
ErlangB(x,y): ErlangB function
BHE: BHE per node
C_i: Number of 64 Kbps channels per E1
D: Number of directions in which BHE are measured
P_b: Blocking ratio
U_{m_BU}: Utilisation factor for the switching matrix (%) in a BU
U_{cp_BU}: Utilisation factor for ports on the concentrator in a BU
U_{pc}: Number of line equivalents per E1
Inv_portm_BU: Investment in port (per E1) on the switching matrix in a BU
G_c: Granularity of concentrator (e.g. multiple of 4 E1s required)
Inv_switch_BU: Investment in switching matrix (per E1)in a BU

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[30] *ErlangB(X, Pb)* indicates the required capacity, determined with the Erlang B-formula, for *X* Busy Hour Erlang and a blocking chance equal to *Pb%*.

Processor

A processor is a device that controls the operations, such as establishing paths through the switching matrix, tearing down connections upon call completion.

$$\textit{Investment in processor in a specific BU} = \frac{BHE}{C_{bhca} * U_{p\_BU}} * Inv\_processor\_BU$$

With:

BHE: BHE per node
C_{bhca}: Conversion from BHE to BHCA[31]
U_{p_BU}: Utilisation factor for the processor (%) in a BU
Inv_processor_BU: Investment cost in processor capacity per BHCA in a BU

The factor U_p should be determined very consciously since the measured BHE figures do not account for the processing power required for the processing of BU-RU traffic.

Accommodation

The accommodation costs of all nodes in the network modeled consist of an annualized cost (CAPEX and OPEX) per m² and of a fixed yearly cost (OPEX) per node. However, since all switching and transmission nodes are collocated, the fixed yearly cost (OPEX) per node needs to be split between the switching and transmission nodes. Arbitrary, it is fully accounted for in the formulae for determining the yearly accommodation cost of the switching nodes and therefore does not reoccur in the formulae for the investments in transmission nodes.

$$\textit{Yearly accommodation cost in a specific BU} =$$

$$Acc_{fix\_BU} + Roundup\left(\frac{\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * 30}{U_{cp\_BU} * G_{BU\_acc}}\right) * Footprint\_BU_{G\_acc} * Acc_{var\_BU} * Corr_{lc\_BU} * (1 + Corr_{oh\_BU})$$

With:

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_{cp_BU}: Utilisation factor (in %) for concentrator port in a BU
G_{BU_acc}: Granularity of BU equipment (in a number of equivalent lines)
Acc_{fix_BU}: Fixed yearly OPEX (fixed per node)
Acc_{var_BU}: Variable annualised OPEX and CAPEX (variable per m²)
$Corr_{lc\_BU}$: Correction factor for the elimination of the footprint requiremets for the line cards
$Corr_{oh\_BU}$: Correction factor for the addition of the overhead surface (for corridors etc)
$Footprint\_BU_{G\_acc}$: Footprint of BU equipment for number of equivalent equal to granularity

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[31] The calculation of this value can be verified in '*LRIC bottom-up model for interconnection - Consultation Document 3.1 & Addenda',* (cfr. http://www.bipt.be)

RESOURCE POOL CAES

The resource pool CAEs comprises of the switching equipment used in the ZTC-CAE nodes, as a CAE is always collocated with a ZTC.

The ZTC-CAE equipment is schematically represented in Figure 12, in which orange and blue colored components respectively identify switching components and transmission components.

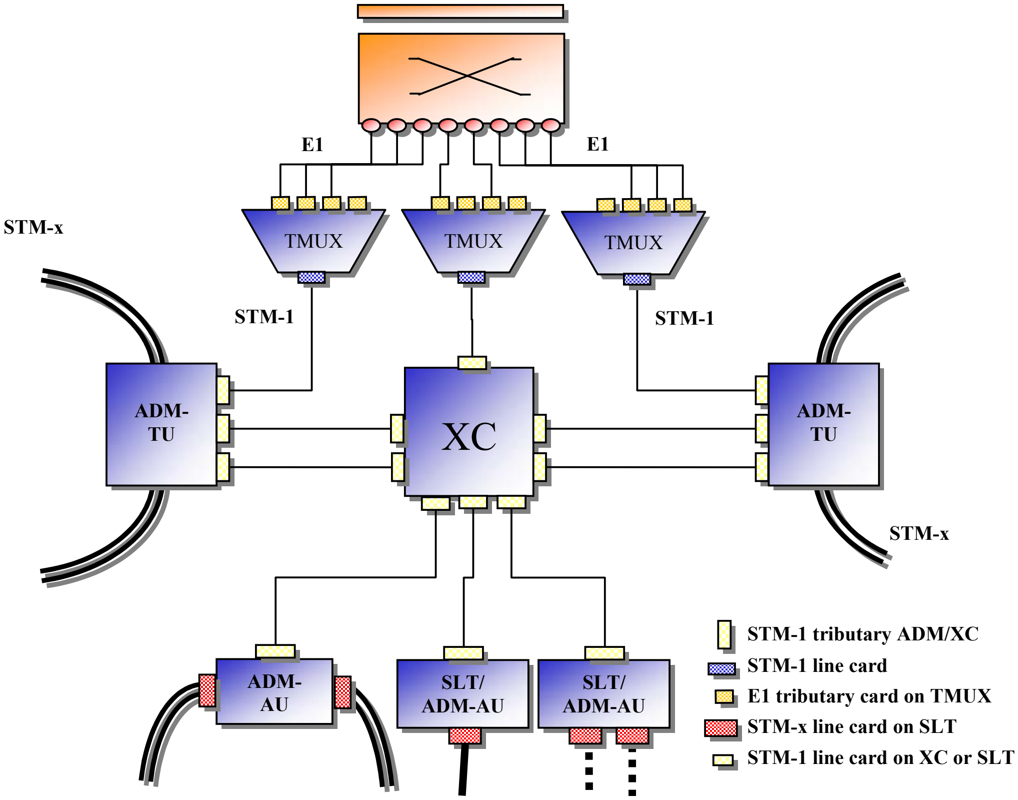

Figure 12. Simplified schematic representation of the ZTC-CAE equipment

The ZTC-CAE switching equipment thus comprises of switching matrix, switching matrix ports and central processor.

Switching Matrix Ports

$$\textit{Investment in switching matrix ports in a specific CAE} = \textit{Roundup}\left(\frac{D * \textit{ErlangB}(BHE/D, P_b)}{U_{mp\_CAE} * C_i}\right) * \textit{Inv\_portm\_CAE}$$

With:

Roundup: Rounds the result to the nearest integer
ErlangB(x,y): ErlangB function
BHE: BHE per node
C_i: Number of 64 Kbps channels per E1
P_b: Blocking ratio
Inv_portm_CAE: Investment in ports (per E1) on matrix in a CAE
U_{mp_CAE}: Utilisation factor for the ports (%) in a CAE
D: Number of directions in which BHE are measured

Switching Matrix

$$\textit{Investment in switching matrix in a specific CAE} =$$

$$Roundup\left(\frac{D * ErlangB(BHE/D,P_b)}{U_{m\_CAE} * C_i}\right) * Inv\_switch\_CAE$$

With:

Roundup: Rounds the result to the nearest integer

ErlangB(x,y): ErlangB function

BHE: BHE per node

C_i: Number of 64 Kbps channels per E1

P_b: Blocking ratio

Inv_switch_CAE: Investment in switching matrix (per E1) in a CAE

U_{m_CAE}: Utilisation factor for the switching matrix (%) in a CAE

D: Number of directions in which BHE are measured

Processor

$$\textit{Investment in processor in a specific CAE} =$$

$$\frac{BHE}{C_{bhca} * U_{p\_CAE}} * Inv\_processor\_CAE$$

BHE: BHE per node

C_{bhca}: Conversion from BHE to BHCA (0,04)

U_{p_CAE}: Utilisation factor for the processor (%) in a CAE

Inv_processor_CAE: Investment cost in processor capacity per BHCA in a CAE

The factor U_p should take into account a normal utilization rate, as opposed to the U_p factor used in dimensioning the BU processors, since all BHE that pass the CAE are effectively measured.

Accommodation

The accommodation costs of all nodes in the network modeled consist of an annualized cost (CAPEX and OPEX) per m² and of a fixed yearly cost (OPEX) per node. However, since all switching and transmission nodes are collocated, the fixed yearly cost (OPEX) per node needs to be split between the switching and transmission nodes. Arbitrary, it is fully accounted for in the formulae for determining the yearly accommodation cost of the switching nodes and therefore does not reoccur in the formulae for the investments in transmission nodes.

$$\textit{Yearly accommodation cost in a specific CAE} =$$

$$Acc_{fix\_CAE} + Roundup\left(\frac{D * ErlangB(BHE/D, P_b)}{U_{m\_CAE} * C_i * G_{CAE\_acc}}\right) * Footprint\_CAE_{G\_acc} * Acc_{var\_CAE} * (1 + Corr_{oh\_CAE})$$

With:

Acc_{fix_CAE}: Fixed yearly OPEX (fixed per node)

Acc_{var_CAE}: Variable annualised OPEX and CAPEX (variable per m²)

Roundup: Rounds up the result to the nearest integer

$Footprint\_CAE_{G\_acc}$: Footprint of CAE equipment for number of E1s equal to granularity

D: Number of directions in which BHE are measured

ErlangB(x,y): ErlangB function

P_b: Blocking ratio

G_{CAE_acc}: Granularity of CAE equipment (in a number of E1s)

U_{m_CAE}: Utilisation factor for the switching matrix (%)

$Corr_{oh\_CAE}$: Correction factor for the addition of the overhead surface (for corridors etc)

C_i: Number of 64 Kbps channels per E1

BHE: BHE per node

4.4.2 TRANSMISSION RESOURCE POOLS

RESOURCE POOL LDC LINKS TRANSMISSION EQUIPMENT

The resource pool LDC Links comprises of the transmission equipment used in the LDC-RU. This subsection documents the formulae used to calculate the investment in transmission equipment in the Local Distribution Centers (LDC). As with switching investments, transmission investments are calculated on a per node basis.

The LDC-RU equipment is schematically represented in Figure 13, in which orange and blue colored components respectively identify switching components and transmission components.

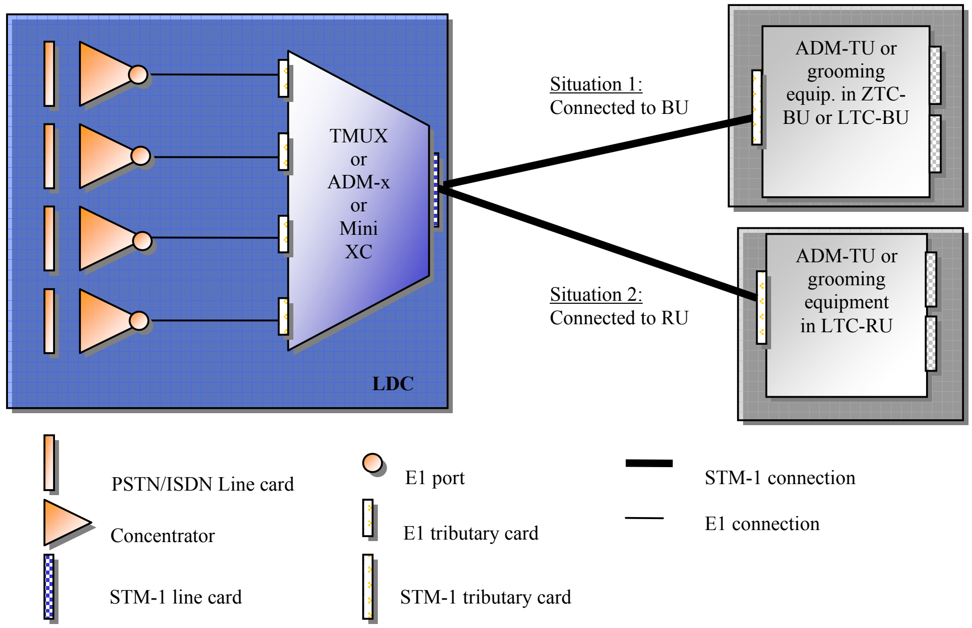

Figure 13. Simplified schematic representation of the LDC-RU equipment

The LDC-RU transmission equipment thus comprises of E1 tributary cards in TMUX, TMUX equipment, STM-1 line cards in TMUX and STM-1 tributary cards at the LTC or ZTC side.

E1 tributary cards in TMUX

The formula below accounts for 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.

$$Investment\ in\ E1\ tributary\ cards\ in\ a\ specific\ LDC = Roundup\left(\frac{E1_{c}}{E1_{trib\_TMUX}}\right) * Inv\_trib_{TMUX}$$

With:

Roundup: Rounds the result to the nearest integer
$E1_c$: Number of E1s originating from concentrators

$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card in a TMUX
Inv_trib_{TMUX}: Investment cost for 1 tributary card (contains $E1_{trib}$ ports) in a TMUX

The number of E1s originating from the concentrators already accounts for a utilization factor; hence no extra utilization factor has to be applied in the above formula.

TMUX equipment

$$\textit{Investment in } T-\textit{MUX equipment in a specific LDC } =$$

$$Roundup\left(\frac{Roundup\left(\frac{E1_{c}}{E1_{trib\_TMUX}}\right)}{TMUX_{trib}}\right) * \; Inv\_TMUX$$

With:

Roundup: Rounds the result to the nearest integer
$E1_c$: Number of E1s originating from concentrators
$TMUX_{trib}$: Maximum capacity of TMUX expressed in tributary cards
$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card in a TMUX
Inv_TMUX: Investment cost for 1 TMUX (Including 0 STM1 interface)

STM-1 line cards in TMUX

$$\textit{Investment in STM } - 1 \textit{ line cards in } T-\textit{MUX in a specific LDC } =$$

$$Roundup\left(\frac{E1_{c}}{63}\right) * Inv\_stm1$$

With:

Roundup: Rounds the result to the nearest integer
$E1_c$: Number of E1s originating from concentrators
Inv_stm1: Investment cost for 1 STM1 line card

STM-1 tributary cards at the LTC or ZTC side

The STM-1 tributary cards at the LTC or ZTC side, are in fact located at the LTC or ZTC node, as shown by Figure 13. The investment representing these STM-1 tributary cards is however taken into account in the investment calculation for the LDC, since there is no exact information on the combination LDC-LTC or LDC-ZTC linking, which makes it impossible to model this cost at the LTC or ZTC side. Note that the STM-1 card can both be situated on a grooming equipment unit that is located in the LTC or ZTC, or on the ADM-TU. However, since the model assumes that the cost of a STM-1 tributary card on a grooming equipment unit equals the cost of a STM-1 tributary card on an ADM-TU, this distinction is not relevant.

$$\textit{Investment in STM } - 1 \textit{ tributary cards at the LTC / ZTC side in a specific LDC } =$$

$$Roundup\left(\frac{E1_{c}}{63}\right) * Inv\_admstm1$$

With:

Roundup: Rounds the result to the nearest integer
$E1_c$: Number of E1s originating from concentrators
Inv_admstm1: Investment cost for 1 STM1 tributary card in ADM-TU or grooming equipment unit, located in the LTC/ZTC

Accommodation

Since the fixed cost per node was accounted for in the switching investments, the accommodation costs for the transmission equipment consists solely of a variable annualized cost (OPEX and CAPEX) per m². These costs have to be added to the accommodation costs of the switching equipment that is collocated in the same network node.

$$\textit{Yearly accommodation cost for the equipment in a specific LDC} =$$

$$\#TMUX_{LDC} * Footprint\_TMUX * Acc_{var\_LDC} * (1 + Corr_{oh\_LDC})$$

With:

Acc_{var_LDC}: Variable annualised OPEX and CAPEX (variable per m²)

Footprint_TMUX: Footprint of TMUX equipment

$\#TMUX_{LDC}$: Number of TMUX in the LDC

$Corr_{oh\_LDC}$: Correction factor for the addition of the overhead surface (for corridors etc)

RESOURCE POOL REGIONAL RINGS TRANSMISSION EQUIPMENT

The resource pool Regional Rings comprises of the transmission equipment used in the LTC-RU and LTC-BU. The following subsections first describe the formulae used for the LTC-RU. Subsequently, the LTC-BU formulae will be commented. As with switching investments, transmission investments are calculated on a per node basis.

The LTC-RU equipment and LTC-BU equipment are schematically represented in Figure 14 and Figure 15, in which orange and blue colored components respectively identify switching components and transmission components.

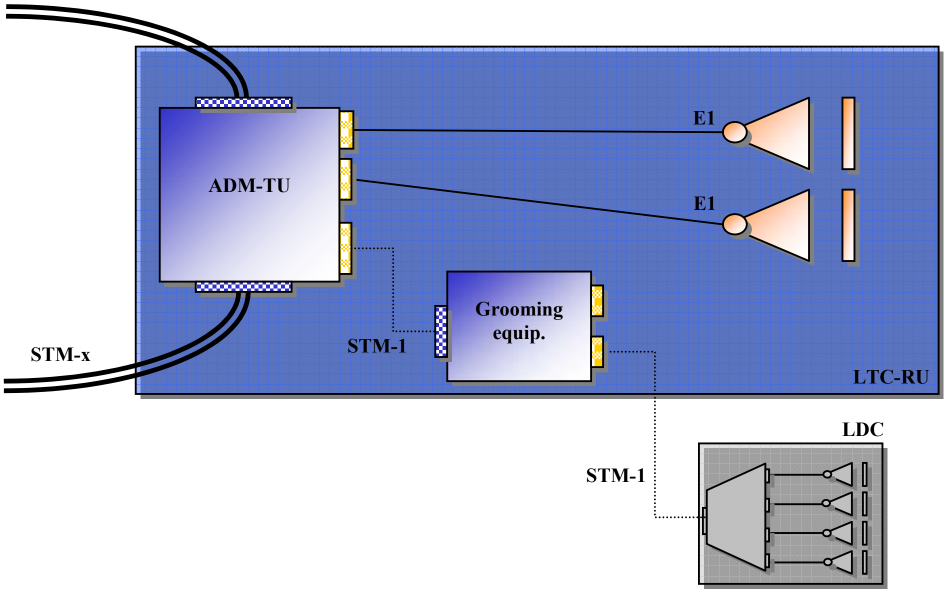

Figure 14. Simplified schematic representation of the LTC-RU equipment

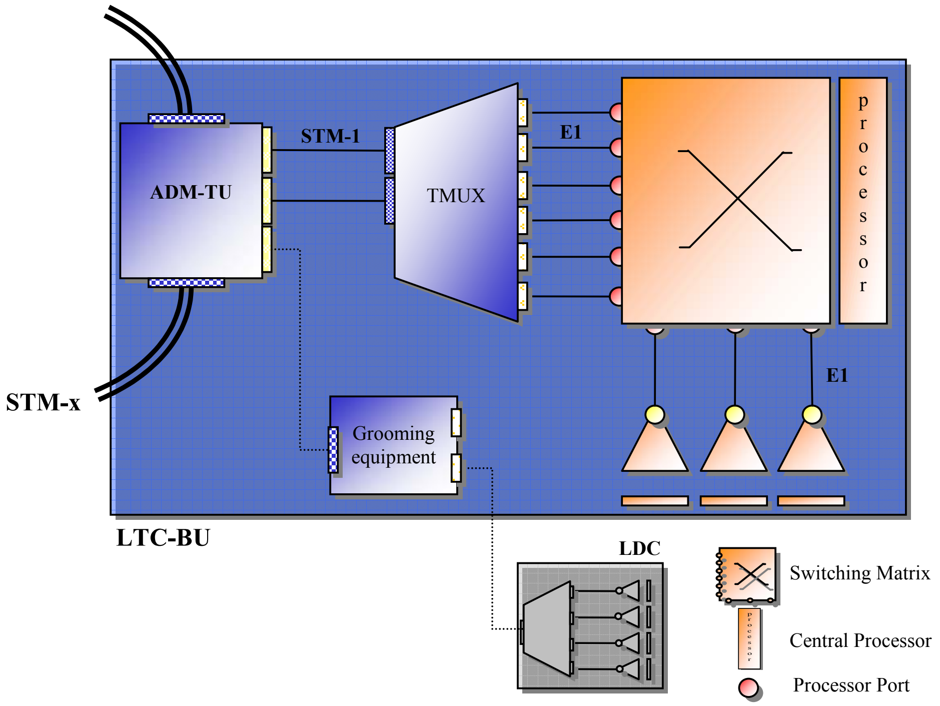

Figure 15. Simplified schematic representation of the LTC-BU equipment

Figure 14 shows that, in case of an LTC-RU, the E1 ports that originate from the concentrator are directly connected to the ports on the E1 tributary cards on the ADM-TU, hence no TMUX equipment is needed in an LTC-RU. In case of a LTC-BU, the connection from the switch to the ADM-TU is always provided through additional TMUX capacity, it follows that no port constraints will occur on the ADM-TU equipment in a LTC-BU.

The LTC-RU transmission equipment thus comprises of LTC-RU Investment in E1 tributary cards on the ADM-TU, LTC-RU Investment in ADM-TU equipment, LTC-BU Investment in E1 tributary cards on the TMUX, LTC-BU Fixed investment in a TMUX, LTC-BU STM-1 line cards in a TMUX, LTC-BU Investment in ADM equipment, LTC-BU Investment in STM-1 tributary cards in ADM and Grooming equipment in LTCs.

LTC-RU Investment in E1 tributary cards on the ADM-TU

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-TU and the concentrators. Therefore, E1 tributary cards should be installed directly in the ADM-TU.

$$\textit{Investment in } E1 \textit{ tributary cards on } ADM - TU \textit{ in a specific } LTC - RU =$$

$$Roundup\left(\frac{E1_{c}}{E1_{trib\_adm}}\right) * Inv\_trib_{adm}$$

With:

Roundup: Rounds the result to the nearest integer

$E1_c$: Number of E1s originating from concentrators

$E1_{trib\_adm}$: Number of E1 ports on 1 tributary card in a ADM

Inv_trib_{adm}: Investment cost for 1 tributary card on the ADM-TU (contains $E1_{trib}$ ports)

LTC-RU Investment in ADM-TU equipment

The appropriate type of ADM-TU equipment is determined by the actually installed capacity of the ring on which the ADM-TU is situated. Possible options are STM-1 ADM-TU, STM-4 ADM-TU, STM-16 ADM-TU and STM-64 ADM-TU. Only in the cases where the installed capacity equaled 2 times a STM-1 ring, the model increases this capacity to a STM-4 level. Furthermore, the investment in ADM-TU includes the line cards to the ring, but excludes the tributary cards towards the switch.

$$Investment\ in\ ADM-TU\ equipment\ in\ a\ specific\ LTC\ (incl.\ line\ cards) =$$
$$Inv\_admX\ *\ Perc\_switch$$

With:

Perc_switch: Percentage of the ring used for switched services

Inv_admX: Investment cost for ADM-TU x equipment, including line cards towards ring with STM X capacity 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 (TMUX) between the switch and the Add Drop Multiplexer (ADM) 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.

LTC-BU Investment in E1 tributary cards on the TMUX

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 (TMUX) between the switch and the Add Drop Multiplexer (ADM) 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.

$$Investment\ in\ E1\ tributary\ cards\ =$$
$$Roundup\left(\frac{E1_{BHE} + E1_{RU} - E1_{Rucol}}{E1_{trib\_TMUX}}\right) * Inv\_trib_{TMUX}$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RU}$: Number of E1s coming from RUs
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU

$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card in a TMUX
Inv_trib_{TMUX}: Investment cost for 1 tributary card on the TMUX (contains $E1_{trib}$ ports) in a TMUX

The above formula is the result of the fact that some RUs are collocated with BUs. This is considered inefficient; therefore the RU lines are modeled as being BU customers. This reasoning is reflected in the above formula by the subtraction of the number of ports from these customers, since they do not pass through the TMUX equipment or the ADM.

Moreover, in some (very few) cases, RUs collocated with a BU have a different host BU. The result of this is that when the RU ports are deducted 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 BU that hosts these RUs.

LTC-BU Fixed investment in a TMUX

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

$$Investment\ in\ TMUX\ equipment\ =$$

$$Roundup\left(\frac{Roundup\left(\frac{E1_{BHE}+E1_{RU}-E1_{Rucol}}{E1_{trib\_TMUX}}\right)}{TMUX_{trib}}\right)*Inv\_TMUX$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card in a TMUX
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RU}$: Number of E1s coming from RUs
$TMUX_{trib}$: Maximum Capacity of TMUX expressed in tributary cards
Inv_TMUX: Investment cost for 1 TMUX (Including 0 STM1 interface)
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU

LTC-BU STM-1 line cards in a TMUX

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

$$Investment\ in\ STM1-1\ line\ cards\ in\ TMUX\ =$$

$$Roundup\left(\frac{E1_{BHE}+E1_{RU}-E1_{Rucol}}{63}\right)*Inv\_stm1$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RU}$: Number of E1s coming from RUs
Inv_stm1: Investment cost for 1 STM1 line card in TMUX
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU

LTC-BU Investment in ADM equipment

The appropriate type of ADM-TU equipment is determined by the actually installed capacity of the ring on which the ADM-TU is situated. Possible options are STM-1 ADM-TU, STM-4 ADM-TU, STM-16 ADM-TU and STM-64 ADM-TU. Only in the cases where the installed capacity equaled 2 times a STM-1 ring, the model increases this capacity to a STM-4 level. Furthermore, the investment in ADM-TU includes the line cards to the ring, but excludes the tributary cards towards the switch.

$$\begin{aligned}&Investment\ in\ ADM - TU\ equipment\ in\ a\ specific\ LTC\ (incl.\ line\ cards)\ =\\&Inv\_admX\ *\ Perc\_switch\end{aligned}$$

With:

Perc_switch: Percentage of the ring used for switched services

Inv_admX: Investment cost for ADM_x equipment, including line cards towards ring with STM X capacity but excluding tributary cards

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 TMUX at the STM-1 level. The model does not take into account higher connection rates. Moreover, it's assumed that no capacity problems will occur at the ADM port level.

The model also assumes 1 STM-1 port per tributary card. Simulations run in the model 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.

$$\begin{aligned}&Investment\ in\ STM-1\ tributary\ cards\ for\ \ ADM\ =\\&Roundup\left(\frac{E1_{BHE}+E1_{RU}-E1_{Rucol}}{63}\right)*Inv\_admstm1\end{aligned}$$

With:

Roundup: Rounds the result to the nearest integer

$E1_{BHE}$: Number of E1s based on BHE data

$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU

$E1_{RU}$: Number of E1s coming from RUs

Inv_admstm1: Investment cost for 1 STM1 tributary card in ADM

Grooming equipment in LTCs

When multiple LDCs are connected to the same LTC, grooming equipment may be required in order to efficiently convey the traffic emerging from the LDC-RUs over the regional rings. As no detailed information regarding the combination LDC-LTC is available, grooming equipment cannot be dimensioned at node level. Therefore, only the total investment cost in grooming equipment is modeled in the BU model and includes:

- The investment costs of the fixed part of the grooming equipment
- The investment costs of the STM-1 line cards on the ADM in the LTC that are required to realize the connection between the grooming equipment and the ADMs
- The investment costs of the STM-1 tributary cards on the ADM in the LDC that are required to realize the connection between the grooming equipment and the ADMs
- Investment costs for accommodation

Please note that the investment costs of the STM-1 tributary cards on the grooming equipment are already taken into account at the LDC side and therefore will not show up in the following formula.

$$\begin{aligned}&\text{Investment in grooming equipment in a LTC} = \\ &\#\_grooming\_LTC * Perc\_switch\_average * \\ &\left(Inv\_grooming\_fixed + Inv\_admstm1 + Footprint\_grooming * \left(1 + Corr_{oh\_LTC} \right) \right)\end{aligned}$$

With:

#_grooming_LTC: number of grooming equipment units, located in a LTC	Inv_grooming_fixed: Investment cost for fixed part of grooming equipment
Footprint_ grooming: Footprint of grooming equipment	Inv_admstm1: Investment cost for STM-1 tributary card on ADM
Perc_switch_average: Average percentage of the grooming equipment used for switched services	$Corr_{oh\_LTC}$: Correction factor for the addition of the overhead surface (for corridors etc)

Accommodation

Since the fixed cost per node was accounted for in the switching investments, the accommodation costs for the transmission equipment consists solely of a variable annualized cost (OPEX and CAPEX) per m². These costs have to be added to the accommodation costs of the switching equipment that is collocated in the same network node.

$$\begin{aligned}&\text{Yearly accommodation cost for the equipment in a specific } LTC - RU = \\ &\#ADM_{LTC\_RU} * Footprint\_ADM * Perc\_switch * Acc_{var\_LTC} * (1 + Corr_{oh\_LTC})\end{aligned}$$

With:

$\#ADM_{LTC\text{-}RU}$: Number of ADM in the LTC-RU	Footprint_ ADM: Footprint of ADM equipment
Perc_switch: Percentage of the ring on which the ADM is located, used for switched services	Acc_{var_LTC}: Variable annualized OPEX and CAPEX (variable per m²)
$Corr_{oh\_LTC}$: Correction factor for the addition of the overhead surface (for corridors etc)	

Please note that these formulae do not include accommodation costs for grooming equipment as they are already taken into account in the investment costs of the grooming equipment.

$$\begin{aligned}&\text{Yearly accommodation cost for the equipment in a specific } LTC - BU = \\ &\left((\#TMUX_{LTC\_BU} * Footprint\_TMUX) + (\#ADM_{LTC\_BU} * Footprint\_ADM * Perc\_switch) \right) * \\ &Acc_{var\_LTC} * (1 + Corr_{oh\_LTC})\end{aligned}$$

With:

$\#TMUX_{LTC\text{-}BU}$: Number of TMUX in the LTC-BU	Footprint_ TMUX: Footprint of TMUX equipment
$\#ADM_{LTC\text{-}BU}$: Number of ADM in the LTC-BU	Footprint_ ADM: Footprint of ADM equipment
Perc_switch: Percentage of the ring on which the ADM is located, used for switched services	Acc_{var_LTC}: Variable annualized OPEX and CAPEX (variable per m²)
$Corr_{oh\_LTC}$: Correction factor for the addition of the overhead surface (for corridors etc)	

RESOURCE POOL CORE LINKS TRANSMISSION EQUIPMENT

The resource pool Core Links Transmission Equipment comprises of the transmission equipment used in the ZTC-BU and ZTC-CAE. The following subsections first describe the formulae used for the ZTC-BU. Subsequently, the ZTC-CAE formulae will be commented. As with switching investments, transmission investments are calculated on a per node basis.

The ZTC-BU equipment and ZTC-CAE equipment are schematically represented in Figure 16, in which orange and blue colored components respectively identify switching components and transmission components. As the ZTC-CAE node does not comprise of grooming equipment, this grooming equipment should only be considered when modeling a ZTC-BU.

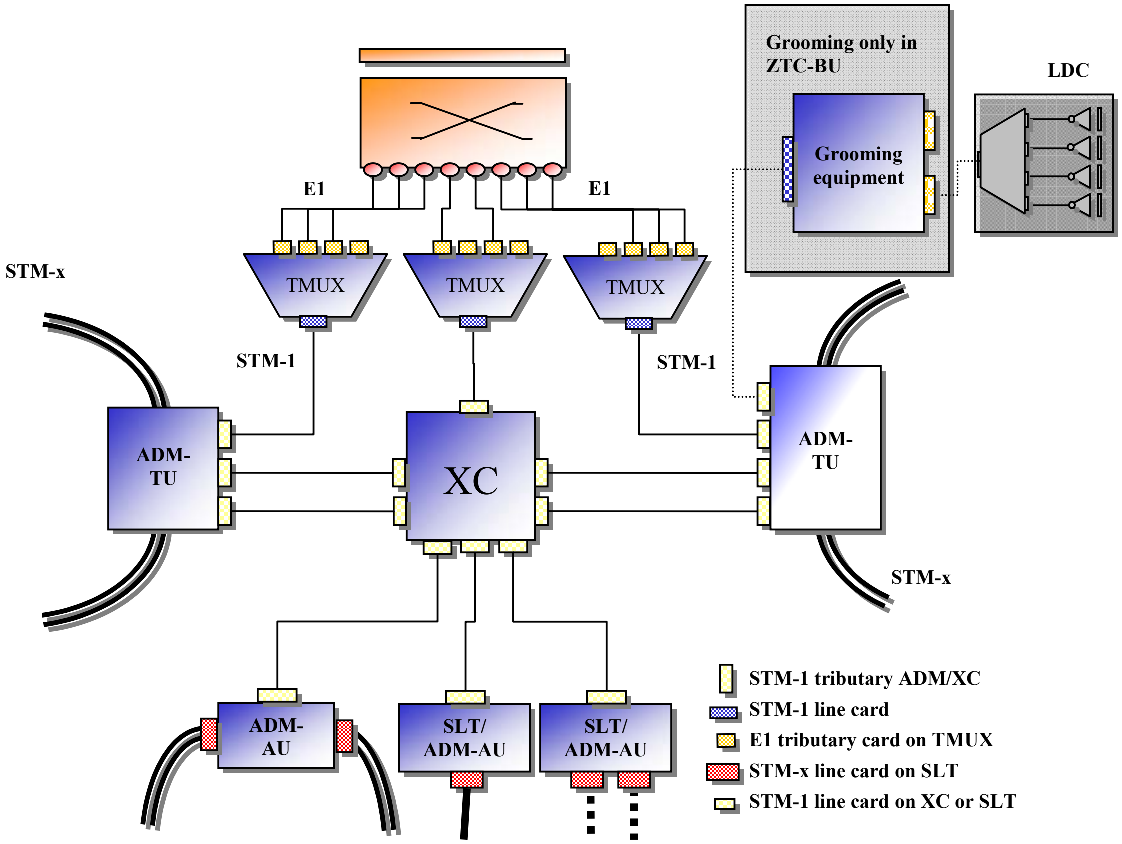

Figure 16. Simplified schematic representation of the ZTC-BU and ZTC-CAE equipment

The Core Link Transmission Equipment thus comprises of Investment in E1 tributary cards in TMUX, Fixed investment in TMUX equipment, Investment in STM-1 line cards in TMUX, Fixed investment in ADM-TU equipment, Investment in STM-1 tributary cards in ADM-TU equipment, Grooming equipment, Fixed investment in cross-connects, Investment in STM1-cards in cross-connect, Investment in SLT line cards, Investment in SLT STM1 tributary cards, Fixed investment in SLT equipment, Investment in ADM-AU line cards, Investment in ADM-AU STM1 tributary cards, Fixed investment in ADM-AU equipment.

Investment in E1 tributary cards in TMUX

The investment in E1 tributary cards on the TMUX located in the ZTC is determined by the formula below. Note that the exact location of these tributary cards in the different TMUX in the ZTC is irrelevant for the cost calculation in the model. But the $E1_{BHE}$ includes the idea of directionality as it is calculated as the sum of the E1s for the different directions.

$$\textit{Investment in } E1 \textit{ tributary cards in ZTC} =$$

$$Roundup\left(\frac{E1_{BHE} + E1_{RU} - E1_{RUcol}}{E1_{trib\_TMUX}}\right) * Inv\_trib\_TMUX$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU
$E1_{RU}$: Number of E1s coming from RUs
$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card
Inv_trib_TMUX: Investment cost for 1 tributary card on the TMUX (contains $E1_{trib}$ ports)

Fixed investment in TMUX equipment

It can easily be depicted from Figure 16 that at least 1 distinct TMUX needs to be configured for each ring and an additional TMUX is required to provide a direct connection from the switch to the cross-connect located in the ZTC. Furthermore, the capacity of the TMUX is limited by a maximum number of tributary cards that can be inserted in the TMUX. Once this capacity is reached, a number of additional TMUX will be installed, equaling the number of rings + 1, as represented by the formula below.

$$\textit{Investment in TMUX equipment} =$$

$$Max\left(Roundup\left(\frac{Roundup\left(\frac{E1_{BHE} + E1_{RU} - E1_{RUcol}}{E1_{trib\_TMUX}}\right)}{TMUX_{trib} * (\#\text{Rings} + 1)} * (\#\text{Rings} + 1)\right), (\#\text{Rings} + 1)\right) *$$

$$Inv\_Tmux$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{trib\_TMUX}$: Number of E1 ports on 1 tributary card in a TMUX
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RU}$: Number of E1s coming from RUs
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU
$TMUX_{trib}$: Maximum capacity of TMUX expressed in tributary cards
Inv_TMUX: Investment cost for 1 TMUX (Including 0 STM1 interface)
\# Rings: Number of rings on which the ZTC is located

Investment in STM-1 line cards in TMUX

The connection between the TMUX and the ADM or the Cross-Connect is provided by means of STM-1 connections and each TMUX has at least 1 STM-1 connection, hence at least 1 STM-1 line card, as easily depicted from the formula below representing the investment calculation of the STM1-line cards in the TMUX.

$$\mathit{Investment\ in\ STM-1\ line\ cards\ in\ TMUX} =$$
$$\mathit{Max}\left(\#\mathrm{TMUX}\ ,\ \mathit{Roundup}\left(\frac{E1_{BHE} + E1_{RU} - E1_{Rucol}}{63} \right) \right) * \mathit{Inv\_stm1}$$

With:

Roundup: Rounds the result to the nearest integer
$E1_{BHE}$: Number of E1s based on BHE data
$E1_{RU}$: Number of E1s coming from RUs

Inv_stm1: Investment cost for 1 STM1 line card in TMUX
#TMUX: Number of distinct TMUX equipment in ZTC
$E1_{RUcol}$: Number of E1s coming from RUs collocated with BU

Fixed investment in ADM-TU equipment

The appropriate type of ADM-TU 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-TU includes the line cards to the ring but excludes the tributary cards towards the switch.

$$\mathit{Investment\ in\ ADM-TU\ equipment\ in\ a\ specific\ ZTC\ (incl.\ line\ cards)} =$$
$$\mathit{Inv\_admX} * \mathit{Perc\_switch}$$

With:

Perc_switch: Percentage of the ring used for switched services

Inv_admX: Investment cost for ADM_ equipment, including line cards towards ring with STM X capacity but excluding tributary cards

Investment in STM-1 tributary cards in ADM-TU equipment

In a specific ZTC, the total investment for STM-1 tributary cards in ADM-TU equipment is the sum of the calculated investments in STM-1 cards per ring for that specific ZTC.

These investments in STM-1 tributary cards for the ADM-TU equipment per ring are calculated by multiplying the capacity of that ring with the percentage that is used for PSTN/ISDN-traffic. The result of this calculation, representing the capacity that needs to transit through the ADM, is divided by 155 and rounded up to calculate the required amount of STM-1 cards per ring.

$$\mathit{Investment\ in\ STM1-1\ tributary\ cards\ in\ ADM-TU\ per\ ring} =$$
$$\mathit{Max}\left(2\ ,\ \mathit{Roundup}\left(\frac{\mathit{Perc\_switch} * \mathit{Cap}_{ring}}{155} \right) \right) * \mathit{Inv\_admstm1}$$

With:

Roundup: Rounds the result to the nearest integer
Perc_switch: Percentage of ring capacity used for switched services

Inv_admstm1: Investment in 1 STM-1 tributary card in ADM
Cap_{ring}: Capacity of the ring (622, 2500, 10000), expressed in Mbps

As the above formula indicates, a minimum of 2 STM-1 cards is required for interfacing with the TMUX of the switch and the cross-connect.

For accuracy's sake, the capacity that needs to transit through the ADM should be reduced by ring capacity, used for local traffic and intra-ring traffic from nodes that are not collocated with the ZTC. However, since this would add to the complexity of the cross-connect formulae without significantly impacting the calculated investment, this is not taken into account. Thus, the number of ports needed on the ADM is slightly overstated.

Grooming equipment in ZTCs

When multiple LDCs are connected to the same ZTC, grooming equipment may be required in order to efficiently convey the traffic emerging from the LDC-RUs over the regional rings. As no detailed information regarding the combination LDC-ZTC is available, grooming equipment cannot be dimensioned at node level. Therefore, only the total investment cost in grooming equipment is modeled in the BU model and includes:

- The investment costs of the fixed part of the grooming equipment
- The investment costs of the STM-1 line cards on the ADM in the ZTC that are required to realize the connection between the grooming equipment and the ADMs
- The investment costs of the STM-1 tributary cards on the ADM in the LDC that are required to realize the connection between the grooming equipment and the ADMs
- Investment costs for accommodation

Please note that the investment costs of the STM-1 tributary cards on the grooming equipment are already taken into account at the LDC side and therefore will not show up in the following formula.

$$\begin{aligned}&\mathit{Investment\ in\ grooming\ equipment\ in\ a\ ZTC}\ =\\&\#\_\mathit{grooming\_ZTC} * \mathit{Perc\_switch\_average}\\&\left(\mathit{Inv\_grooming\_fixed} + \mathit{Inv\_STM1trib} + \mathit{Footprint\_grooming} * \left(1 + \mathit{Corr}_{oh\_ZTC}\right)\right)\end{aligned}$$

With:

#_grooming_ZTC: number of grooming equipment units, located in a ZTC
Footprint_ grooming: Footprint of grooming equipment
Perc_switch_average: Average percentage of the grooming equipment used for switched services
Inv_grooming_fixed: Investment cost for fixed part of grooming equipment
Inv_STM1trib: Investment cost for STM-1 tributary card on ADM
Corr_{oh_ZTC}: Correction factor for the addition of the overhead surface (for corridors etc)

Fixed investment in cross-connects

The number of cross-connects is calculated by formula below.

$$\mathit{Fixed\ investment\ in\ Cross-Connects}\ =\ \mathit{Roundup}\left(\frac{STM1_{cc}}{CC_{cap}}\right) * CC_{pstn} * Inv\_CC$$

With:

Roundup: Rounds the result to the nearest integer
Inv_CC: Fixed investment in cross-connect
CC_{cap}: Maximum number of ports on cross-connect
$\mathrm{STM1}_{CC}$: Number of STM1 ports on cross-connect for all services
CC_{pstn}: % of the cross-connect used for PSTN/ISDN services

The percentages for switched services are approximated by the percentages measured in the nodes, and although calculating the weighted average of the percentages measured on the rings would be more accurate, this simplification is considered reasonable vindicated by the network design and location of the PSTN measuring points.

Investment in STM1-cards in cross-connect

The number of STM1 cards for the cross-connect equals the number of STM1 ports on the cross-connect, which is calculated as the sum of the total number of STM1 ports on the ADM plus the number of active VC4s that originate from the core links.

$$Investment\ in\ STM1\ cards\ for\ cross-connect\ =$$

$$\left(STM1_{adm} + roundup\left(\frac{VC4}{U_{VC4}} \right) * VC4_{pstn} \right) * Inv\_CC\_stm1$$

With:

Roundup: Rounds the result to the nearest integer

Inv_CC_stm1: Investment in 1 STM-1 port on cross-connect

$STM1_{adm}$: Number of STM1 ports used for PSTN/ISDN services on the ADMs

VC4: Number of active VC4s on core link (all services)

$VC4_{pstn}$: Percentage of the links used for switched services

U_{VC4}: Utilization factor for the active VC4s

Since, this calculation method depends on the calculated number of STM1 ports on the ADMs used for PSTN/ISDN services, the same comments concerning accuracy apply here. The resulting investment will indeed be slightly overestimated, since the part of ring capacity used for the Local and IAA Intra-Ring traffic is unjustly taken into account, where in reality this does not affect the cross-connection dimensioning. Also, part of the IAA Inter-Ring traffic will transit through the switch without using the cross-connect, again overestimating the required number of STM1 ports on the cross-connect.

This overestimation is countered by not accounting for the non-Local and non-Intra-Ring traffic from customers directly connected to the BU collocated with the ZTC, while in reality this traffic utilizes the cross-connect equipment.

These approximation are vindicated by the fact that the actual formula is considerably more complicated and the impact on the final transmission cost is considered insignificant (<0,5%). In summary, the investment cost for the STM1 cards facing the ADMs is overestimated and the cost for the STM1 cards facing the TMUX of the switch is slightly underestimated. The impact on the final results however is negligible.

Investment in SLT line cards

The SLT equipment provides the connection between the cross-connect and the physical cable infrastructure of the core network, and realizes a point-to-point connection in the normal layer of the core transmission network. Actually, this SLT equipment is only a special configuration of an ADM.

In order to obtain the required number of SLT line cards, for each ZTC the required number of line card interfaces, expressed in a number of STM4, STM16 and STM64 capacities, are summed. This approach respects the individuality of the links, whereas an aggregate approach based on the total capacity and providing only one port for this capacity, would seriously underestimate the investment 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.

$$\begin{aligned}&Investment\ in\ SLT\ line\ cards\ for\ the\ cross-connect\ =\\&\left(STM4_{slt}\ *\ Inv\_slt\_stm4\ +\ STM16_{slt}\ *\ Inv\_slt\_stm16\ +\ STM64_{slt}\ *\ Inv\_slt\_stm64\right)\\&*VC4_{pstn}\end{aligned}$$

With:

$STM4_{slt}$: Number of STM4 ports required on the SLT 4
$STM16_{slt}$: Number of STM16 ports required on the SLT 16
$STM64_{slt}$: Number of STM64 ports required on the SLT 64

Inv_slt_stm4: Investment for 1 STM-4 SLT line card
Inv_slt_stm16: Investment for 1 STM-16 SLT line card
Inv_slt_stm64: Investment for 1 STM-64 SLT line card
$VC4_{pstn}$: Percentage of the links used for switched services

Investment in SLT STM1 tributary cards

The investment in SLT STM1 tributary cards depends on the total number of active VC4s that enter the ZTC through the core connections. These connections are partly conveyed by means of SLT equipment, whilst others are conveyed by means of ADM-AU equipment. Once the proportion of VC4s that is conveyed by means of SLT equipment is determined, the investment in SLT tributary cards can be expressed by the formula underneath:

$$\begin{aligned}&Investment\ in\ SLT\ tributary\ cards\ for\ the\ cross-connect\ =\\&Roundup\left(\frac{VC4}{U_{VC4}}\right)\ *\ VC4_{slt}\ *\ Inv\_slt\_stm1\ *\ VC4_{pstn}\end{aligned}$$

With:

VC4: Number of active VC4s
U_{VC4}: Utilization factor for the active VC4s
$VC4_{slt}$: Percentage of the active VC4s that are conveyed by means of SLT equipment

Inv_slt_stm1: Investment for 1 STM1 SLT tributary card
$VC4_{pstn}$: Percentage of the links used for PSTN/ISDN services
Roundup: Rounds the result to the nearest integer

Fixed investment in SLT equipment

The fixed investment in SLT equipment is determined, based on the result of the calculation of the number of active SLT line cards, since it is assumed that the capacity restraints are situated at the line card level (STM4, STM16 or STM64) and not at the tributary (STM1) level.

$$\mathit{Investment\ in\ SLT\ tributary\ cards\ for\ the\ cross-connect}\ =$$

$$\left(Roundup\left(\frac{STM4_{slt}}{Cap\_slt\_stm4} \right) * Inv\_sltfix\_stm4\ + \right.$$

$$Roundup\left(\frac{STM16_{slt}}{Cap\_slt\_stm16} \right) * Inv\_sltfix\_stm16\ +$$

$$\left. Roundup\left(\frac{STM64_{slt}}{Cap\_slt\_stm64} \right) * Inv\_sltfix\_stm64 \right) * VC4_{pstn}$$

With:

Roundup: Rounds the result to the nearest integer
$STM4_{slt}$: Number of STM4 ports required on the SLT 4
$STM16_{slt}$: Number of STM-16 ports required on the SLT 16
$STM64_{slt}$: Number of STM-64 ports required on the SLT 64
Cap_slt_stm4: Maximum number of STM-4 ports on SLT 4
Cap_slt_stm16: Maximum number of STM-16 ports on SLT 16
Cap_slt_stm64: Maximum number of STM-64 ports on SLT 64
Inv_sltfix_stm4: Fixed investment for 1 STM-4 SLT excl. line cards
Inv_sltfix_stm16: Fixed investment for 1 STM-16 SLT excl. line cards
Inv_sltfix_stm64: Fixed investment for 1 STM-64 SLT excl. line cards
$VC4_{pstn}$: Percentage of the links used for PSTN/ISDN services

Investment in ADM-AU line cards

ADM-AUs are used to realize the connection with the core ADM-AU rings of the core transmission network, both in the normal and in the express layer. The required line capacity is an input for each individual connection.

In order to obtain the required number of ADM-AU line cards, the maximum number of ADM-AU equipment per STM16 (or STM64) is multiplied by a factor expressing the filling ratio of line cards in the ADM-AU.

$$\mathit{Investment\ in\ ADM-AU\ line\ cards}\ =$$

$$Cap\_adm\_au\_stm16\ *\ \#ADM\_TU_{ZTC16}\ *\ Inv\_adm\_au\_stm16\ +\ Cap\_adm\_au\_stm64\ *$$

$$\#ADM\_TU_{ZTC64}\ *\ Inv\_adm\_au\_stm64)\ *\ VC4_{pstn}$$

With:

Cap_adm_au_stm16: Maximum number of STM-16 line cards on the ADM-AU STM16
Inv_ adm_au _stm16: Investment for 1 STM-16 ADM-AU line card
$\#ADM\_TU_{ZTC64}$: Number of ADM-TU in the ZTC with STM-64 ports
$\#ADM\_TU_{ZTC16}$: Number of ADM-TU in the ZTC with STM-16 ports
Cap_adm_au_stm64: Maximum number of STM-64 line cards on the ADM-AU STM64
Inv_adm_au_stm64: Investment for 1 STM-64 ADM-AU line card
$VC4_{pstn}$: Percentage of the links used for switched services

Investment in ADM-AU STM1 tributary cards

The investment in SLT STM1 tributary cards depends on the total number of active VC4s entering the ZTC through the core connections. These connections are partly conveyed by means of SLT equipment, whilst others are conveyed by means of ADM-AU equipment. Once the proportion of VC4s that is conveyed by means of SLT equipment is determined, the investment in SLT tributary cards can be expressed by the formula underneath:

$$Investment\ in\ ADM - AU\ tributary\ cards\ =$$
$$Roundup\left(\frac{VC4}{U_{VC4}}\right) * VC4_{adm-au} * Inv\_adm\_au\_stm1 * VC4_{pstn}$$

With:

VC4: Number of active VC4s	U_{VC4}: Utilization factor for the active VC4s
$VC4_{adm\_au}$: Percentage of the active VC4s that are conveyed by means of ADM-AU equipment	Inv_adm_au_stm1: Investment for 1 STM1 ADM-AU tributary card
$VC4_{pstn}$: Percentage of the links used for PSTN/ISDN services	Roundup: Rounds the result to the nearest integer

Fixed investment in ADM-AU equipment

Finally, the fixed investment in ADM-AU equipment has to be determined. Assuming that capacity restraints are at the line card level (STM16 or STM64) and not at the tributary (STM1) level, the formula below returns the fixed investment in ADM-AU equipment based on the number of active line cards calculated above.

$$Fixed\ investment\ in\ ADM - AU\ equipment\ =$$
$$\left(Roundup\left(\frac{STM16_{adm\_au}}{Cap\_adm\_au\_stm16}\right) * Inv\_adm\_aufix\_stm16\ + \right.$$
$$\left. Roundup\left(\frac{STM64_{adm\_au}}{Cap\_adm\_au\_stm64}\right) * Inv\_adm\_aufix\_stm64\right) * VC4_{pstn}$$

With:

$STM16_{adm\_au}$: Number of STM-16 ports required on the ADM-AU	Cap_adm_au _stm16: Maximum number of STM-16 line cards on ADM-AU
Inv_adm_aufix_stm16: Fixed investment for 1 STM-16 ADM-AU excl. line cards	$STM64_{adm\_au}$: Number of STM64 ports required on the ADM-AU
Cap_adm_au_stm64: Maximum number of STM-64 line cards on ADM-AU	Inv_adm_aufix_stm64: Fixed investment for 1 STM-64 ADM-AU excl. line cards
$VC4_{pstn}$: Percentage of the links used for PSTN/ISDN services	Roundup: Rounds the result to the nearest integer

Accommodation

Since the fixed cost per node was accounted for in the switching investments, the accommodation costs for the transmission equipment consists solely of a variable annualized cost (OPEX and CAPEX) per m². These costs have to be added to the accommodation costs of the switching equipment that is collocated in the same network node.

$$
\begin{aligned}
&\mathit{Yearly\ accommodation\ cost\ for\ the\ equipment\ in\ a\ specific\ ZTC-BU} = \\
&\Big[\#TMUX_{ZTC} * Footprint\_TMUX + \#ADM\_TU_{ZTC} * Footprint\_ADM\_TU * perc\_switch\_ZTC + \\
&Roundup\left(\frac{STM1_{adm} + roundup\dfrac{VC4}{U_{VC4}} * VC4_{pstn}}{8}\right) * Footprint\_CC_{8lc} + \\
&\left(\#SLT_{ZTC} * Footprint\_SLT + \#ADM\_AU_{ZTC} * Footprint\_ADM\_AU\right) * VC4_{pstn}\Big] * \\
&Acc_{var\_ZTC} * \left(1 + Corr_{oh\_ZTC}\right)
\end{aligned}
$$

With:

Roundup: Rounds the result to the nearest integer
$\#TMUX_{ZTC}$: Number of TMUX in the ZTC
$\#ADM\_TU_{ZTC}$: Number of ADM-TU in the ZTC
Perc_switch_ZTC: Average percentage of all the ADMs in a specific ZTC used for switched services
VC4: Number of active VC4s on core link (all services)
$VC4_{pstn}$: Percentage of the core links used for PSTN/ISDN services
$\#SLT_{ZTC}$: Number of SLT in the ZTC
$\#ADM\_AU_{ZTC}$: Number of ADM-AUs in the
Acc_{var_ZTC}: Variable annualized OPEX and CAPEX (variable per m²)

Footprint_ TMUX: Footprint of TMUX equipment
Footprint_ ADM_TU: Footprint of ADM-TU equipment
$STM1_{adm}$: Number of STM1 ports used for PSTN/ISDN services on the ADMs
U_{VC4}: Utilization factor for the active VC4s
Footprint_ CC_{8lc}: Footprint of cross-connect equipment per 8 linecards
Footprint_SLT: Footprint of SLT equipment
Footprint_ADM_AU: Footprint of ADM-AU equipment
$Corr_{oh\_ZTC}$: Correction factor for the addition of the overhead surface (for corridors etc)

Please note that this formula does not include accommodation costs for grooming equipment as they are already taken into account in the investment costs of the grooming equipment.

4.4.3 TRANSMISSION LINK RESOURCE POOLS

LDC LINK

No detailed information regarding the length of the individual LDC Links is obtainable, 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, the average length was used in the BU model.

Investment in trenches and ducts for the LDC Links

As can be depicted from the formula below, it is assumed that only a single cable is used for the *LDC Links*. Consequently, the connection requires only one trench and one duct.

Moreover, the following elements were also taken into account:

- Not only traffic from PSTN/ISDN-services is transmitted, but also traffic from leased lines, data-services etc. Consequently, only a certain percentage of the costs for ducts and trenches are 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*.

$$Investment\ in\ trenches\ per\ LDC - LTC\ Link\ =$$

$$Av\_length\ *\ Inv\_trench\ *\ \%Switch\_trench\_LDC\ *\ \%Shared\_trench\_LDC$$

$$Investment\ in\ duct\ per\ LDC - LTC\ Link\ =$$

$$Av\_length\ *\ Inv\_duct\ *\ \%Switch\_duct\_LDC\ *\ \%Shared\_duct\_LDC$$

With:

Av_length: Average length of a *LDC Link* (i.e. link between a LDC and a regional ring), expressed in meter

%Switch_trench_LDC: Percentage of the trench used for PSTN/ISDN-services

Inv_duct: Price of a duct, 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.

Inv_trench: Price of a trench, expressed in € per meter

%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.

%Switch_duct_LDC: Percentage of the duct used for PSTN/ISDN-services

Investment in cables for the LDC Links

In the formula to compute the investment in cables, it is assumed that only two fibers are used to create the STM-1 connections between the LDC and the Regional Ring. Therefore, since the standard number of fibers within one cable is equal to 12, 24, 48, or 96, it suffices for all links to use a cable featuring 12 fibers.

$$Investment\ in\ cables\ per\ LDC - LTC\ Link\ =$$

$$Av\_length\ *\ Inv\_cable\_12\ *\ \%Switch\_cable\_LDC\ *\ \%Shared\_cable\_LDC$$

With:

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 fibers, 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

REGIONAL RINGS

For every *regional ring* in modeled, information regarding the total length of the ring, the capacity of the SDH ring and the percentage used for PSTN/ISDN-services is known.

Analogous to the reasoning for the *LDC_LTC Links*, it is assumed that only a single cable is needed for the Regional Rings that consists of STM-4 or STM-16 capacities. Moreover, a cable featuring 12 fibers suffices. Consequently, the connection requires only one trench and one duct as well.

Investment in trenches and ducts for the Regional Rings

$$\mathit{Investment\ in\ trenches\ per\ Regional\ Ring} =$$

$$\mathit{Length\_regring} * \mathit{Inv\_trench} * \%\mathit{Switch\_trench\_regring} * \%\mathit{Shared\_trench\_regring} * \left(1 - \psi * \xi * \gamma\right)$$

$$\mathit{Investment\ in\ duct\ per\ Regional\ Ring} =$$

$$\mathit{Length\_regring} * \mathit{Inv\_duct} * \%\mathit{Switch\_duct\_regring} * \%\mathit{Shared\_duct\_regring} * \left(1 - \psi * \xi * \gamma\right)$$

With:

Length_regring: Length of the regional ring, expressed in meter

%Switch_trench_regring: Percentage of the trench used for PSTN/ISDN-services

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

Inv_duct: Price of a duct, expressed in € per meter

%Shared_duct_regring: Percentage of the duct used for the regional rings, i.e. exclusive the percentage for the local access network.

Inv_trench: Price of a trench, 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.

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

%Switch_duct_regring: Percentage of the duct used for PSTN/ISDN-services

γ: total length of core links divided by total length of regional rings

Investment in cables for the Regional Rings

$$\mathit{Investment\ in\ cables\ per\ Regional\ Ring} =$$

$$\mathit{Length\_regring} * \mathit{Inv\_cable\_12} * \%\mathit{Switch\_cable\_regring} * \%\mathit{Shared\_cable\_regring} * \left(1 - \psi * \xi * \gamma\right)$$

With:

Length_regring: Length of the regional ring, expressed in meter

%Switch_cable_regring: Percentage of the cable used for PSTN/ISDN-services

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

γ: Total length of core links divided by total length of regional rings

Inv_cable_12: Price of a cable featuring 12 fibers, expressed in € per 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.

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

CORE NETWORK

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

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

Investment in duct and trenches for the core links

With respect to the *Core Links*, 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 fibers, the number of the fibers actually used and the percentage used for PSTN/ISDN-services, is to our disposal.

$$\textit{Investment in trenches per Core Link} =$$

$$\textit{Length\_corelink} * \textit{Inv\_trench} * \textit{\%Switch\_trench\_corelink} * \textit{\%Shared\_trench\_corelink} * \left(1 - \xi * \left(1 - \psi\right)\right)$$

$$\textit{Investment in duct per Core Link} =$$

$$\textit{Length\_corelink} * \textit{Inv\_duct} * \textit{\%Switch\_duct\_corelink} * \textit{\%Shared\_duct\_corelink} * \left(1 - \xi * \left(1 - \psi\right)\right)$$

With:

Length_corelink: Length of the core link, expressed in meter
%Switch_trench_corelink: Percentage of the trench used for PSTN/ISDN-services
ξ: length of the core rings that are realised over regional rings / total length core links
Inv_duct: Price of a duct, expressed in € per meter
%Switch_duct_corelink: Percentage of the duct used for PSTN/ISDN-services
Inv_trench: Price of a trench, expressed in € per meter
%Shared_trench_corelink: Percentage of the trench used for the regional and core transmission network (i.e. excl. local access network)
ψ: the number of fibers occupied by the core links/total number of occupied fibers
%Shared_duct_corelink: Percentage of the duct used for the regional and core network (i.e. excl. local access network)

Investment in cables for the core links

$$\textit{Investment in cables per Core Link} =$$

$$\textit{Length\_corelink} * \textit{Inv\_cable\_}24 * \textit{\%Switch\_cable\_corelink} * \textit{\%Shared\_cable\_corelink} *$$

$$\left(1 - \xi * \left(1 - \psi\right)\right)$$

With:

Length_corelink: Length of a core link, expressed in meter
%Switch_cable_corelink: Percentage of the cable used for PSTN/ISDN-services
ξ: length of the core rings that are realised over regional rings / total length core links
Inv_cable_24 : Price of a cable featuring 24 fibers, expressed in € per meter
%Shared_cable_corelink: Percentage of the cable used for the regional and core transmission network (i.e. excl. local access network)
ψ: the number of fibers occupied by the core links/total number of occupied fibers

5. ROUTING FACTORS

5.1. *DEFINITION OF ROUTING FACTORS*

Routing factors are defined per resource pool and communication type. The routing factor $RF_{i,j}$ expresses the usage of resource pool *i* by the calls of communication type *j*. In other words, on average a call from communication type *j* uses resource pool *i* $RF_{i,j}$ times. This definition is explained hereafter in more detail.

The determination of a routing factor is directly related to the model of the network. The network comprises of resource pools that are defined such that a given resource pool is used completely or not at all when establishing a given call. The routing of calls therefore defines the separation of the network into resource pools[32].

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[32] The identification of the different resource pools was done in chapter 3.

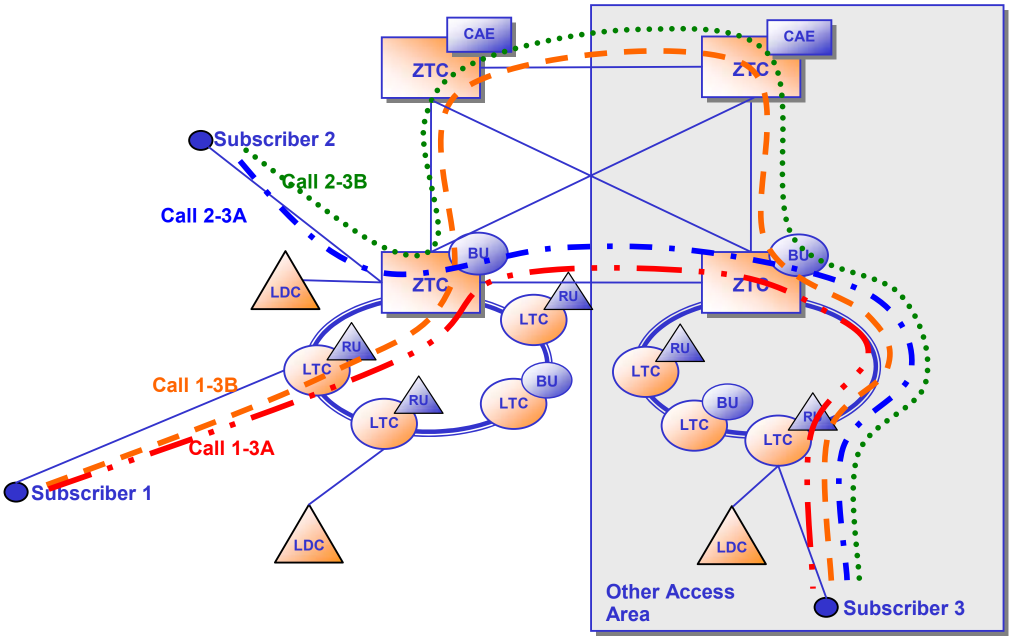

Figure 17. Calls in an example network

A given call has a routing factor RF_i for each of the i resource pools of the network. The factor RF_i is the number of times (zero, one, multiple) the call has used resource pool i. Two calls that belong to the same communication type j do not necessarily have the same routing factor for each of the resource pools. After all, the way in which caller and the called party are connected to the network can differ, as well as the routing that is followed for setting up the call. These two characteristics of a specific call will determine the appropriate routing factor. Figure 17 serves as example.

This figure presents an example network with 3 subscribers connected to it in different ways and shows 4 possible calls:

- Call 1-3A: From subscriber 1 to subscriber 3
- Call 2-3A: From subscriber 2 to subscriber 3
- Call 1-3B: From subscriber 1 to subscriber 3
- Call 2-3B: From subscriber 2 to subscriber 3

In the notation of the calls "A" stands for type A calls routed via a direct link between BUs and "B" for type B calls routed via CAEs, while the digits 1,2 or 3 indicate originating and terminating subscribers. In fact, the routing factor is not a function of the direction of the call, thus all calls are considered bidirectional. The routing factors RF_i for all illustrated calls and their directional opposites, assuming equal volumes for all sorts of calls, are given in Table 4. RF_7, RF_8 *en* RF_9 are respectively referring to the resource pools RUs, BUs en CAEs (cf. paragraph 3.4).

Table 4. Routing factors for example calls

	RF_7 (RU)	RF_8 (BU)	RF_9 (CAE)
Call 1-3A	2	2	0
Call 1-3B	2	2	2
Call 2-3A	1	2	0
Call 2-3B	1	2	2
Call 3-1A (call 1-3A set-up by user 3)	2	2	0
Call 3-1B (call 1-3B set-up by user 3)	2	2	2
Call 3-2A (call 2-3A set-up by user 3)	1	2	0
Call 3-2B (call 2-3B set-up by user 3)	1	2	2
Average RF_i	**1,5**	**2**	**1**

The derivation of these routing factors RF_i for all 8 calls follows following principles:

- **Routing factor RF_7** : Subscribers can be directly connected to a BU, as is the case for subscriber 2, or indirectly via a RU, as is the case for subscribers 1 and 3, resulting in a routing factor of respectively 1 and 2 for the resource pool RUs.
- **Routing factor RF_8** : All calls from all subscribers are always routed via a host BU, resulting in a invariable routing factor of 2 for the resource pool BUs for all 8 calls.
- **Routing factor RF_9** : Due to the direct switching link between the two BUs, type A calls can be conveyed between subscriber 1 and subscriber 3 with or without usage of a CAE. Type B calls however are switched via the CAE and thus have a resource factor of 2 for this resource pool.

Assuming that the 8 calls have an equal probability of occurrence, the average routing factor RF_i is derived by averaging RF_i over the ensemble[33] of the 8 calls. In this example, the averages of RF_i (with i equal to 7, 8 or 9) are the routing factors of the given communication type *EAA traffic* over the resource pools 7 (RUs), 8 (BUs) and 9 (CAEs).

The assumption of equal probability of call occurrence is in fact a simplification, and in fact a weighted average needs to be calculated pro rata the occurrence of calls within a specific communication type j. Taking this into account, the routing factor for the resource pool RUs is affected by the ratio of the numbers of users directly connected to the BU and the number of users indirectly connected to the BU. Consequently, changing the connection of subscriber 1 into a direct connection to a BU changes the routing factor for the RUs from 1,5 to 1. Thus, the chosen architecture and the distribution of subscriber connections influence the value of the routing factors.

A more generic way to calculate routing factors will be presented in the next paragraph.

5.2. *CALCULATION OF ROUTING FACTORS*

The previous paragraph illustrated the derivation of a routing factor by calculating the weighted average of the routing factor per call over all possible calls of a given communication type. This paragraph further analyses the derivation of routing factors, but from a more generic perspective.

---

[33] Here the ensemble of the 8 calls is the collection of the 8 calls. The term ensemble is used in statistical calculations. Ensemble means the collection of instances for which one calculates a statistical quantity such as an average of a property of the ensemble.

A given call c_k, belonging to communication type j, has a routing factor $RF_i\ (c_k)$ indicating the usage of resource pool i by the call c_k. Hence, the ensemble average over all possible calls c_k, with k ranging from 1 to K, of the communication type j is the routing factor RF_{ij} and this routing factor is calculated as shown in the following formula:

$$RF_{ij} = \sum_{k=1}^{K} p(c_k) \cdot RF_i(c_k) \tag{1}$$

With:

- c_k indicating a call that belongs to communication type j and k ranging from 1 to K.
- $p(c_k)$ reflects the probability that a call c_k, of the communication type j, occurs.

  Thus $\sum_{k=1}^{K} p(c_k) = 1$ or 100%.
- $RF_i\ (c_k)$ is the routing factor for the call c_k over the resource pool i.

Since the above equation (1) accounts for every individual call, it will be reduced to a more practical form. Dividing all the calls c_k of communication type j into M groups having equal routing factors $RF_i\ (c_k)$; the calls c_k and c_l (of communication type j) belong to the same group g_m if and only if $RF_i\ (c_k) = RF_i\ (c_l)$ for all i. This reduces equation (1) to:

$$RF_{ij} = \sum_{m=1}^{M} p(g_m) \cdot RF_i(g_m) \tag{2}$$

With:

- g_m indicating a group of calls belonging to communication type j and m ranging from 1 to M.
- $p(g_m)$ reflects the probability that a call c_k, of the communication type j, belongs to the group g_m. Thus $p(g_m)$ also represents the weight of the group g_m within the communication type j, thus $\sum_{m=1}^{M} p(g_m) = 1$ or 100%.
- $RF_i\ (g_m)$ is the routing factor for all the calls belonging to g_m over the resource pool i.

The equation (2) is more practical, as can be concluded from comparing the magnitude of K in equation (1), roughly 10^{12}, with the magnitude of M in equation (2), typically smaller than 100.

In the calculation of a given routing factor, the definition of the groups g_m will be clear from the architecture. The next paragraph explains an example derivation of the routing factor for the RUs, BUs en CAEs in local traffic, with M=36 groups of calls belonging to the communication type *local traffic.*

5.3. *EXAMPLE: CALCULATION OF THE ROUTING FACTOR FOR RUS, BUS AND CAES IN LOCAL TRAFFIC*

This example provides a detailed insight in the derivation of the routing factors for the RUs, BUs and CAEs in local traffic, which was defined in paragraph 3.2 as traffic between two users, connected to the same base unit (BU) or to remote units (RUs) dependent of the same BU.

Consistent with Table 2 on page 21, this example uses following indices:

- $j = 1$ for communication type Local Traffic
- $i = 7$ for resource pool RUs
- $i = 8$ for resource pool BUs
- $i = 9$ for resource pool CAEs

As illustrated by Figure 18, local networks are comprised of subscribers connected to a host BU, either directly or indirectly via a RU. All the calls originating from these subscribers are conveyed exactly once by their host BU, furthermore the definition of local traffic implies that all the local calls are only conveyed by their host BU, resulting in a value of 1 for $RF_{81} = 1$ and $RF_{91} = 0$. This leaves us with the calculation of RF_{71}.

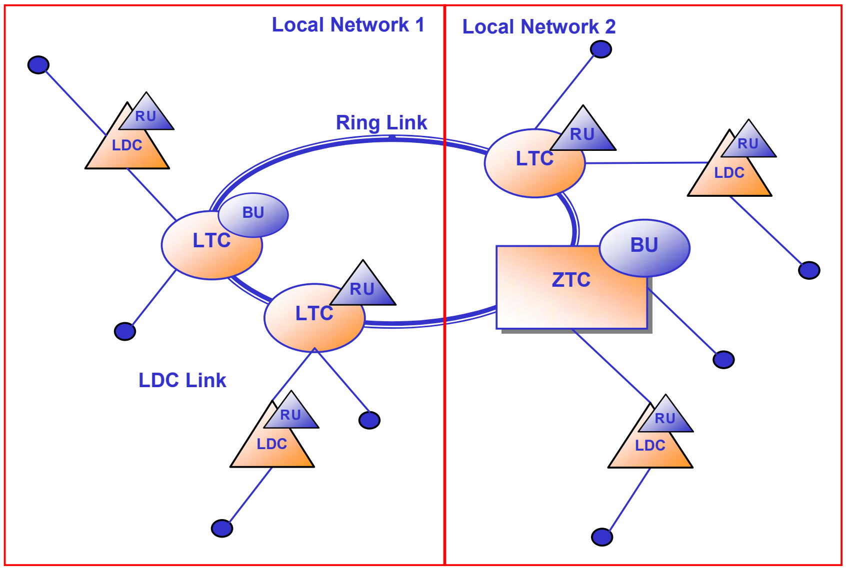

Figure 18. Example Model of Local Networks

The modeled network includes a number of BU hosts collocated with a LTC transmission node represented by *#LTC-BU*, and a number of BU hosts collocated with a ZTC transmission nodes represented by *#ZTC-BU*. Thus, subscribers can be connected in one of the following ways:

- Directly connected to a LTC-BU
- Directly connected to a LTC-RU, which indirectly connects the subscriber to a
  - LTC-BU
  - ZTC-BU
- Directly connected to a LDC-RU, which indirectly connects the subscriber to a
  - LTC-BU
  - ZTC-BU
- Directly connected to a ZTC-BU

These connection types are summarized in the following table.

Table 5. Local network subscriber connection types

Connection of subscriber on:	LTC-BU	LTC-RU	LTC-RU	LDC-RU	LDC-RU	ZTC-BU
Host BU	LTC-BU	LTC-BU	ZTC-BU	LTC-BU	ZTC-BU	ZTC-BU
Values for *O(originating subscriber) and D(destination subscriber)*	1	2	3	4	5	6
Number of Equivalent Lines related to direct connections (# Equiv. Lines – line cards)	a	b	c	d	e	f

This table mentions the notion of an “Equivalent Line” related to the direct connections. These equivalent lines refer to the amount of line cards that connect the subscribers to the network in a RU or BU. Different kinds of line cards are modeled in the network, they each relate to a different types of end-user lines and to different volumes of equivalent lines:

- One PSTN end-user line (line card) counts for 1 equivalent line;
- One ISDN-BA end-user line (line-card) counts for 2 equivalent lines;
- One ISDN-PRA end-user line (line-card) counts for 30 equivalent lines.

The number of equivalent lines per node (RU or BU), will be used to weight the probability of occurrence of a group of calls g_m within one communication type j.

Please note that in this context, the number of equivalent lines solely relate to the *line cards* and not to the 2 Mbps *trunk cards* which will also count for 30 equivalent lines when dimensioning the switching equipment.

From the *Number of Equivalent Lines, related to direct connections* (#Equiv. Lines – line cards) for a given connection type (e.g. LTC-BU) in the complete network and represented by the letters a, b, c, d, e and f; the corresponding values A, B, C, D, E and F can be derived. These indicate the average # Equiv. Lines – line cards per type of connection on a average local network, build up around a LTC-BU or a ZTC-BU:

$$\frac{A}{a} = \frac{B}{b} = \frac{D}{d} = \frac{1}{\#\mathrm{LTC\text{-}BU}}$$

$$\frac{C}{c} = \frac{E}{e} = \frac{F}{f} = \frac{1}{\#\mathrm{ZTC\text{-}BU}}$$

As stated, *A, B, C, D, E* and *F* are averaged over all local networks and do not necessary reflect reality. However, since detailed data on connection types other than the *Number of Equivalent Lines, related to direct connections* (# Equiv. Lines –line cards) values was not to our disposal, the calculation is based on an averaged network, in which the *#LTC-BU* and *#ZTC-BU* local networks are replaced by local networks with equal average size.

Additionally, it considerably simplifies the calculation itself, as a calculation based upon the detailed connection types would be impractical.

In Table 5 the values for *O* and *D*, both ranging from 1 to 6, are used to indicate the connection type of the originating subscriber O and the destination subscriber D. Since 6 possible connection types were identified, the number of possible pairs of connection types equals 36.

The 36 pairs *(O,D)* correspond to the concept of groups g_m, a notion introduced in the previous paragraph as the grouping of calls having equal routing factors for all resource pools. It suffices to determine the probability of occurrence *p(O,D)* and the routing factor $RF_I(O,D)$ for each of the 36 groups or connection scenario's between a subscriber O and a subscriber D. However, since the definition of the communication type *local traffic* implies that the subscribers belong to the same BU, there are only 18 calls possible out of the 36 pairs of connection types *(O,D)* within the local traffic communication type.

The probability of occurrence *p(O,D)* will be determined by dividing the number of possible calls *n(O,D)* in the group or pair of connection types *(O,D)* by the total number of possible calls for all pairs of connections types, as illustrated by following formulae:

$$p(O,D) = \frac{n(O,D)}{N} \tag{3}$$

with:

$$N = \sum_{O=1}^{6} \sum_{D=1}^{6} n(O,D) \tag{4}$$

By the determining probabilities for the local network through counts of possible calls, following two hypotheses were implicitly applied:

Hypothesis 1: In the local network, individual possible calls have equal probability of occurrence. This hypothesis is deemed fair because the behavior of individual subscribers is considered unpredictable. Furthermore, the probabilities are determined for groups of calls with sizes of the order of 10^8 and larger, and as the statistical *law of large numbers* dictates the differences in individual behavior will be averaged out in such large groups. Also, there is no reason to differ the behavior of individual subscribers on the basis of their connection type.

Hypothesis 2: In the local network, individual possible calls have equal duration. This can be easily accepted if one restates the combination of the two hypotheses as: In the local network, each possible "routed" minute has the same probability as any other possible minute. The justification of this hypothesis is similar to the one for the first hypothesis.

Using the formulae (3) and (4), the probability of occurrence of *p(O,D)* for the 36 possible calls is readily deducted from Figure 18 and Table 5. For example, the value of the probability of occurrence of *p(**1**,**4**)* is deducted by the reasoning that each calling subscriber O directly connected to a LTC-BU can reach *D* subscribers that are connected to the same LTC-BU via a LDC-RU in the hypothetical average local network. This can occur *a* times since there are in total *a* subscribers directly connected to a LTC-BU in the network. Therefore *n(**1**,**4**) = a D* and *p(**1**,**4**) = a D / N*. Similarly, to calculate *p(4,4)* the followed reasoning is that *d* calling subscribers are connected to an LTC-BU via a LDC-RU. Each of those can reach *(D-1)* subscribers in the average local network that are connected to the local LTC-BU host via a LDC-RU. One is subtracted to account for the fact that a subscriber is not likely to call himself.

Following 18 formulae represent these possibilities in case the local host is a LTC-BU.

$p(\mathbf{1,1}) = a\,(A-1)\,/\,N$ $p(\mathbf{2,1}) = b\,A\,/\,N$ $p(\mathbf{3,1}) = 0$
$p(\mathbf{4,1}) = d\,A\,/\,N$ $p(\mathbf{5,1}) = 0$ $p(\mathbf{6,1}) = 0$

$p(\mathbf{1,2}) = a\,B\,/\,N$ $p(\mathbf{2,2}) = b\,(B-1)\,/\,N$ $p(\mathbf{3,2}) = 0$
$p(\mathbf{4,2}) = d\,B\,/\,N$ $p(\mathbf{5,2}) = 0$ $p(\mathbf{6,2}) = 0$

$p(\mathbf{1,4}) = a\,D\,/\,N$ $p(\mathbf{2,4}) = b\,D\,/\,N$ $p(\mathbf{3,4}) = 0$
$p(\mathbf{4,4}) = d\,(D-1)\,/\,N$ $p(\mathbf{5,4}) = 0$ $p(\mathbf{6,4}) = 0$

Following 18 formulae represent these possibilities in case the local host is a ZTC-BU :

$p(\mathbf{1,3}) = 0$ $p(\mathbf{2,3}) = 0$ $p(\mathbf{3,3}) = c\,(C-1)\,/\,N$
$p(\mathbf{4,3}) = 0$ $p(\mathbf{5,3}) = e\,C\,/\,N$ $p(\mathbf{6,3}) = f\,C\,/\,N$

$p(\mathbf{1,5}) = 0$ $p(\mathbf{2,5}) = 0$ $p(\mathbf{3,5}) = c\,E\,/\,N$
$p(\mathbf{4,5}) = 0$ $p(\mathbf{5,5}) = e\,(E-1)\,/\,N$ $p(\mathbf{6,5}) = f\,E\,/\,N$

$p(\mathbf{1,6}) = 0$ $p(\mathbf{2,6}) = 0$ $p(\mathbf{3,6}) = c\,F\,/\,N$
$p(\mathbf{4,6}) = 0$ $p(\mathbf{5,6}) = e\,F\,/\,N$ $p(\mathbf{6,6}) = f\,(F-1)\,/\,N$

Since the roles of both subscribers are interchangeable, and in accordance with the requirement that the derivation of routing factors cannot depend on the direction of the call, the probability of occurrence of calls between a pair of connection types is symmetric.

N is determined as:

$$N = \sum_{O=1}^{6}\sum_{D=1}^{6} n(O,D) \tag{5}$$

After insertion of the above formulae for $n(O,D))$, which are in fact the nominators of the formulae for $p(O,D))$, into formula (5) and simplification of the resulting expression, this formula is converted into:

$$N = (a + b + d)\;(A + B + D - 1) + (c + e + f)\;(C + E + F - 1) \tag{6}$$

The routing factor RF_{71} for local traffic over the resource pool RUs is found as a sum over 36 groups or pairs of connection types:

$$RF_{71} = \sum_{O=1}^{6}\sum_{D=1}^{6} p(O,D)\cdot RF_7(O,D) \tag{7}$$

Where $RF_7(O,D)$ is the usage of the resource pool RUs for calls between a pair of connection types (O,D) and easily verified using the Figure 18 to be:

$RF_7\,(\mathbf{1,1}) = 0$ $RF_7\,(\mathbf{2,1}) = 1$ $RF_7\,(\mathbf{4,1}) = 1$
$RF_7\,(\mathbf{1,2}) = 1$ $RF_7\,(\mathbf{2,2}) = 2$ $RF_7\,(\mathbf{4,2}) = 2$
$RF_7\,(\mathbf{1,4}) = 1$ $RF_7\,(\mathbf{2,4}) = 2$ $RF_7\,(\mathbf{4,4}) = 2$

$RF_7\,(\mathbf{3,3}) = 2$ $RF_7\,(\mathbf{5,3}) = 2$ $RF_7\,(\mathbf{6,3}) = 1$
$RF_7\,(\mathbf{3,5}) = 2$ $RF_7\,(\mathbf{5,5}) = 2$ $RF_7\,(\mathbf{6,5}) = 1$
$RF_7\,(\mathbf{3,6}) = 1$ $RF_7\,(\mathbf{5,6}) = 1$ $RF_7\,(\mathbf{6,6}) = 0$

Combining the formula (7) with the formulae for $p(O,D)$ and formulae (6) and finally inserting the values for RF_7, this results in:

$$RF_{71} = 2 \cdot \frac{(b+d)\cdot(A+B+D-1)+(c+e)\cdot(C+E+F-1)}{(a+b+d)\cdot(A+B+D-1)+(c+e+f)\cdot(C+E+F-1)} \tag{8}$$

When applying dimensioning parameters from the network modeled for a, b, c, d, e, f, *#LTC-BU* and *#ZTC-BU*, the resulting value for RF_{71} can be found.

5.4. *APPROACH FOR THE CALCULATION OF ALL OTHER ROUTING FACTORS*

This paragraph describes the approximations, hypotheses and principles used in the analogous derivation of all other routing factors.

5.4.1 APPROXIMATIONS

In the example calculation for RF_{71} the notion of an averaged or uniform local network, being an approximation to a *real* local network, was introduced. This approximation can be extended to the whole network for the calculation of all routing factors, implying that the averaged network has:

- *#LTC-BU* local hosts with *A, B, D* numbers of connection types 1, 2 and 4
- *#ZTC-BU* local hosts with *C, E, F* numbers of connection types 3, 5 and 6
- Each ZTC-BU has an equal number of rings that pass through and share the ZTC-BU.
- 8 Access Areas, equal in size, with an equal number of rings, LTC-BUs and ZTC-BUs.

5.4.2 HYPOTHESES

As stated in the previous paragraph, determining the probabilities of occurrence for pairs of connection types through counts of possible calls is based on two hypotheses, restated here in a more generic form as these hypotheses are also needed in the calculation of all other routing factors.

Hypothesis 1: Individual possible calls have equal probability of occurrence. This hypothesis is deemed fair because the behavior of individual subscribers is considered unpredictable. Furthermore, the probabilities are determined for groups of calls with sizes of the order of 10^8 and larger. and as the statistical *law of large numbers* dictates the differences in individual behavior will be averaged out in such large groups. Also, there is no reason to differ the behavior of individual subscribers on the basis of their connection type.

Hypothesis 2: Individual possible calls have equal duration. This can be easily accepted if one restates the combination of the two hypotheses as: Each possible “routed” minute has the same probability as any other possible minute. The justification of this hypothesis is similar to the one for the first hypothesis.

5.4.3 OTHER

Routing factors RF_{9j} (CAEs) are derived using information on the average traffic streams per communication type in the BU-CAE links.

The routing factors RF_{2j} (Regional Rings), RF_{3j} (ZTC-ZTC Links), RF_{5j} (LTC Transmission equipment) and RF_{6j} (Core Link Transmission Equipment) consist of two parts:

- a part independent of CAE usage, as if all BU-BU traffic was conveyed over direct BU-BU links, using hypotheses 1 and 2.
- and an additional part accounting for the CAE usage, of which the calculation uses knowledge on the average traffic streams per communication type in the BU-CAE links.

5.5. *DISCUSSION OF THE CALCULATED ROUTING FACTORS*

This section clarifies the derivation of the 9 x 17 (I x J) routing factors that need to be calculated. Rather than detailing the calculation of each routing factor, this section provides an explanation of the derivation.

5.5.1 LOCAL TRAFFIC

- $RF_{1,1}$: For each of the 18 possible pairs of connection types or groups, the individual routing factor is determined as 0, 1 or 2 depending on the connection type of subscribers 1 and 2. The routing factor follows through application of equation (7).
- $RF_{2,1}$: Analogous to the derivation of $RF_{1,1}$, however comprising of an extra difficulty because the distinction between LDC-RUs connected directly to the host and LDC-RUs connected via an LTC-RU needs to be taken into account.
- $RF_{3,1}$: Is zero since no ZTC Equipment is involved in local traffic.
- $RF_{4,1}$: $RF_{4,1} = RF_{1,1}$ because routing over the LDC link requires equal usage of LDC equipment.
- $RF_{5,1}$: $RF_{5,1} = 2 * RF_{2,1}$ because each routing over a Regional Ring requires usage of LTC equipment at both ends of that Regional Ring.
- $RF_{6,1}$: Is zero since no ZTC-ZTC transmission is involved in local traffic.
- $RF_{7,1}$, $RF_{8,1}$, $RF_{9,1}$: A detailed derivation can be found in the previous paragraph.

The relationships $RF_{4,j} = RF_{1,j}$ and $RF_{5,j} = 2 * RF_{2,j}$ are persistent for all communication types, as the usage of one resource pool can physically imply the usage of another resource pool and visa versa, e.g. the *LDC Link* resource pool ($RF_{1,j}$) physically implies to usage of the resource pool *Equipment LDC* ($RF_{4,j}$). Also, $RF_{6,j} = 2 * RF_{3,j}$ except for $j = 3$ (IAA Inter-Ring Traffic), *5 (VAS) and 6 (Internet)*.

5.5.2 IAA INTRA-RING TRAFFIC

- $RF_{1,2}$: Is derived in the same manner as $RF_{1,1}$. As for *Local Traffic*, the probabilities for the 36 groups or pairs of connection types are derived for IAA Intra-Ring Traffic. This is a straightforward but lengthy calculation that requires the distinction between subscribers that are connected to a host that is common to more than one ring and other subscribers.
- $RF_{2,2}$: The usage of the Regional Ring is calculated, taking into account the direct and indirect connection of LDCs to their host BU and Regional Ring usage involved when using the CAE.

- **$RF_{3,2}$** : The calculation is based on the knowledge on the average traffic streams per communication type in the BU-CAE links and on the probability that the CAE is on the same ring as the two host BUs.
- **$RF_{6,2}$:** $RF_{6,2} = 2 * RF_{3,2}$ since the ZTC is only used to reach the CAE and the usage of the ZTC-ZTC link requires to use ZTC equipment twice for this communication type.
- **$RF_{7,2}$** : The routing factors RF_7 for each of the 36 groups can have values 0, 1 and 2 and they are the same as in the calculation of $RF_{7,1}$. The 36 probabilities of occurrence for IAA Intra-Ring Traffic however do differ from these applied in the calculation of $RF_{7,1}$.
- **$RF_{8,2}$** : Is invariably 2 since both the host of subscriber O and subscriber D are used once.
- **$RF_{9,2}$** : Accounts for the usage of the CAE versus the usage of direct links between BUs. The calculation is based on the knowledge on the average traffic streams per communication type in the BU-CAE links.

5.5.3 IAA INTER-RING TRAFFIC

- **$RF_{1,3}$** : Is derived in the same manner as $RF_{1,1}$. It's noteworthy that the number of possible calls per group for IAA Inter-Ring traffic are calculated by subtracting the number of possible calls per group for IAA Intra-Ring traffic from the total number of possible calls IAA per group.
- **$RF_{2,3}$** : The derivation of $RF_{2,3}$ (Regional Rings) is based on the probability that two rings are adjacent and furthermore accounts for direct and indirect connections of LDCs to their host BU and the Regional Ring utilization when using the CAE.
- **$RF_{3,3}$** : The calculation is based on the average traffic streams per communication type in the BU-CAE links, on the probability that the CAE is on the same ring as the two host BUs and on the probability that regional rings are adjacent.
- **$RF_{6,3}$** : $RF_{6,3} \geq 2 * RF_{3,3}$, because of the fact that, in case of adjacent rings, the ZTC equipment is used to convey traffic, while the ZTC-ZTC link resource pool is not. The rest of the derivation is similar to the calculation of $RF_{3,3}$.
- **$RF_{7,3}$** : As for local traffic and IAA Intra-Ring traffic, the routing factor RF_7 for each of the 36 groups can have values 0, 1 and 2 and these routing factors are equal to the ones applied in the calculation of $RF_{7,1}$ and $RF_{7,2}$.
- **$RF_{8,3}$** : Is invariably 2 since both the host of subscriber O and subscriber D are used once.
- **$RF_{9,3}$** : Accounts for the usage of the CAE versus the usage of direct links between BUs and is based on the knowledge of the average traffic streams per communication type in the BU-CAE links.

5.5.4 EAA TRAFFIC

- **$RF_{1,4}$** : Is derived analogously to $RF_{1,1}$ for local traffic and $RF_{1,2}$ and $RF_{1,3}$ for IAA communication types.
- **$RF_{2,4}$** : The usage of the Regional Ring is calculated, taking into account the direct and indirect connection of LDCs to their host BU and differing host types of both subscribers, either ZTC-BU or LTC-BU.
- **$RF_{3,4}$** : The calculation is based on the knowledge on the average traffic streams per communication type in the BU-CAE links.
- **$RF_{6,4}$** : $RF_{6,4} = 2 * RF_{3,4}$.
- **$RF_{7,4}$** : The routing factor RF_7 for each of the 36 groups can have values 0, 1 and 2 and they are equal to the ones applied in the calculation of $RF_{7,1}$, $RF_{7,2}$ and $RF_{7,3}$.

- $\boldsymbol{RF_{8,4}}$: Is invariably 2 since both the host of subscriber O and subscriber D are used once.
- $\boldsymbol{RF_{9,4}}$: Accounts the usage of the CAE versus the usage of direct links between BUs. The calculation is based on the knowledge on the average traffic streams per communication type in the BU-CAE links, especially between BUs and CAEs of different areas.

5.5.5 VAS TRAFFIC

$\boldsymbol{RF_{i,5}} = x\% * RF_{i,2} + y\% * RF_{i3}$ where *x%* is the percentage of VAS traffic that is IAA Intra-Ring and *y%* the percentage that is IAA Inter-Ring.

5.5.6 INTERNET TRAFFIC

Internet traffic is either conveyed by the PSTN/ISDN network (classical routing) or is treated separately from the PSTN/ISDN network over the data network (offload)[34]. In the latter case the traffic leaves the PSTN/ISDN network directly after the *Local Exchange* (LEX[35]) to an access server. Therefore, the routing factors for internet traffic are calculated as the weighted average of the routing factors for *classical routing of internet traffic* and *offload internet traffic*.

Furthermore, the routing factors for *classical routing* are a weighted average of the routing factors of *IAA Intra-ring traffic* and *IAA Inter-ring traffic*, since a classical routed call can belong to these communication types. Because the second LEX in a call for *classical routed internet traffic* is always a BU, the routing factors calculated for *IAA traffic* in previous paragraphs are modified accordingly.

The routing factors for *offload internet traffic* are derived by considering the 6 possibilities for the subscriber connections of Table 5. The probabilities for each of the 6 groups of connection types follow directly from their number of equivalent lines. The individual routing factors follow:

- $\boldsymbol{RF_{1,6}}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $\boldsymbol{RF_{2,6}}$: The individual routing factor is:
    - 0 for connection types 1 and 6.
    - 1 for connection types 2 and 3.
    - Between 0 and 1 for connection types 4 and 5. Here the distinction is made between LDC-RUs connected directly to the host and LDC-RUs connected via a LTC-RU.
- $\boldsymbol{RF_{3,6}}$: Is 0 since the *offload internet traffic* uses only the local part of the PSTN/ISDN network.
- $\boldsymbol{RF_{6,6}}$: Is 0 because no ZTC-ZTC link is used.
- $\boldsymbol{RF_{7,6}}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation 7 yields the routing factor.
- $\boldsymbol{RF_{8,6}}$: Is invariably 1, since all calls are conveyed by the host of the calling subscriber.
- $\boldsymbol{RF_{9,6}}$: Is 0, since no CAE is used.

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[34] Cf. Description of theoretical routing factors for the top-down model 2003: http://www.bipt.be/Actualites/Communications/routingfactortheorie-presentatie%20nl.pdf

[35] A Local Exchange (LEX) indicates a RU or BU, located on a Regional Ring.

5.5.7 TERMINATING LOCAL

Analogous to the derivation *for offload internet traffic*, the probabilities of occurrence of the 6 groups of connection types, found in Table 5 and derived from the number of equivalent lines, are the basis for the calculation of the routing factors for *terminating local traffic*:

- $RF_{1,7}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $RF_{2,7}$: The individual routing factor is:
    - 0 for connection types 1 and 6.
    - 1 for connection types 2 and 3.
    - Between 0 and 1 for connection types 4 and 5. Here the distinction is made between LDC-RUs connected directly to the host and LDC-RUs connected via an LTC-RU.
- $RF_{3,6}$: Is 0 since only the local part of the PSTN/ISDN network is used.
- $RF_{6,6}$: Is 0 because no ZTC-ZTC link is used.
- $RF_{7,6}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $RF_{8,6}$: Is invariably 1 since all calls are conveyed by the host of the subscriber where the call is terminated.
- $RF_{9,6}$: Is 0, since no CAE is used.

5.5.8 TERMINATING IAA

Analogous to the derivation *Terminating Local Traffic*, the probabilities of occurrence of the 6 groups of connection types, found in Table 5 and derived from the number of equivalent lines, are the basis for the calculation of the routing factors for *Terminating IAA Traffic*:

- $RF_{1,8}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $RF_{2,8}$: The individual routing factors for the 6 connection types are determined while on the one hand discerning between LDC-RUs connected directly to the host and LDC-RUs connected via an LTC-RU; and on the other hand differentiating between ZTC-BU connected directly to the ZTC-CAE and to other ZTC-BUs.
- $RF_{3,8}$: The individual routing factors depend on the probability that the ZTC-CAE is located on the ring where the call is terminated.
- $RF_{6,8}$: $RF_{6,8} = 2 * RF_{3,8}$.
- $RF_{7,8}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $RF_{8,8}$: Is invariably 1 as all calls are conveyed by the host of the subscriber where the call is terminated.
- $RF_{9,8}$: Is invariably 1 as all calls are conveyed by the CAE of the access area where the call is terminated.

5.5.9 TERMINATING EAA

Similarly to the derivation *Terminating Local Traffic*, the probabilities of occurrence of the 6 groups of connection types, found in Table 5 and derived from the number of equivalent lines, are the basis for the calculation of the routing factors for *Terminating EAA Traffic*. The derivation is analogous to the derivation for the *Terminating IAA Traffic*:

- $RF_{1,9}$: $RF_{1,9} = RF_{1,8}$.

- $\boldsymbol{RF_{2,9}}$: $RF_{2,9} = RF_{2,8}$.
- $\boldsymbol{RF_{3,9}}$: $RF_{3,9} = 1 + RF_{3,8}$, since an additional Core Link is used between the CAEs of the different access areas.
- $\boldsymbol{RF_{6,9}}$: $RF_{6,9} = 2 * RF_{3,9}$.
- $\boldsymbol{RF_{7,9}}$: $RF_{7,8} = RF7_{,8}$.
- $\boldsymbol{RF_{8,9}}$: $RF_{8,9} = RF_{8,8}$.
- $\boldsymbol{RF_{9,9}}$: $RF_{9,9} = RF_{9,8}$.

5.5.10 COLLECTING LOCAL

Due to the bidirectional nature of calls, all routing factors for *Collecting Local Traffic* are equal to their respective counterparts for *Terminating Local Traffic*, or $\boldsymbol{RF_{i,10}} = RF_{i,7}$.

5.5.11 COLLECTING IAA

Due to the bidirectional nature of calls, all routing factors for *Collecting IAA Traffic* are equal to their respective counterparts for *Terminating IAA Traffic*, or $\boldsymbol{RF_{i,11}} = RF_{i,8}$.

5.5.12 TRANSIT IAA

Transit IAA Traffic is conveyed from one OLO to another within the same access area by using one CAE. Therefore $\boldsymbol{RF_{i,12}} = 0$, except for $\boldsymbol{RF_{9,12}} = 1$.

5.5.13 TRANSIT EAA

Transit EAA Traffic is conveyed from one OLO to another OLO in another access area. The CAEs from both access areas and the link between them are used. Therefore $\boldsymbol{RF_{i,13}} = 0$, except for $\boldsymbol{RF_{3,13}} = 1$, $\boldsymbol{RF_{6,13}} = 2$ and $\boldsymbol{RF_{9,13}} = 2$.

5.5.14 INTERNATIONAL IN & OUT

Similarly to the derivation *Terminating Local Traffic*, the probabilities of occurrence of the 6 groups of connection types, found in Table 5 and derived from the number of equivalent lines, are the basis for the calculation of the routing factors for *International Traffic In & Out*, for which the directionality, in- or outgoing international traffic, is irrelevant.

- $\boldsymbol{RF_{1,14}}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $\boldsymbol{RF_{2,14}}$: The individual routing factors for the 6 connection types are determined while discerning between LDC-RUs connected directly to the host and LDC-RUs connected via an LTC-RU.
- $\boldsymbol{RF_{3,14}}$: The individual routing factors depend on the probability that the international exchange is located on the ring of the subscriber, the probability that the CAE is used and the probability that the ZTC-CAE lies on the ring of the subscriber.
- $\boldsymbol{RF_{6,14}}$: $RF_{6,14} = 2 * RF_{3,14}$.
- $\boldsymbol{RF_{7,14}}$: The individual routing factor is determined as 0 or 1 depending on the connection type. Applying equation (7) yields the routing factor.
- $\boldsymbol{RF_{8,14}}$: Is invariably 1 as all calls are conveyed by the host of the subscriber.
- $\boldsymbol{RF_{9,14}}$: Depends on the probability that the CAE is used in conveying this call.

5.5.15 INTERNATIONAL TRANSIT

This traffic, between an OLO and an international exchange, is conveyed for *x%* inside an access area (IAA) and for *y%* between two access areas. Hence, the resulting routing factors can be calculated as $\boldsymbol{RF_{i,15}} = x\% * RF_{i,12} + y\% * RF_{i,13}$.

5.5.16 IC OTHERS: BGC TO FOLO

Of the communication type *IC Others: BGC to FOLO*[36] *x* percent is *IAA traffic* and y percent is *EAA traffic*. Therefore, the routing factors are calculated as $\boldsymbol{RF_{i,16}} = x\% * RF_{i,8} + y\% * RF_{i,9}$.

5.5.17 IC OTHERS: BGC TO MOLO

Of the communication type *IC Others: BGC to MOLO*[37] *x* percent is *IAA traffic* and y percent is *EAA traffic*. Therefore, the routing factors are calculated as $\boldsymbol{RF_{i,17}} = x\% * RF_{i,8} + y\% * RF_{i,9}$.

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[36] FOLO stands for *Fixed Other Licensed Operator*

[37] FOLO stands for *Mobile Other Licensed Operator*