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Study for the Institut Luxembourgeois de Régulation (ILR)

Development of a Bottom-Up Mobile Network and Cost Model for the Determination of the Cost of Terminating Calls in Mobile Networks

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List of abbreviations

2G	Second Generation Mobile Technology
3G	Third Generation Mobile Technology
3GPP	3rd Generation Partnership Project (3GPP)
ADM	Add Drop Multiplexer
AMR-WB	Adaptive Multi-Rate Wideband (AMR-WB)
BH	Busy Hour
BHCA	Busy Hour Call Attempt
BLER	Block Error
BSC	Base Station Controller
BTS	Base Transceiver Station
BW	Bandwidth
CAPEX	Capital Expenditures
CIR	Committed Information Rate
DCH	Dedicated Channel
DL	Down-Link
DLL	Dynamic Link Library
DSG	Digital Subscriber Group
E1	Physical layer protocol for leased line transmissions. E1 lines have 32x64 kbps channels at 2.048 Mbps.
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data Rates for GSM Evolution
EIR	Equipment Identity Register
eNode-B	Evolved Node B
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
G/G/1	Single-server queue model with arbitrarily distributed packet stream and packet length
GGSN	Gateway GPRS Support Node
GHz	Giga Hertz
GIS	Geographic Information System
gMUF	Global Mark-up Factor

GoS	Grade of Service
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IC	Interconnection
IETF RFC	Internet Engineering Task Force RFC
IMS	IP Multimedia Subsystem
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
kbps	Kilobit per Second
KEL	Cost of Efficient Service Provision
LAN	Local Area Network
LRIC	Long Run Incremental Cost
M/M/1	Single-server queue model, that can be used to approximate simple systems
MBA	Mobile Broadband Access
mBd	Mean Bandwidth Downlink
Mbps	Megabit per Second
mBu	Mean Bandwidth Uplink
MGW	Mediagateway
MHz	Mega-Hertz
MIMO	Multiple-Input-Multiple-Output
mLu	Mean Length of Packets (Uplink)
mLd	Mean Length of Packets (Downlink)
MME	Mobility Management Entity
MMS	Multimedia Messaging Service
MPLS	Multiprotocol Label Switching

MPLS-TE	Multiprotocol Label Switching Traffic Engineering
MSC	Mobile Services Switching Centre
MuF	Mark-up Factor
NGN	Next Generation Network
Node B	Basis station in a UMTS Mobile Network
OC-N	Optical Carrier type N
OFDMA	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditures
OSI	Open Systems Interconnection Reference Model
OTN	Optical Transport Network
P2P	Peer to Peer
PCU	Packet Control Unit
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
qMUF	Mark-up Factor according to QoS for each Services Category
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RADM	Standard Configuration of an Add-and-Drop Multiplexer
RB	Resource Blocks
RNC	Radio Network Controller
ROADM	Reconfigurable Optical Add-and-Drop Multiplexer
SAEGW	System Architecture Evolution Gateway
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDH	Synchronous Digital Hierarchy
SGSN	Serving GPRS Support Node
SINR	Signal to Interference Noise Ratio
SMS	Short Message Service
STM	Synchronous Transport Module
TBS	Transport Blocking Size
TDM	Time Division Multiplexing
TRX	Transceiver

UL	Up Link
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice Over Internet Protocol
VPN	Virtual Private Network
WACC	Weighted Average Cost of Capital
WCDMA	Wideband Code Division Multiple Access

1 Introduction

This document forms part of the call for inputs by the Institut Luxembourgeois de Régulation (ILR) on the development of a bottom-up mobile network and cost model. Following the market analysis on termination of voice calls on mobile networks (market 7/2007), the mobile network and cost model determines the related termination costs. The cost of termination is determined based on a Pure LRIC methodology as recommended by the EC for termination services[1].

The purpose of this document is to provide greater transparency over the structure of the bottom-up mobile network and cost model and the calculations with it. This is to enable stakeholders to comment on the methodology used.

In order to implement a bottom-up model, different modelling processes are needed and integrated in the model. A demand and specification process defines the particular conditions and needs for the territory of Luxembourg. Thereafter, the resulting characteristics are considered in the process of network planning. In this process the network is designed as well as dimensioned according to the particular situation of Luxembourg. Finally, a costing process calculates the cost per year for the defined network. From this cost the cost per minute of termination is then derived.

The following sections explain the methodologies used in the different modelling processes. The structure is as follows:

- Section 2 describes the situation, requirements and specifications of the territory of Luxembourg;
- Section 3 describes the network planning process;
- Section 4 describes the determination of the cost of termination; and
- Section 5 describes the features of the software tool with which the model is implemented.

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[1] See EU Commission (2009).

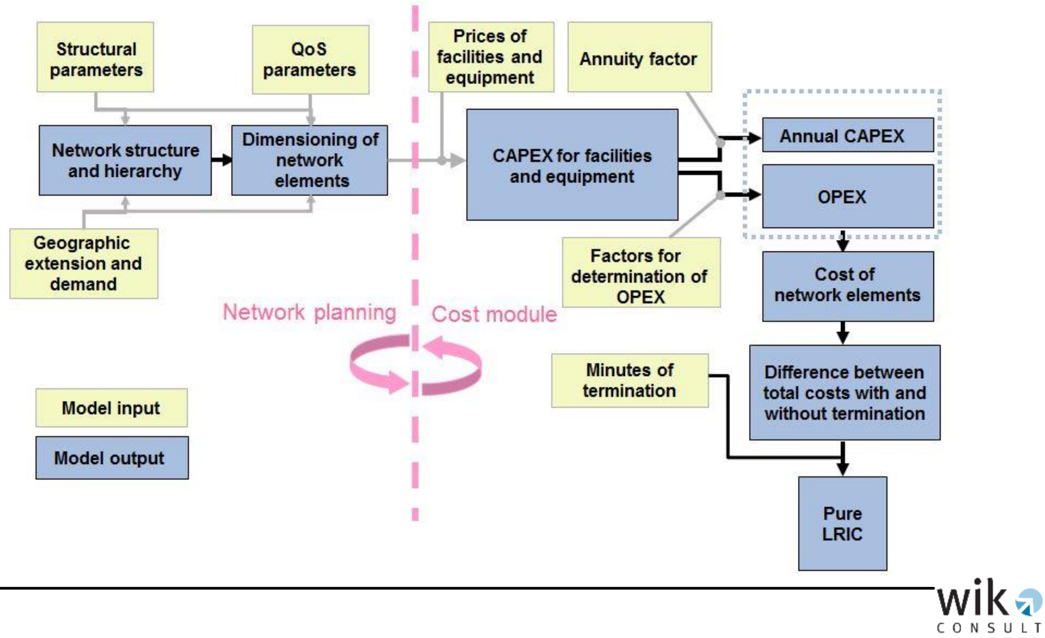
2 Background, requirements and specifications

2.1 Overview

The Bottom-Up Mobile Network and Cost Model (henceforth „the model“) performs the modelling of the network of an efficient operator newly entering the market (henceforth „the reference network operator“) that has a particular market share (chosen according to the purposes of the model user) of the demand in Luxembourg. At the same time it takes into account the conditions under which the existing operators are currently working. The starting point of the model is the demand of users in Luxembourg, which is determined according to the regional distribution of the population, the work places and presence of travellers in the country, assuming an average profile demand per user. The model then plans a mobile network which is able to satisfy that part of this user demand which corresponds to the market share of the operator in question, and based on the prices of the inputs determines the total cost of the network. The cost of termination of incoming calls on the modelled network is then calculated as a part of this total network cost.

Figure 2-1 shows a schematic overview of the modelling process. It distinguishes between the network planning process (left side of the figure) and the cost calculation process (right side of the figure). The network planning tool is programmed based on the C++ standard, but included into an MS Excel environment. The cost module is developed exclusively in MS Excel. The two modules are described in detail in Chapters 2 and 3 in a way that the functioning of both processes can be understood by the reader.

Figure 2-1: Schematic overview of the modelling process



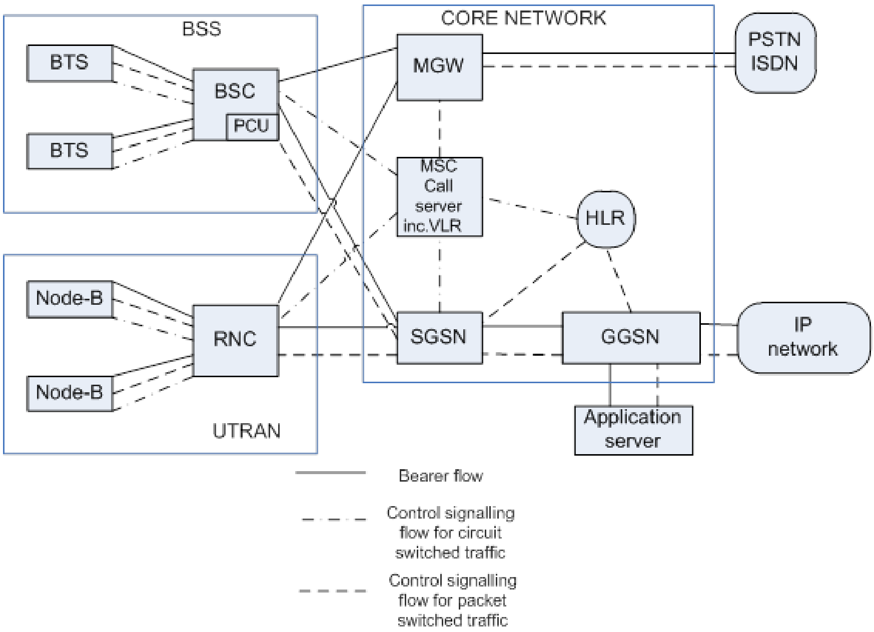
The model will be able to plan mobile networks based on the current state-of-the-art technologies for voice transmission available in Luxembourg: GSM/EDGE, UMTS, and UMTS with HSPA. LTE is not included as it is not yet used to carry voice services. The specification of the model will allow implementing networks based on pure technology choices, i.e. based on only GSM/EDGE, only UMTS, or only UMTS/HSPA, as well as hybrid networks based on combinations of the different technologies.

The model allows covering the demand resulting from up to nine services, i.e. from voice service to mobile broadband access service (regarding the various services taken into account, see Section 2.4 and Table 2-6). The definition of the demand of the different services is relevant insofar as the services have different requirements affecting the dimensioning of the network, and therefore this can be taken into account in the modelling process. There is a difference whether, for example, the user demand is based on an 80% share of voice service and a 20% share of data, or vice versa; not only in the size of the cells of the radio access network, but also in the fixed network parts, depending on where the corresponding traffic needs to be directed.

Since the dimensioning of a network depends to a large extent on the frequency bands used, the model allows using all the relevant frequency bands. Which specific frequency combinations can be used for each of the feasible technologies will be discussed further below.

The most relevant feature of the model is the flexibility with which the different technologies can be combined in the radio access network. This is shown in Figure 2-2, where a schematic illustration of the network architecture is shown. It is based on the network elements defined by the 3GPP in the Releases 4 to 8.

Figure 2-2: Architecture of the network to be modelled



As already mentioned, the network modelling process is described in detail in Chapter 2, and the cost determination process is described in Chapter 3. In the remaining sections of this chapter we cover the prerequisites for this modelling process in respect of the derivation of demand, choice of technology, availability of frequencies and description of service categories. This information is used by the module "scenario generator" to set up the specific scenario for which the network is to be developed.

The objective of the model is to be as close as possible to reality. However, every model is based on stylised assumptions regarding external conditions, and the WIK-model is not an exception (as are also all the planning models used by operators). The influence of particular external circumstances that cannot be explicitly defined in the model are taken into account by conservative assumptions (capacity utilization rates, etc.) that have proved to be reliable in planning and modelling practice.

2.2 Demographical and geographical input data

2.2.1 Definition of users

The network is modelled to cover a specific area – in this case the national territory of Luxembourg – and to satisfy the demand generated by the users consisting of the population residing in this area and travellers present in it. The relevant data are compiled from data on the local government areas in Luxembourg, which provide the population and the geographical characteristics of each area. From the number of people in each area, the number of modelled subscribers is derived using the country's average penetration rate and the market share assumed for that operator. The traffic demand is thus determined bottom-up. The requested traffic volume is not purely statically defined, but also dynamically making use of a so-called movement model, which takes into account the spatial migration of the working population. This movement model is described in detail later in this section.

For the radio access network modelling process sketched in Section 2.1, the national territory of Luxembourg is divided into zones. Within each of these zones homogeneous conditions are assumed to apply so that a corresponding cell deployment can be performed. In addition, the resulting zones constitute the first level of aggregation with regard to the whole network, over which the incoming and the outgoing traffic from the base stations are carried. The process of determining the zones is described in the next section. The remaining part of this section describes how the basic data are obtained.

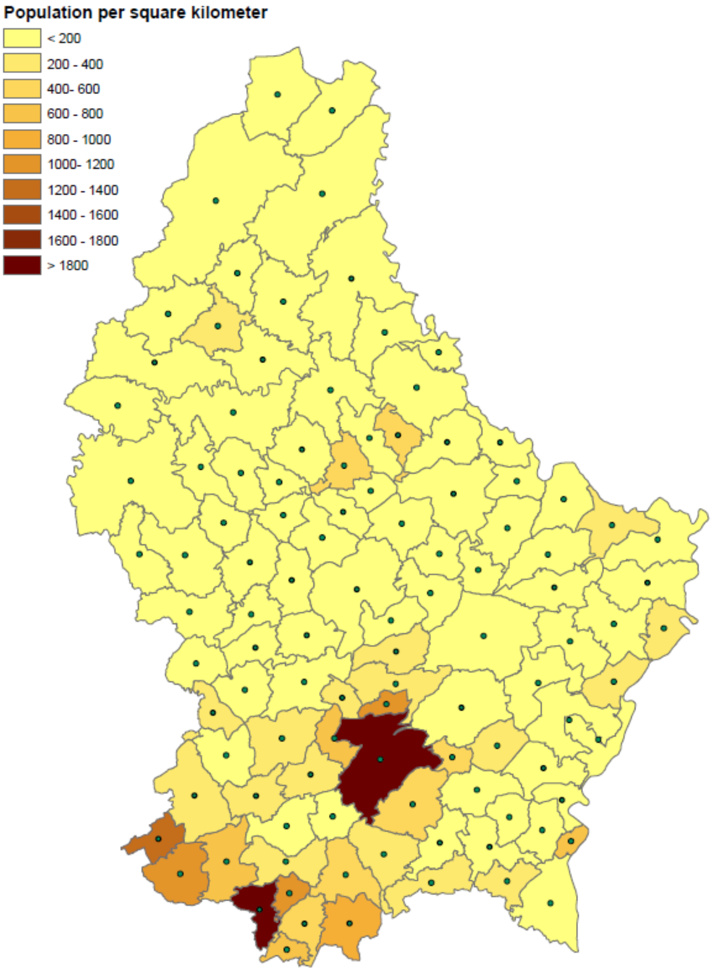
The basic data consist of the following categories:

- Population,
- Enterprises and employees,
- Travellers,
- Railways and highways,
- Luxembourg's international airport,
- Luxembourg City's main railway station, and
- Differences in altitude.

Above statistical data are provided via ILR from the government statistics service of Luxembourg "STATEC". All GIS data are provided via ILR from the government cadastral and topology service of Luxembourg "ACT".

The population data set provides the information about the distribution of residents over the national territory of Luxembourg. It consists of population data at the disaggregated level of local government areas and allows to reflect different demand levels necessary for network planning. In other words, the demand to be met by the network is based on the assumption that the number of customers of a mobile network operator can be derived from the number of residents (as evidenced by the number of active SIM cards) where each user generates a given average volume of traffic in the busy hour. Total demand for an operator deriving from residents in a given local government area (besides working people and travellers there, see below) is then this average demand times the total number of residents times penetration rate times market share of the operator. Figure 2-3 shows the distribution of local government areas of Luxembourg differentiated according to their densities of population.

Figure 2-3: Local government areas of Luxembourg according to population density



The model is able to take into account the spatial distribution of the traffic generated by mobile users who are present at different places during the day, which means that movements of such users is taken into account. The movement of the population during a day is primarily due to working people – in particular also those from the neighbouring countries – going to their work places in the morning and returning home in the afternoon. In order to accommodate correctly these commuters' movements, the model uses the geographical information about the spatial distribution of employees and enterprises.

The specification of the movement model, which records the migration of the workers on a daily basis, is as follows:

- The total number of persons who regularly go to work is identified as the total number of reported jobs for the whole country of Luxembourg.
- The fraction of the population that during the day does not stay at home but moves to its working place is set equal to this number.
- This number is reduced by the workers moving in from neighbouring countries,
- The balance is set equal to the number of local commuters.
- Local commuters are removed from the residential population in every local government area to identify the fraction of the population remaining in its residential area during the whole day.
- The total number of working people are assigned to their corresponding work places, which are known for each local government area.

Example: Assume that there is a residential population of 500,000 in Luxembourg and there are 120,000 work places. Of these work places, 20,000 are occupied by commuters from neighbouring countries who work in Luxembourg on a daily basis. It follows that 100,000 of the 120,000 work places are filled by residents from Luxembourg. To compensate for the movement of working people away from residences in Luxembourg, the residential population in each zone will be reduced by one fifth (100,000/500,000). Since the sum of all residential populations in the local government areas is equal to the total population in Luxembourg, the sum of the people removed from their residential locations adds up to 100,000.

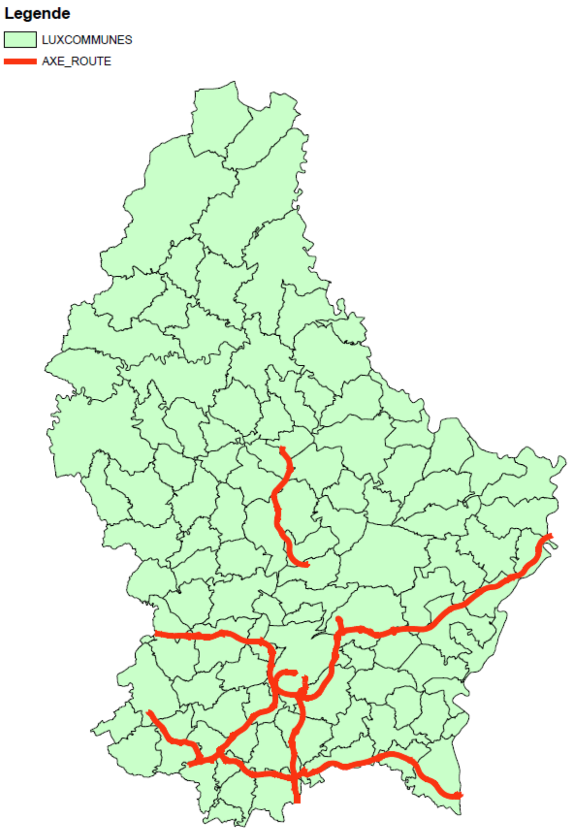
As a consequence of these movements, it can be expected that the peak load for the network in areas with a relatively small number of households but large number of enterprises, particularly in urban areas, happens during the day time, while in other areas (suburban and rural) the peak load is observed in the evening.

It must also be considered that local working people who are present at two places during busy hour periods, i.e. at their work place during the day and at home in the evening, generate demand at both places during the respective peak hours. Through an appropriate adjustment it is assured that the total demand arising from these commuters in the peak periods at the two different places corresponds to the demand of these people for the whole day.

Travellers, as distinct from working people moving to their places of work, are also separately taken into account. Their treatment differs insofar as no correction is carried out for them in the number of the residential population due to the absences when people are travelling, since this number remains the relevant one for the peak hour demand during most of the year. The number of travellers present in given local government areas is estimated from the accommodation capacity of the hospitality sector in these areas. Thus, holiday destinations with a relative low number of households can still have a larger number of users. From the inclusion of the travellers follows that areas with a relatively low population may turn into high visitor regions during vacation time, which then determines the peak period.

As will be discussed in detail in Section 2.3, the modelled network assures that the supply of the area of Luxembourg with mobile services is largely assured when it is dimensioned on the basis of the above described information regarding the geographical distribution of the population, employed people and travellers. In addition, however, it is assumed that additional mobile demand arises along the motorways and major railway lines. Along these traffic arteries, additional mobile base stations are installed, ensuring the provision of this extra demand. Figure 2-4 shows the motorways in Luxembourg taken into account for this additional supply. There will also be roamers from abroad, especially from the nearby neighbouring countries Belgium, France and Germany. We will discuss in section 2.3 how we deal with these users.

Figure 2-4: Motorways in Luxembourg



For the service provision within a covered area, the model pays special attention to places where a large number of persons are present. In Luxembourg such high traffic areas are the international airport and the main railway station in Luxembourg City. These places will be separately identified to be able to provide them with additional cell locations to accommodate the demand by the passengers passing through them. The consideration of these two places covers the vast majority of the demand of all passengers in Luxembourg. Regarding the passengers at other railway stations, it is assumed that their demand is already served by the normal coverage on the basis of population, work places and travellers. In addition, there will be the option to serve temporary hotspots with mobile base stations (e.g. base stations mounted on motorised vehicles).

Regarding the number of passengers during the peak time at the international airport, it is assumed that, on average, each passenger is accompanied by a person, both of whom are at the airport one hour before the take-off. Based on this assumption, the traffic of passengers and their companions overlaps with the traffic of the persons who took off during the hour before, which is taken into account when determining the relevant amount of traffic.

As regards rail travellers, the relevant traffic is estimated on the basis of the number of incoming and outgoing passengers as well as transit passengers.

Summarising the above discussion, Table 2-1 provides overview of the different types of users whose movement are taking into account.

Table 2-1: Types of moving users

Type of moving user	Description	Compensation of the number of residents for this movement (in the zones)
Local commuter	Local resident who moves from home to work on a daily basis	Yes
Commuter from abroad	People from neighbouring countries who work in Luxembourg and use a SIM card from an operator in Luxembourg	No
Traveller	Local resident who is temporarily neither in his residential nor in his working place zone	No
Moving people	People moving on motorways or in trains	No
International roamer	Visitor from abroad with SIM cards of foreign operators. See Section 2.3 for the relevant discussion.	No

2.2.2 Consideration of topographical features

The propagation properties of radio frequencies depend mainly on the topology of the areas served. The range of radio stations is less affected in flat areas, than in hilly or mountainous regions. Hills and mountains are obstacles in the path of the signals resulting either in complete loss of the signal or in major impairments in the signal strength. Therefore, we consider no loss in flat areas, but 1.7 dB in hilly and 7 dB in mountainous areas.[2] Due to these losses, cells may be smaller.

The model takes these effects of hills and mountains into account by the use of an altitude model. This model is based on a geographic data set that includes altitude information. The height-related information is available in a 100 m by 100 m grid. With

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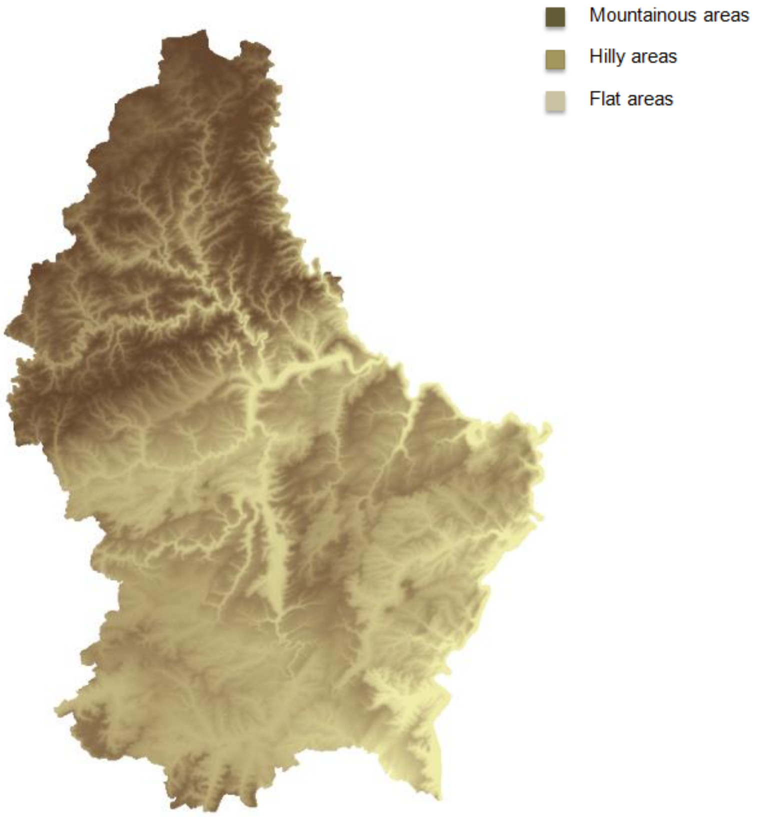
[2] These values are derived on the basis of simulations with the tool “Radio Frequency Propagation Calculator” (see: http://www.cjseymour.plus.com/software.htm) that were carried out by Prof. Portilla of the University of Alcala (Spain) and used in corresponding research, see Sánchez Garcia et al. (2012).

an appropriate GIS tool, the differences in altitude between adjacent grids within a given zone are determined. The average difference in altitude between adjacent grids is calculated for every zone. The model distinguishes three types of differences in altitude, i.e. “flat”, “hilly” and “mountainous”. Table 2-2 shows the values for these three classes that were also used in previous WIK projects (Switzerland, Austria). Figure 2-4 represents the altitude profile of Luxembourg showing how mountainous, hilly and flat areas are distributed over the national territory.

Table 2-2: Topographical classes based on differences in altitude

Topographical classification	Average difference in altitude between reference points 100 m apart	Share of the territory of Luxembourg
Flat	< 2,5 %	12 %
Hilly	2,5 – 7,5 %	41 %
Mountainous	> 7,5 %	47 %

Figure 2-5: Altitude profile of the territory of Luxembourg



2.3 Determination of the demand and its spatial distribution

The traffic demand, on which the dimensioning of the network is based, is derived from the demand of a representative mobile user in the busy hour, which is multiplied by the number of these representative users. There may be several types of users, which can be distinguished as business, premium and standard users, as well as their spatial distribution over different types of areas. It is therefore necessary to determine the demand of residents, commuters and travellers in their spatial distribution. The task consists in processing the data and the information described in Section 2.2 so that the information about the demand to the network planning modules is provided in the right format. This means that the territory of Luxembourg must be divided into zones, each of which is relatively homogenous, so that the supply of the appropriate cells and base stations can be determined for each of them. Each of these zones is divided into sub-areas with high, medium or low density according to the user density. A zone may consist of a single sub-area type, e.g. of a purely high density area, but could also consist of all three sub-area types, e.g. a small city with an urban area in the centre, a suburban ring and a rural periphery.

The starting point is a file, in which all the local government areas with their corresponding information (residents, work places, travellers, topography) are listed. The individual local government areas are sorted according to user density. The zones are formed – as described below – starting with the most densely populated areas, to which the surrounding areas are assimilated according to a distance criterion.

In detail, this aggregation procedure works as follows:

- The list of local government areas is sorted based on their population density, i.e. according to the ratio of persons per km^2 that are in that area during the relevant time.
- The algorithm starts with the area at the top of the list and in the following always continues with the one of the remaining (not yet aggregated) area with the highest population density.
- The aggregating local government areas assimilate all other such areas that are located within a specific distance, which is defined by a parameter. As criterion are taken the distances between the geographic centres of the areas.
- The distance thresholds depend on the type of the aggregating area, i.e. they differ according to whether the aggregating area is assigned high, medium or low density. The threshold for areas with high density is lower than the one for areas with medium density, and the one for the latter is lower than the one for areas with low density. The reason is that the resulting zones should be smaller if their population density is relatively high, and they should be bigger if the density is relatively low, because the cell ranges are smaller or bigger depending on the population density and the corresponding demand, while the cell clusters in the various types of zones should be as homogenous as possible.

Figure 2-6 shows the flow diagram for this algorithm. Table 2-3 shows the values of the parameters to be used in this process that on a first screening of the data appear to be relevant for Luxembourg.

Figure 2-6: Flow chart for the aggregation process from local government areas to zones

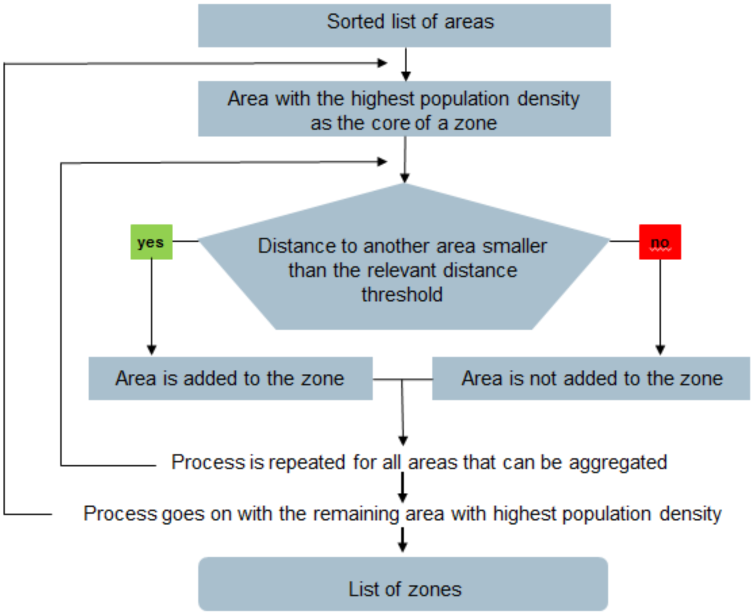


Table 2-3: Typical values of the parameters for the forming of the zones

Parameter	Density		
	High	Medium	Low
Population density (per km^2) for the classification in urban, suburban and rural	600	170	>0
Distance between the centres of the relevant areas (km)	4	8	12

As described above, the algorithm begins with the local government area with the highest population density, and it repeats the process as long as areas having neighbouring areas with lower population density remain. When an area has been aggregated to a zone, it is marked and thus identified as an area that no longer represents an aggregation candidate to other areas. After every aggregation step, the resulting zone is stored in a zone list with all its detailed information. Zones may consist of different sub-areas (high, medium or low density), which are separately considered for the provision with sites and base stations. One zone may also consist of one single local government area. This can be the case if the centre of this area is located far enough from the centre of any other local government area with which it might be assimilated. Such relatively big, typically rural, areas become zones by themselves.

The objective of the above described process is to derive the demand of local users of the network. In addition, roaming users have to be considered. In Luxembourg a long lasting national roaming agreement does not exist, so we have to consider only international roamers.

Every mobile network has users which it temporarily loses to another international network while it also gains users from an international network. An approach for the modelling would be not to consider international roamers, based on the assumption that in each network the users temporarily lost and won compensate each other. If this approach is not supported, then the total number of users should be adjusted by the balance of roamers (positive or negative) based on corresponding information.

In Luxembourg, the people coming to Luxembourg on a daily basis are not considered to be international users (roamers). It seems to be that a lot of those foreign commuters are customers of a Luxembourgish mobile operator. So those foreign commuters shall not be considered as roamers. If there is a significant share of foreign commuters without being customer of a Luxemburgish operator, then those have to be added to the category of international roamers. This could lead to a positive balance of international roamers in the national network and these should then be taken into account.

Moving one step ahead and looking at cell planning, it is also necessary to describe how demand is met by the use of the facilities of the different radio access technologies. Thus a given share of demand can be assigned to GSM and the other share to native UMTS and/or HSPA. This distribution will depend on parameters which are introduced by the model user. They are usually selected according to the density of demand which in turn depends on the density of users. Section 2.5 describes in detail which technology options are available as well as the process by which this selection takes place.

2.4 Description of the service categories and user types

The services in current mobile networks can be described at two different layers of the model of open communication (OSI[3]). At the upper layer, services are categorised as individual activities of users using different applications. At the lower layer, they are defined in physical categories from which the parameters needed for the dimensioning

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[3] For a short introduction the seven layer OSI model see http://encyclopedia2.thefreedictionary.com/Seven-layer+OSI+model.

of the network are deduced. This reference document is limited to the description of services at the upper level.

The description of services is based on a study of the UMTS Forum whose results are shown in Table 2-4.[4] We believe that this description is sufficiently generic for the consideration of new services due to, for example, the introduction of smart phone terminals.

Table 2-4: Services categories and description from the UMTS Forum study

Category	Description of the services (original text from the study)	Market segment
Mobile Intranet/Extranet Access	A business 3G service that provides secure mobile access to corporate Local Area Networks (LANs), Virtual Private Networks (VPNs), and the Internet.	Business
Customised Infotainment	A consumer 3G service that provides device-independent access to personalised content anywhere, anytime via structured-access mechanisms based on mobile portals.	Consumer
Multimedia Messaging Service (MMS)	A consumer or business 3G service, which offers non-real-time, multimedia messaging with always-on capabilities allowing the provision of instant messaging. Targeted at closed user groups that can be services provider- or user-defined. MMS also includes machine-to-machine telemetry services.	Consumer
Mobile Internet Access	A 3G service that offers mobile access to full fixed ISP services with near-wire line transmission quality and functionality. It includes full Web access to the Internet as well as file transfer, email, and streaming video/audio capability.	Consumer
Simple Voice and Rich Voice	A 3G service that is real-time and two-way. Simple Voice provides traditional voice services including mobile voice features (such as operator services, directory assistance and roaming). Rich Voice provides advanced voice capabilities (such as voice over IP (VoIP), voice-activated net access, and Web-initiated voice calls, and mobile videophone and voice enriched with multimedia communications.	Consumer and Business

The UMTS forum includes for each of these service categories the values for the following features:

- Number of sessions per month and service,
- Percentage according to origin and destination: on-net, off-net outgoing, off-net incoming,
- Uplink/downlink ratio,
- File size (kbytes) of uplink and downlink,
- Busy hour traffic percentage.

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[4] See Mobile Forum (2003).

This model considers the services categories determined by the UMTS forum as starting point, but it makes adjustments so that the definition of the services is compatible with current applications and a mapping on traffic classes with its corresponding QoS is facilitated. Table 2-5 outlines the resulting possible services categories. It should be underlined that these service categories aggregate different single services with common QoS characteristics.

Table 2-5: Service categories used in the model

Services categories	Description
Real time voice (circuit switched)	Two-way communication between two persons via a connection with fixed determined capacity.
Other real time	Aggregated traffic of other real time services like rich voice[5], video telephony, multimedia, real time gaming.
VoIP (packet switched)	Two way communication between to persons via a virtual connection
Streaming	Video Streaming, typically from servers to other networks
Guaranteed data	Data communication with high QoS requirements considering delay, jitter and PER, like VPN, intranet connections between mobile users or between mobile terminal devices like in machine-to-machine communication
Best effort mobile	Data communication with low QoS requirements, access to services via mobile platforms and external services like Web services, shopping, E-mail
SMS, MMS	Short message service, multimedia message service
Mobile broadband access	Multimedia and data communication with high band widths

Table 2-6 shows for illustrative purposes plausible values for these features. It should be mentioned that these service categories are defined for UMTS and several of them cannot be provided over other technologies, which is noted in the last column of the table. Further it should be stated that the illustrative bandwidths requirements count for the application layer level. The values in Table 2-6 result from publications of different forums, e.g. GSM-Association, equipment providers, e.g. Ericsson, recent text books and earlier regulation studies.

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[5] Rich voice service is defined by the UMTS Forum as a simultaneous voice and data service, for example allowing mobile users to talk while viewing a shared document on the screens of their mobile devices, see: http://www.umts-forum.org.

Table 2-6: Example values for the characteristics of the considered service categories

Service Categories	**mBu** (kbps)	**mBd** (kbps)	**mLu** (Bytes)	**mLd** (Bytes)	**Duration** (min)	**Percentages of origin and destination**					**QoS class**	**Not available in**
						On-net	**Off-net out**	**Off-net in**	**To ICIP**	**To other server**		
Real time voice	12.2	12.2	25	25	3	0.4	0.3	0.3	0	0	1	HSPA
Other real time (for example video telephony)	64	64	240	240	5	1	0	0	0	0	1	GSM
VoIP	12.2	12.2	25	25	3	0.4	0.3	0.3	0	0	1	GSM
Streaming	4.8	64	30	256	5	0	0	0	0.7	0.3	2	
Guaranteed data	20	80	30	256	1	0.1	0	0	0.7	0.2	3	
Best effort	20	80	30	256	3	0.1	0	0	0.6	0.3	4	
SMS	9.6	9.6	100		0.001	0	0	0	0	1	4	
MMS	40	40	1000		0.002	0	0	0	0	1	4	
Mobile broadband access	80	160	256	256	5	0	0	0	0.4	0.6	4	GSM, UMTS

The services in Table 2-6 represent the possible range of services. For the purpose of cost studies related primarily to voice service, also fewer services can of course be considered. In some previous applications, only voice, SMS, MMS, a general category of data and mobile broadband access have been implemented. In these applications, video telephony has been included with data, because it has comparable requirements in respect of quality.

The model allows that the various service categories can be used in varying degrees by three user types. For example, the following three user types have been used in earlier cost models:

- Business user,
- Premium user and
- Standard user.

However, also other types can be defined. The ratio assigned to each user type for the different service categories should be set exogenously as parameter values. Table 2-7 shows for a hybrid network a plausible distribution of the types of services defined in the example above. These services are provided by a network deploying GSM, UMTS and UMTS/HSPA technologies.

Table 2-7: Example for the distribution of traffic shares according to the different technologies used in a hybrid network as well as per user type

Services	**Shares of the traffic per user for**			**Traffic values during the BH (in Erlang)**		
	GSM	**UMTS**	**HSPA**	Business	Premium	Standard
Real time voice	0.5	0.5	0	0.05	0.005	0.006
Video telephony	0	1	0	0.01	0.0025	0
VoIP	0	1	0	0.01	0.0025	0
Streaming to content server	0.0	0.5	0.5	0	0.005	0
Guaranteed data	0	0.5	0.5	0.002	0	0
Best effort	0	0.5	0.5	0.001	0.01	0.002
SMS	0.5	0.5	0	0.1	0.05	0.01
MMS	0	1	0	0.01	0.02	0
Mobile broadband access	0	0	1	0.01	0.005	0

The user types with their demand profiles can be distributed differently among the single area types, which can be set exogenously via appropriate parameter values. Table 2-8 illustrates possible values for this distribution.

Table 2-8: Examples for the distribution of user types among the area types

User type	**urban**	**suburban**	**rural**
Business user	0.100	0.075	0.025
Premium user	0.200	0.100	0.050
Standard user	0.700	0.825	0.925

The differentiation of the demand according to services, user and area types allows the model to dimension cells in each zone according to the specific demand generated there. However the level of detail with which this differentiation can be carried out depends strongly on the availability of the relevant information. In previous applications the model could for example be parameterised for only one standard user due to the lack of detailed data.

2.5 Technology Mix

The model allows the use of three technologies for the radio access network:

- GSM/EDGE (i.e. GSM with EDGE capabilities),

- UMTS and
- UMTS/HSPA (i.e. UMTS with HSPA capabilities).

LTE, as the latest technological development is not included since it is not yet universally used by all operators and in particular it is not yet used to carry voice services. Thus, for the purpose of this model, UMTS in combination with HSPA is considered to be the state-of-the-art technology. Nevertheless, the legacy GSM technology is still ubiquitously provided in most networks while this may not be true for UMTS, a fact which the model takes into account. While GSM/EDGE is provided throughout the country, for UMTS no universal coverage is automatically assumed, but one which is determined by a parameter representing the degree of demand. There is no explicit modelling of GSM/GPRS as it is supposed that the services based on GPRS (for example machine to machine) can be provided meanwhile more efficiently with equipment that is downwards compatible to GSM/EDGE. For demand, which is to be carried via native UMTS or via UMTS/HSPA, the corresponding base stations are determined at the cell planning stage; however, in both cases UMTS/HSPA equipment is always installed, because as operators have stated this corresponds to the reality of present networks. The two equipment variants do not differ in the model since they are realised through different parameterization.

In summary, the following technologies and hybrid technology combinations will be represented in the modelled network:

- Only GSM/EDGE,
- Only UMTS/HSPA,
- UMTS/HSPA plus GSM/EDGE,

As described in the preceding paragraph, (native) UMTS equipment is deployed according to the expressed demand but always with UMTS/HSPA equipment.

In case of modelling hybrid networks, there will be areas with cells equipped with both technologies. Thereby a part of these cell locations is shared, which means that radio facilities of more than one technology are provided at those locations. Cells with only one technology are then cells with the dominant technology, i.e. the technology that supplies more cells in that area than any other.

The coverage of the different area types with the various types of hybrid networks is regulated by thresholds of population density in every area. Table 2-9 shows two examples of technology configurations depending on given population densities and corresponding demand. The threshold values to be used in actual applications of the model have to be determined when it is calibrated to the situation in Luxembourg.

Table 2-9: Examples of thresholds for the determination of hybrid networks

Technology configuration	**High density**	**medium density**	**low density**
	Population density: Number of people/km^2		
GSM everywhere, UMTS/HSPA in all high density, UMTS/HSPA above a certain threshold in medium density, no UMTS in low density	GSM and UMTS/HSPA above 0	GSM above 0, UMTS/HSPA above 150	GSM above 0
GSM and UMTS/HSPA everywhere in high and medium density, UMTS above a certain threshold in low density	GSM and UMTS/HSPA above 0	GSM and UMTS/HSPA above 0	GSM above 0, UMTS/HSPA above 50

Cells along highways, freeways and main railway lines are equipped with GSM or UMTS/HSPA, respectively.

2.6 Frequency availability and use

The model allows a flexible use of the different frequency bands available for mobile communications. The actually deployable bands in the model are:

- For GSM 900 MHz and 1800 MHz, and
- For UMTS or UMTS/HSPA all available frequency bands, usually, however, 2100 MHz.

The reference network will be provided with a standard frequency assignment. This standard assignment should as closely as possible be equivalent to the real situation of the operators in Luxemburg. In the actual application of the model, this assignment will have to be set by the ILR.

3 Network design and dimensioning

In Figure 2-2 in Section 2.1 we had shown that a cellular network is based on two main parts, on the one hand, the radio access network including the controllers, and on the other, the core network. For a more detailed description, it is useful to divide this dichotomy further into:

(1) Radio access network in the narrow sense, consisting of the radio cells,

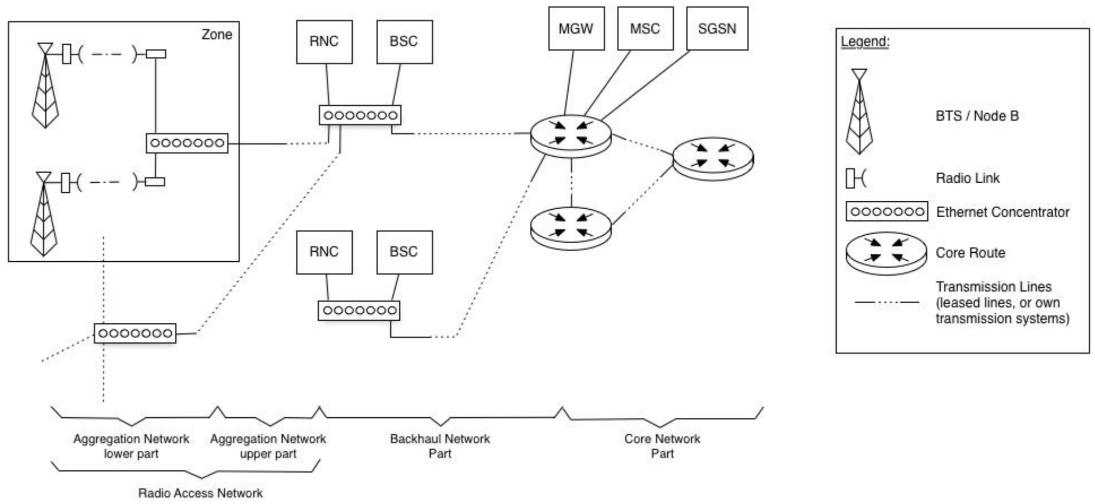
(2) Aggregation network, which connects the cells with the controllers, including the controllers themselves and which is subdivided into a lower and an upper part,

(3) Backhaul network, which connects the controllers with the devices of the core network, and

(4) Core network with its facilities and the links connecting its different core locations.

Figure 3-1 provides a simplified picture of these four network parts which emphasises the main network elements.

Figure 3-1: Structure and main elements of the mobile network



The following sections will describe the modelling tasks regarding the above specified network parts. These tasks are:

- Network design,
- Dimensioning and
- System assignment.

A special section will deal with questions of redundancy and QoS.

3.1 Radio Access Network

The planning of the radio access network is the first and most fundamental step when modelling a mobile network. It is based on the geographical distribution of demand, the different services implemented by the operator, the technologies used and the available frequency spectrum. The design of the radio access network includes the determination of the number of sites and the number of base stations with their corresponding equipment, which are able to meet the demand for the services offered by the operator, as well as the distribution of these sites and base stations over the considered zones and sub-areas. The module performing the cell planning presented here, uses data which has been made available through the process of zone determination. In addition to the zone-specific geographic information, this data informs about the distribution of the users within the zones and the demand these users generate.

The process used to perform the cell planning is described in the next sections for each candidate technology, i.e. GSM, UMTS, and UMTS with HSPA. The cell planning determines – for each sub-area within a zone – the type of site and the corresponding type of base station, as well as their numbers. A symmetrical distribution of the locations within a sub-area is assumed. The term “base station” is used for both “base station transceiver (BTS)” in GSM networks and “nodes B” in UMTS networks.

The cell planning process is carried out independently for each sub-area within a zone. For this purpose, an algorithm for each of the different used technologies is available. Each algorithm is capable of determining the size and number of the required cells of the given technology, taking into consideration the characteristics of the area as well as its user demand.

3.1.1 Definition of the radio access network equipment

Different from the other network parts, the network design, dimensioning and system assignment will be carried out for the radio access network simultaneously. The reason for this is that here the network design – more concrete the planning of the sizes of the cells in the various areas – can only be carried out if in the corresponding calculations the capacities of the various available base station systems are taken into account, which means that these systems can immediately be assigned to these cells.

Here we show the cell types and the types of base station used in such cell sites. In 2G GSM networks these are:

- Macrocells with up to three sectors, each sector with up to two TRX,
- Microcells with up to three sectors, each sector with up to three TRX, and
- Picocells with up to three sectors, each sector with up to three TRX.

The cell types used in 3G UMTS networks are the following:

- Macrocells with one, two or three sectors,
- Microcells with one, two or three sectors, and
- Picocells with one, two or three sectors.

Strictly speaking, in cells with multiple sectors, each sector is a cell by itself, due to each sector being assigned its own spectrum. However, we set a cell equal to the area served by a base station, and in case of multi-sector cells or multi-sector base stations, “cell” in the strict sense is referred as a sector and not as an independent cell.

Macrocells / base stations apply for rural and suburban areas, microcells / base stations for suburban and inner-city areas, and picocells / base stations for urban areas. Moreover, macrocells / base stations with two sectors can also be deployed along highways and railway lines.

The parameters that determine the type of base station, and apply to both BTS and node B, are the following:

- Transmission power,
- Transmitter / receiver antenna gain,
- Number of sectors,
- Receiver sensitivity and noise characteristics,
- Parameters that define a base stations as suitable for a macro, micro or picocell,
- Investment into the site, and
- Investment into the radio equipment per sector.

In addition, for BTS the following parameters are added:

- Number of TRX per sector,
- Average number of signalling packets, and
- Number of slots reserved for handover when moving from one cell to another,

and for Nodes B:

- Maximum interference margin allowed.

When planning the cells for each area, all available suitable types of base stations are taken into consideration for being deployed. The type which covers the traffic demand and requires the minimum investment is picked. For this purpose, the information about the investment per base station is included in the parameters list of the base stations.

It should be noted that the antenna of the radio equipment is not considered as an independent network element. The model provides the equipment with standard antennas and not with more cost-effective combinations of antenna. The objective of this is to keep the complexity of the model manageable.

3.1.2 Cell deployment for 2G GSM

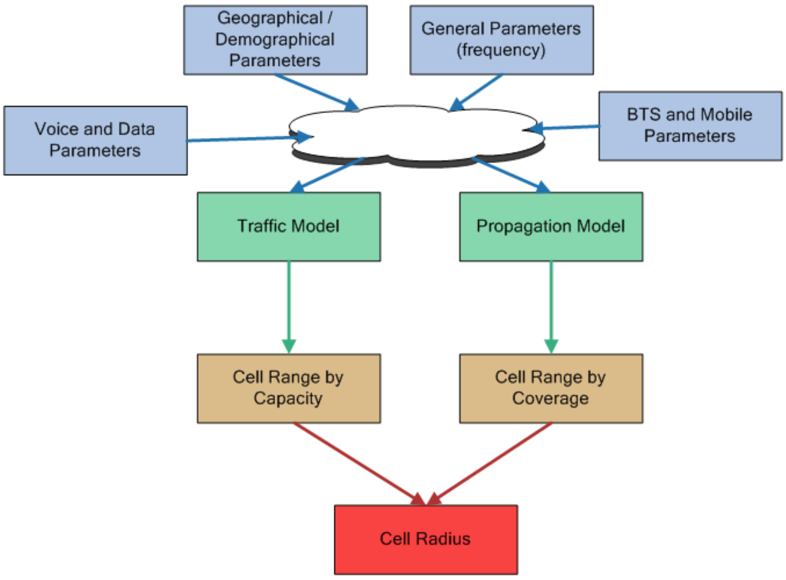
The objective here is to calculate the range of a cell, the covered area of the cell, and thus the number of cells that are required for the provision with services of a given area. As possible frequency bands, the 900 MHz and 1800 MHz frequency bands are used.

Based on the parameters mentioned in the previous section, and the features of a given area, the cell planning algorithm estimates the corresponding cell range. This calculation is carried out separately for the specific propagation properties of the used frequency bands and for the volume of traffic to be carried, due to the fact that in GSM the amount of traffic does not critically influence propagation (in contrast to the 3G UMTS cell range calculation as outlined in the following sections). First, the algorithm determines the cell range corresponding to propagation properties. This cell range is the largest that can be covered by a cell using a given frequency band, since the propagation properties of the given frequency band do not allow communications with an acceptable quality beyond this cell range. The cell range is then determined according to the volume of traffic. In this case, the cell range is determined by the number of channels needed to satisfy the traffic demanded. In case that the number of channels available for a single sector according to the available spectrum is not enough to satisfy the traffic, the number of cells (in the strict sense) in a location and thus the capacity is increased by sectoring. The number of possible sectors and the number of transceivers (TRX) per sector is restricted: In the model, a maximum number of three sectors and three TRX per sector are assumed. Thus, the capacity of a cell site is determined by the number of sectors and the number of TRX per sector defined for that cell site.

For a given cell range, determined on the basis of propagation limitations, the number of TRX available per sector increases with the volume of traffic. In case that the required number of TRX exceeds the maximum capacity, the cell range must be reduced. Thus, it follows that under high traffic conditions the sizes of cells are traffic driven, while under low traffic conditions cells are propagation driven.

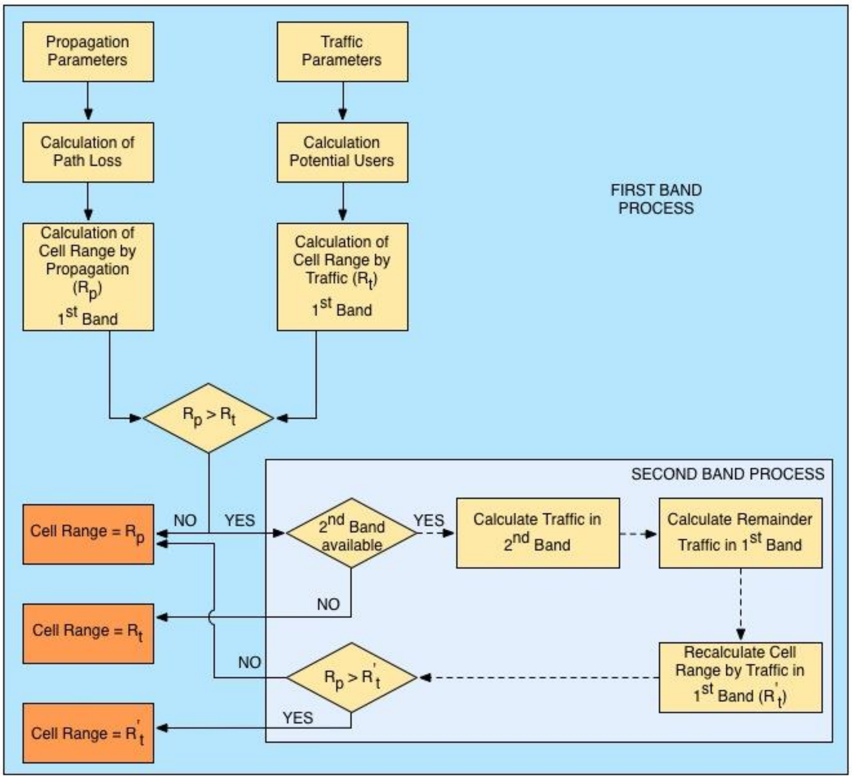
Figure 3-2 shows a schematic view of this network dimensioning process.

Figure 3-2: Schematic overview of the process to dimension 2G GSM cells



The above solution is valid in the case that only one frequency band (either 900 MHz or 1800 MHz) is available. In case that both bands are available and the cell range obtained due to propagation properties is larger than the cell range due to traffic being served with one of the available frequency bands, i.e. the traffic demand is such that the propagation properties of the used frequency band do not represent the limiting factor, it is possible to install additional equipment using the second frequency band at the same site. This additional equipment allows meeting the additional demand, thereby increasing the traffic driven cell range and reducing the number of required sites in the area. The cell range of both possible solutions is determined in an iterative process. Since the use of the second frequency band is only worthwhile in case the savings in cost due to the lower number of sites required outweigh the additional cost due to the additional radio devices installed at each location, the model checks whether such a saving takes place. In the case that no saving is observed, the model discards the use of this additional equipment. Figure 3-3 shows the flow chart of this algorithm.

Figure 3-3: Flowchart for calculating the cell range for 2G GSM



Once the cell range of a site is estimated, its corresponding covered area is determined. The number of required sites in a given area is calculated by dividing the total extension of that area by the area covered by a single site. When performing this calculation, it is taken into account that the circular areas calculated from the cell ranges overlap; for this, a compensation is carried out by reducing the cell areas by a corresponding percentage. This process is carried out for every sub-area of a zone and for every zone, which in the end leads to a cell deployment covering the whole territory to be covered.

The above described process does not take into account the presence of shadow areas that occur in urban and other areas due to buildings, which may significantly weaken the radio signal. The model takes this into account by providing an increment factor, which is defined as a parameter (and its value is based on empirical observation). It allows increasing by a percentage the number of base stations where appropriate.

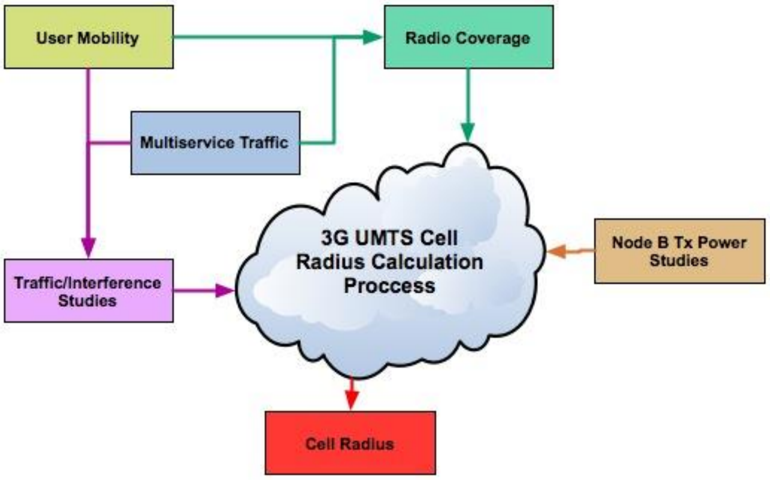
3.1.3 Cell Deployment for 3G

With “3G system” two standards, UMTS and HSPA, are meant. Both technologies are based on Wideband Code Division Multiple Access (WCDMA), which implies that the cell size depends on the amount of interference in the cell. This interference is generated by the users of the cell as well as system users from the adjacent cells. The allowed interference in the cell is defined by a parameter. In this section descriptions of the dimensioning process for each of the two technologies are given.

3.1.3.1 3G UMTS

As UMTS is a WCDMA technology, the cell size in a UMTS system depends on the allowed amount of interference in the system. In the model, this parameter is used by the algorithm to determine the link budget, from which based on the given propagation conditions the cell range is estimated. Every user within a cell is considered as a source of interference, and therefore the total interference caused by all the users within the propagation cell range must be in line with the maximum amount of allowed interference in the area defined by that range. There is an interdependency between the cell range due to propagation characteristics and the cell range due to the amount of interference caused by the traffic of the users within a cell. This requires the implementation of an iterative algorithm capable of managing this interdependency. This constitutes a new feature of UMTS systems that differ from GSM networks, where the cell size is strictly limited either by the propagation characteristics of the spectrum or by the available bandwidth delivering the number of channels available for carrying user traffic. Figure 3-4 shows a schematic representation of the process followed to determine the cell range in 3G UMTS networks.

Figure 3-4: Schematic representation of the process to determine the cell range for 3G UMTS cells



The available amount of bandwidth determines the cell sizes. UMTS/WCDMA is based on blocks of spectrum with a 5 MHz bandwidth each. The algorithm developed in the model is capable of dimensioning a network based either on a single 5 MHz frequency block or on multiple 5 MHz blocks which are then considered as one single larger block. In both cases, the algorithm optimises the cell size as described above, taking into account the allowed interference within a cell and the interference caused by the users within that cell.

The algorithm optimises the cell range of a node B for a given portfolio of services.[6] For this, it considers that the services with the specified grade of service (GoS), expressed by a corresponding blocking probability, will be offered throughout the whole area covered by the node B.

The corresponding algorithm used to estimate the cell range consists of two steps:

- Solving the so-called outer problem, which determines the maximum allowed interference within a cell that balances the cell range due to propagation conditions and due to capacity requirements.
- Solving the inner problem, by which the optimal allocation of capacity to every considered service is estimated. This optimal allocation of capacity is based on the value of interference defined at each iteration of the outer problem.

The solution is obtained by applying an interrelated iterative process. The outer problem consists in the determination of the cell range taking propagation impairments into account. This is based on the interference margin which is defined for each iteration. This cell range obtained from each outer problem iteration step is used as a starting point for the next iterative step of the inner problem. The provisional cell range obtained by solving the inner problem (by capacity) forms the input for the outer problem. This one then compares both cell ranges and, if appropriate, defines a new interference margin. After this, a new iterative step is performed. A flow chart describing the two processes is given in Figure 3-5. The detailed description of this cell range process is found in Subsection 3.1.3.1.1.

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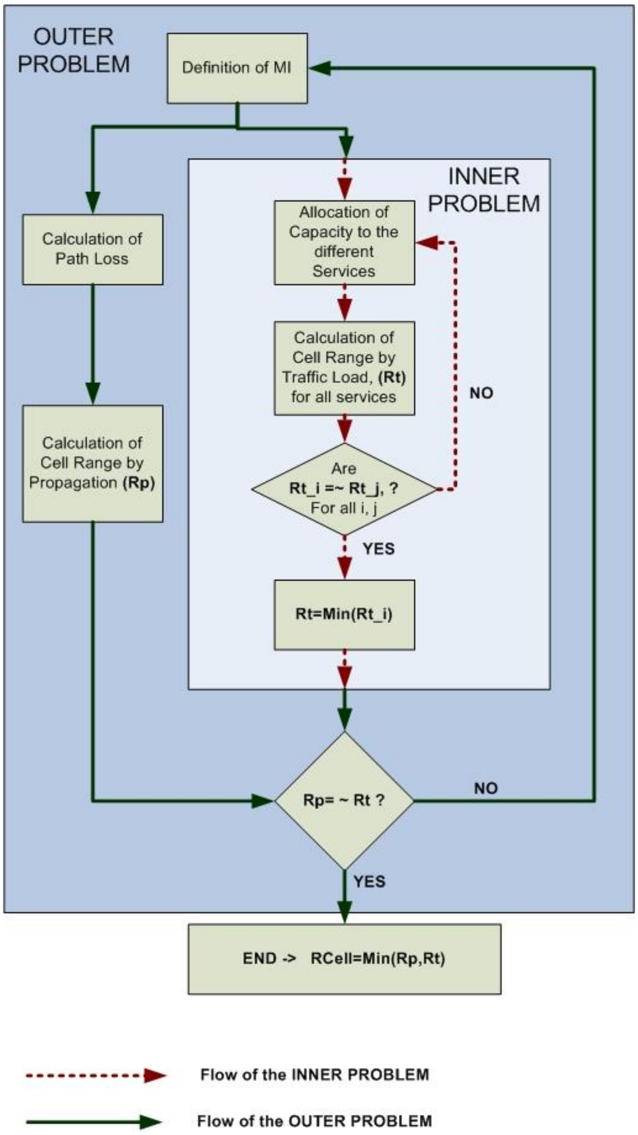
[6] See Portilla et al. (2009).

Figure 3-5: Flow chart for the calculation of the cell range in 3G networks



3.1.3.1.1 Step by step process for calculating the cell range of a 3G cell

This section gives a detailed description of the dimensioning process of a 3G UMTS radio access network. The discussion is quite technical so that readers without a background in mobile network design theory may choose to skip it.

The first step is the calculation of the cell range due to propagation characteristics. For this purpose, an individual analysis of coverage for each service in both, uplink and downlink, is performed. The most restrictive cell range, R_P, is the starting point of the capacity study. This cell range is used for allocating the initial load of each service. This procedure is based on a concept proposed by Lindberger[7] for a multiservice loss network, extended here to cover the particular features of the WCDMA cell design.

The capacity analysis is based on two main parameters, the aggregated load factors of the whole set of services η_S and the maximum capacity of the cell (load factor of the cell) η_{cell}.

The aggregated load factor η_S is calculated as follows: Based on the previously calculated R_P, the allocation of the load factor for each of the services is carried out. For this purpose, the number of users within each cell is calculated based on the population density of the area under study, and therefore the total traffic demand per sector for each service is carried out. Making use of basic traffic concepts, based on the Erlang-B formula and the characteristic soft capacity concept for WCDMA[8], the number of required channels to satisfy the calculated user demand with a specific blocking probability P_{bi} is obtained. The numbers of channels are assumed to be the maximum number of simultaneous connections for each service N_{aci}. The next step is to calculate the load factor of a single connection for each service, l_i, which depends on the defined input parameters of the services considered, such as binary rate, bit energy over noise ratio, etc. The load factor of each service, based on the number of simultaneous connections and the individual load factor per connection, L_i, is then estimated. Finally, the model calculates the total demanded load factor η_S as the sum of the different load factors for each service.

The maximum capacity of the cell η_{cell} is calculated as follows: It depends on two parameters: the amount of allowed interference in the system, defined as an input parameter, and the number of 5 MHz frequency blocks available. Initially and independently on the number of frequency blocks available, the model estimates the capacity of the cell for one single frequency block.

The objective of the capacity analysis is to verify that the maximum capacity of the cell is larger than, or at least equal to, the demanded aggregated load factors of the services. For this purpose, once both η_S and η_{cell} are calculated, an iterative process, where the total amount of the allocated load of all the services is compared with the maximum capacity of the cell, is performed. In the case that $\eta_S > \eta_{cell}$, an additional frequency block (if available) is used and η_{cell} is recalculated and compared with η_S. This process is iteratively performed until $\eta_S < \eta_{cell}$ or there is no further frequency block available. In this last case, the total load assigned to the services is reduced to

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[7] See Lindberger (1988).

[8] For details about the Erlang-B formula, the soft capacity concept, and the load factor estimation, see Chapter 8 in Holma and Toskala (2010).

satisfy the following condition $\eta_S = \eta_{cell}$. The rest of the dimensioning process is performed using the maximum capacity available according to the last mentioned condition.

Considering the values of the service depending load factors, a new solution of the cell radius for each individual service, as against that derived from propagation, is calculated and the load factor over the i services with the minimum value, min L_i, defines the cell radius.

This process is done for the downlink, which is typically the most restrictive direction in the capacity, and also for the uplink, typically the most restrictive in terms of propagation.

Once the cell radius is calculated, the algorithm checks whether the node B has enough power to simultaneously serve all users in the coverage area. If that is the case, the cell radius obtained is the final cell radius for the node B configuration. If that is not the case, the interference margin has to be decreased and the complete process has to start again.

Finally, when the final cell radius of the site/node B configuration is obtained, the number of sites is calculated similarly as it was done for 2G, dividing the extension of the area to be served by the area covered by the site.

In both cases (for a single or for several 5 MHz frequency blocks), the model will allow to define a picocell increment factor, similarly to the 2G design to consider possible shadow areas or hot spots.

3.1.3.2 3G HSPA

As mentioned, HSPA is a technology of the WCDMA family and is usually deployed when there is also UMTS deployment. When the latter is the case and deployment of the two technologies takes place using the same frequency band, the model requires for HSPA the availability of blocks of 5 MHz which are different from any block of frequencies used for UMTS. The algorithm to calculate the number of required sites works similarly as the algorithms for GSM and UMTS. In a first step it calculates the area covered by a single site and thereafter the number of sites is calculated by the division of the extension of the area under study by the area covered by the site.

The algorithm to calculate the HSPA cell range, and hence the area covered by the HSPA site, works as shown in Figure 3-6 below. From the technical information available for the services shown in Table 2-7, it is possible to calculate the most suitable set of modulation/code rate/number of multicodes/inter TTI for the guaranteed binary rate. This set is directly related with a specific signal to interference and noise (SINR) ratio at the receiver.

On the other hand, the transmission power of the node B is also known. With this value, it is possible to calculate the maximum path loss which guarantees the defined SINR at the edge of the cell. With this value of the path loss and a propagation method, typically Okumura-Hata[9], it is possible to obtain an initial value for the cell range by propagation R_{HSPA_0}. Given this cell range, we know the number of HSPA users generating the throughput to be carried in this cell range (B_{HSPA_0}).

The next step is to estimate the maximum throughput of the node B. For this purpose, the model takes into consideration the number of sectors of the node B and the definition of the HSPA frame structure in terms of time transmission intervals (TTI) and number of available codes. In addition, the type of modulation and coding scheme (MCS) used is also considered. Based on these elements and the relevant technical equations, the maximum capacity of the node B is estimated ($\Omega_{HSPA\_Site\_0}$). If this value is equal or higher than the B_{HSPA_0} determined above, the cell range calculated R_{HSPA_0} is the final cell range of the site. If not, the algorithm starts an iterative procedure to reduce the cell radius (10 % in each iteration) until the throughput in a given iteration $\Omega_{HSPA\_Site\_i}$ is equal or higher than the B_{HSPA_i}.

Once this value is obtained, the number of sites required to provide HSPA services in the area is calculated. This number is compared with the number of UMTS sites. The maximum value of both will be the final number of sites. Note that in case of hybrid GSM/UMTS areas, the number of UMTS/HSPA sites is also compared with the number of GSM sites to obtain the final number of locations.

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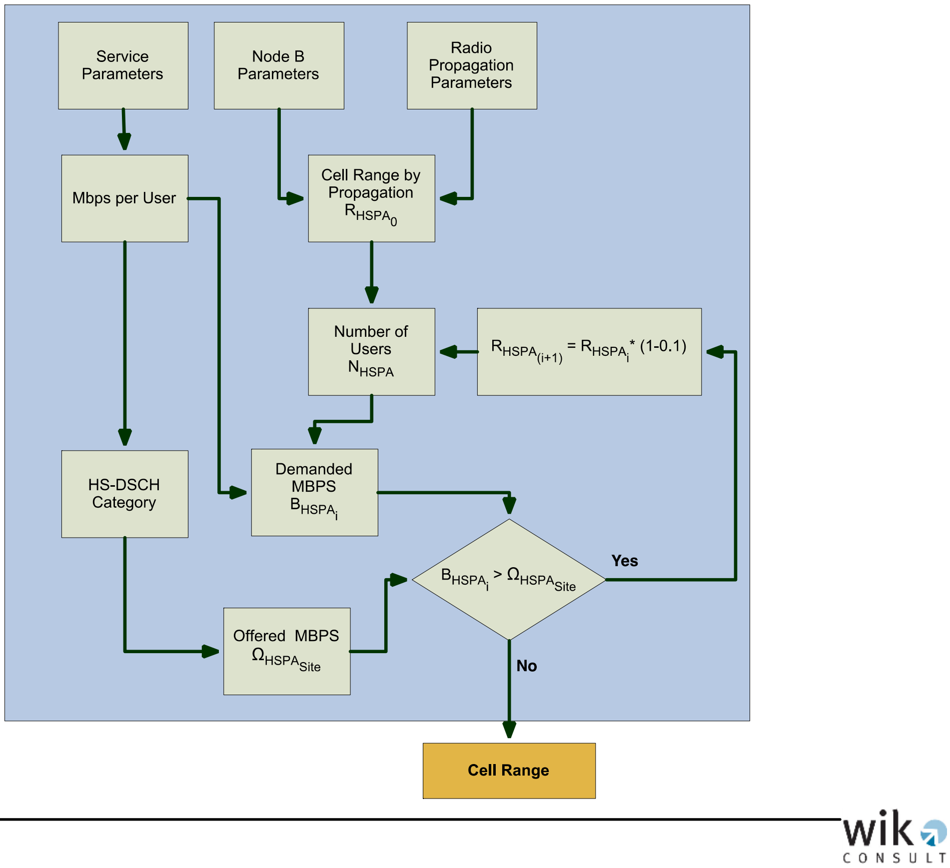
[9] For more details regarding the cell dimensioning under the Okumara Hata model see Chapter 8 in Holma and Toskala,(2010).

Figure 3-6: HSPA cell range calculation procedure



While above discussion has been in terms of HSPA, it also applies similar to HSPA+ which can also be modelled. The use of the HSPA+ technology depends directly on the maximum required throughput per user. With these inputs the model chooses the most suitable modulation and coding scheme. If the maximum demanded throughput is larger than a given value, the model selects an HS-DSCH category corresponding to HSPA+ and follows the same process as described before.

3.1.4 Considerations regarding hybrid deployment

In case of areas with hybrid cell deployments, the demand is divided into shares to be satisfied by the different technologies. The cell deployment is then performed independently for each technology based on the corresponding traffic demand for each technology. Once the number of sites required for each technology is obtained, the option of sharing infrastructure must be considered. For this purpose, the algorithm considers that the total number of sites to be installed in a given area corresponds to the number of sites of the technology that requires the largest number of sites. A technology with a lower number of sites will be placed at a subset of the locations of the technology with the largest number of sites. There will then be locations at which only the latter technology is present. The possible technology combinations at areas with a hybrid deployment are shown in Section 2.5.

3.1.5 Considerations regarding highways and railways

As already stated, motorways and the main railways lines are considered by the model as separate and independent deployments. The technologies considered in the model to be deployed for this purpose are either GSM, UMTS or UMTS with HSPA.

The area to be covered along motorways and railways is more similar to a line than a circle, which implies that only specific types of base stations can be deployed there. The requirements that these base stations must satisfy are that they cover large distances, have large transmission power and dispose of two sectors.

3.1.6 Signalling

Besides the actual signalling functions, there are several internal control functions for which corresponding channels are also to be considered. In this section, all traffic resulting from these functions is grouped under the name of “signalling traffic”. The signalling traffic is treated in the radio access network and in the transport network each time in its own way. Furthermore, the way the signalling is treated in the radio access network differs between GSM and UMTS/HSPA.

Since GSM is a circuit-switched technology, physically separate capacities are provided for the signalling traffic. In the model, in order to guarantee that an already established connection is not interrupted when a user moves from one cell to a neighbouring cell, one of the eight slots per TRX is reserved for signalling purposes, together with a second slot for handover purposes. As the traffic in the aggregation network between the BTS and the BSC is carried over 2Mbps E1 groups, one of the 32 slots of 64Kbps of such a group is reserved for signalling traffic.

In UMTS/HSPA, no physical connections are reserved for signalling traffic. Rather the total available capacity of the cell is shared by the total traffic to be carried within the cell, and the corresponding connections are provided only virtually. In the dimensioning process, the transmission power of the node B is therefore divided according to the requirements of the user and of signalling. This sharing is done in such a way that the increased signalling traffic due to new services (i.e., “always online” for smartphones) is guaranteed. For the connections from the node B to the RNC (and conversely), a corresponding increase in capacity is specified to provide for this traffic.

While the signalling traffic in the radio interface is explicitly taken into account, this is not done in the dimensioning of the transmission capacity in the backhaul and core networks, since there the signalling capacity in relation to the user demand is relatively low. The model provides mark-up factors (see Table 3-5 in Section 3.5) which limit the rate of utilization of the transport capacities and thereby also provide sufficient capacity for the signalling traffic.

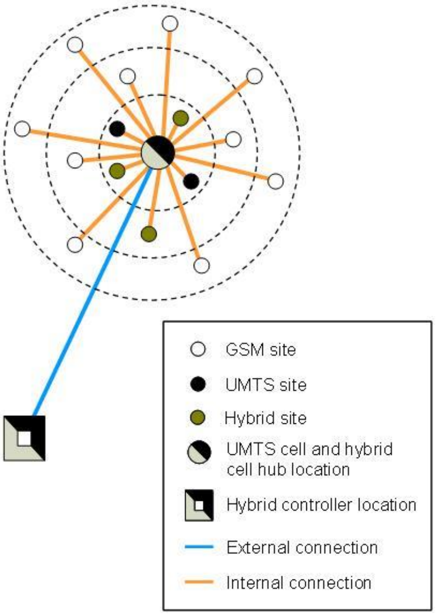
3.2 Aggregation network

In both GSM and UMTS/HSPA networks, the aggregation network connects the base stations with the controllers. With regard to the physical network, it is useful to divide the aggregation network into two separate parts: (a) connections from the individual cell sites of a zone to a central location, hereinafter referred to as cell hub, which represents the first concentration point of the mobile radio network, and (b) the connections of the cell hubs to a corresponding controller location (BSC in 2G and RNC in 3G). In addition, controller locations are considered as part of the aggregation network in the dimensioning process.

In the model, it is assumed that each zone has a cell hub which is geographically located in the centre of the zone. The locations of the controllers are determined endogenously as a subset of the cell-hub sites. The number of the controller locations is a parameter to be provided by the model user. The dimensions of the links in the aggregation network and of the systems at the cell hubs are determined by the aggregated traffic and its associated bandwidth. The systems at the cell hubs aggregate the traffic on the basis of carrier grade Ethernet equipment (facilities of the OSI layer 2).

A special feature of the aggregation network in a hybrid network is that the infrastructure for the traffic and bandwidth aggregation of all the cells at both the cell-hub and the controller locations is independent of the radio technology used. Depending on the type of network, there may thus be cell hubs aggregating traffic from BTS and nodes B. Figure 3-7 shows a schematic example.

Figure 3-7: Schematic example of an aggregation system in a hybrid network



For the design and dimensioning of the aggregation network, the model has to solve the following tasks:

(1) Determination of the controller node locations,

(2) Assignment of the cell hub locations to the controller locations,

(3) Determination of the optimal topology for each controller cluster (formed by a controller location and its associated cell hubs), and the capacity routing over the corresponding links (blue line in Figure 3-7),

(4) Calculation of the required interconnection capacity between individual cells or base stations and their corresponding cell-hub (orange lines in Figure 3-7),

(5) Calculation of the required interconnection capacity between cell-hubs and controllers, and

(6) Dimensioning of the facilities at the controller locations.

Tasks (1) and (2) correspond to a classical location problem, while problem (3) describes a topology problem which can be solved with a tree algorithm (Minimum Spanning Tree Algorithm[10]).

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[10] Regarding the Minimum Spanning Tree see Kevin et al. (1972).

3.2.1 Determination of the controller locations

3.2.1.1 Algorithm for determining the controller locations and assigning the cell hubs

The number of controller node locations is externally provided by the model user, while the concrete locations of the controllers and the linking of the cell-hub locations to the controllers are determined by the model. The solution leads to controller clusters each of which consists of a controller node location and its associated cell-hub locations. The following cost drivers for the solution of the problem are considered in the model:

- Cost of the bandwidth required to carry the aggregated traffic from the cell-hubs to the controllers, and
- Distance-depending costs as a function of the geographical distances between the cell-hubs and the controllers.

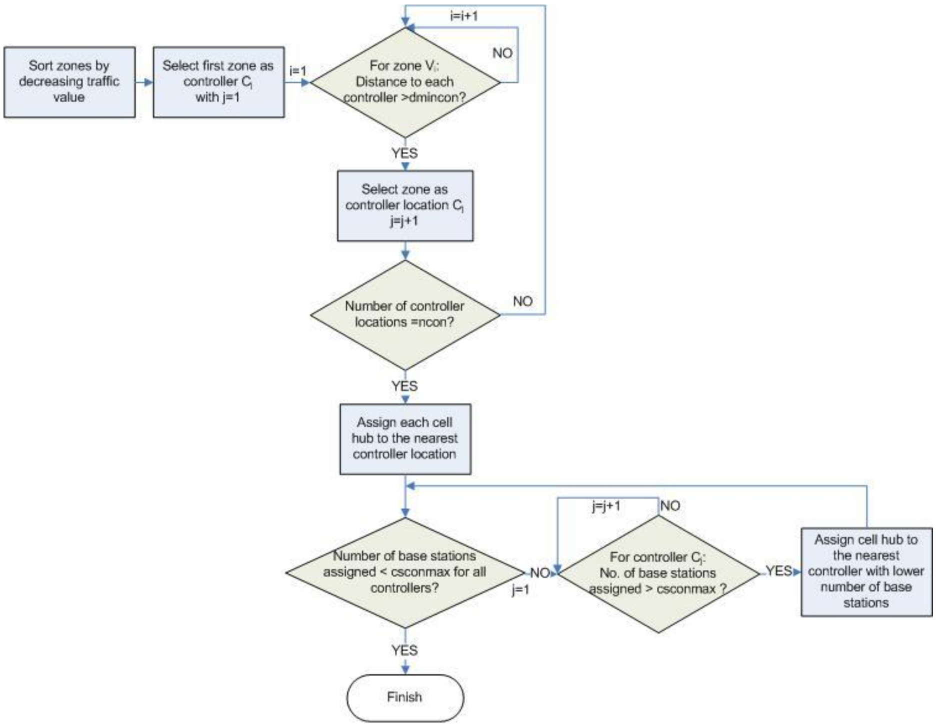
It is assumed that the controller locations are a subset of the cell-hub locations. The algorithm selects as first candidates for controller locations those cell-hubs that aggregate the highest volume of traffic. In high concentration traffic urban areas, this could lead to solutions where some controller cluster locations are situated next to each other which would imply very large distances of the links between the cell-hubs and the controller node locations. The algorithm can be adjusted in a way that a spatial distributed structure is generated, for which graph theory related methods can be used. This could in turn result in a selection of controller locations with very small traffic loads and remaining cell hub locations with large traffic volumes which must be connected to the corresponding controller locations in some cases again over large distances. For this reason a heuristic algorithm is used which solves both problems simultaneously using a distance parameter the value of which is under the control of the model user. The algorithm selects the locations with the largest capacity weights, which must meet a minimum distance criterion set by the user as an input parameter. The algorithm is supported by numeric and graphical information so that the user can conveniently select the minimum distance criterion leading to an optimal distribution of the controller locations.

Once the locations of the controllers are determined, the algorithm assigns each cell-hub location to the geographically nearest controller location. In order to obtain a balanced distribution of the cell hub locations to the controller locations, the algorithm considers a maximum number of cell sites which can be assigned to one controller location. This parameter is provided by the user of the model. If the selected number of cell-hubs per controller location is not sufficient to assign all the cell sites, a warning message is shown. In this case the value of the maximum number per controller location may be increased.

The corresponding algorithm starts with a list of the cell-hub locations sorted according to traffic load. From this list it selects successively the (remaining) location with highest load that fulfils the minimum distance criterion. For this it uses the Depth First Search Principle.[11] The algorithm then assigns first each cell-hub location to the nearest controller location and after that it reassigns cell-hub locations in such a way that the maximum number of cell-hubs per controller location is met.

Figure 3-8 shows a flow chart for the algorithm.

Figure 3-8: Flowchart for the determination of the controller stations and the allocation of the cell-hubs



Legend:
dmincon – Minimum distance criterion
csconmax – Maximum number of cell-sites per controller location
ncon – Number of controller locations (input parameter)

3.2.1.2 Algorithm for determining the links of cell-hub locations with controller locations

If N cell-hubs must be connected to a controller location, then this results in a tree structure with N-1 links. Among all the possible tree structures the one is selected that minimises the cost. These costs are driven by two main parameters, the traffic demand resulting from the corresponding capacity required on each link, expressed in

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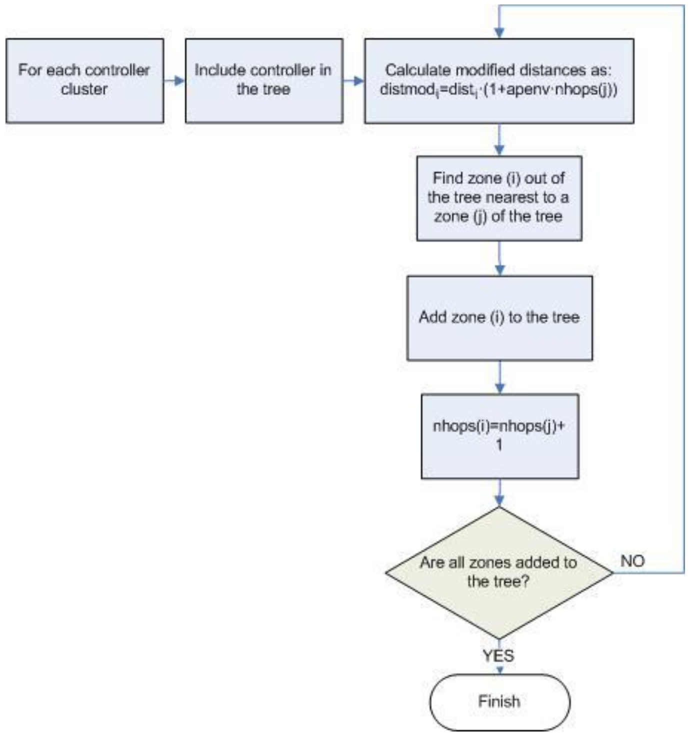
[11] For more details regarding the Depth First Search Principle see Cormen et al. (2001).

bandwidth, and the length of the links. In the case that the cost driver of the geographical distance has no or only a minor effect, the optimal solution is a star topology. If the length-dependent costs dominate, the optimal topology to be selected is that which minimises the distance, the so-called minimum spanning tree, i.e., a tree topology with minimum total length. A star topology usually arises when an operator relies on leased lines from a fixed network provider, while a tree topology is used when the operator builds its own physical infrastructure, usually through microwave systems, or with dark fibre.

To obtain an optimal tree topology, the model takes into account both cost drivers (length and required capacity in terms of bandwidth). This algorithm is known from the literature for calculating minimal length of a tree (minimum spanning tree, MST), which is modified in such a way that the number of links between the cell-hub and the controller locations – referred to as depth of the tree – is limited. To limit this depth, an additional parameter is introduced, which increases the lengths of the links artificially, from which follows that the lengths of the links are given more weight in the dimensioning process. The appropriate value for the corresponding parameter depends mainly on the geographical topography of the area to be covered, the parameters of the transmission systems used for the links, and the cost of the systems to be installed. The value of the parameter is provided as an exogenous parameter by the model user, after taking into consideration the above mentioned factors.

Figure 3-9 shows the flow chart of the process described above. In Figure 3-13 of Section 3.2.2.2.2.2 below, which covers the dimensioning of the links between the cell-hubs and the controller locations, the process is described in detail with the help of a numerical example.

Figure 3-9: Flowchart of the calculations for determining the locations of the topology between cell-hubs and controllers



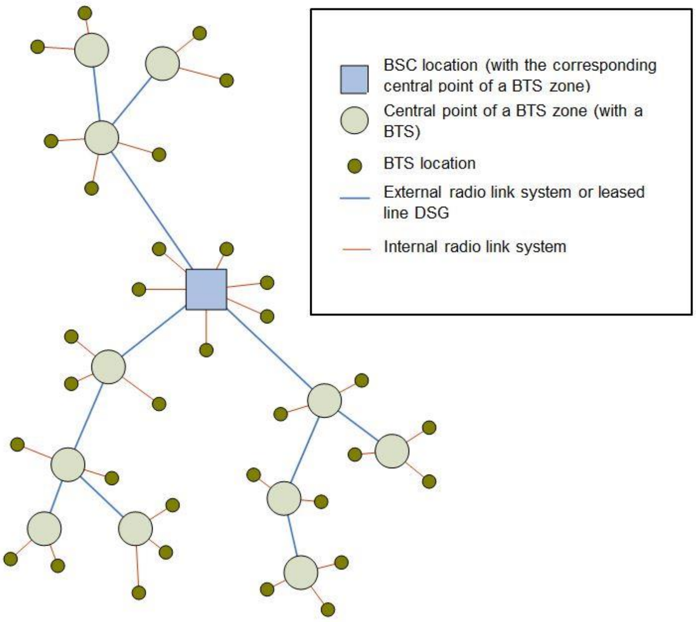
3.2.2 Topology, dimensioning of the capacity and determination of the systems

3.2.2.1 Topology

The logical structure in the aggregation network for the connection of the individual cells / base stations to the cell-hubs is approximated by a star topology. The corresponding lengths are determined using the average distances between sites for each sub-area. This approximation is sufficient because the model assumes a uniform distribution of cell sites in the sub-area of a zone.

For the logical topology of the connections between the cell-hubs and the controllers two different options are considered, either a star or a tree topology. The selection of the one or another topology depends on the transmission system used. The use of leased lines suggests a star topology for both the logical and the physical topology; when using systems that are built by the mobile operator itself, i.e., by microwave or dark fibre, the optimal topology is a tree. The capacities that are carried on these connections are the sum of the traffics of the cell-hubs that are connected via them to the controller. Figure 3-10 shows an example of a tree topology in a 2G GSM network for a controller cluster of cells, cell-hubs and the corresponding BSC.

Figure 3-10: Example of a tree topology for a cluster controller that connects the cell locations, cell-hubs and the controller locations in a GSM network

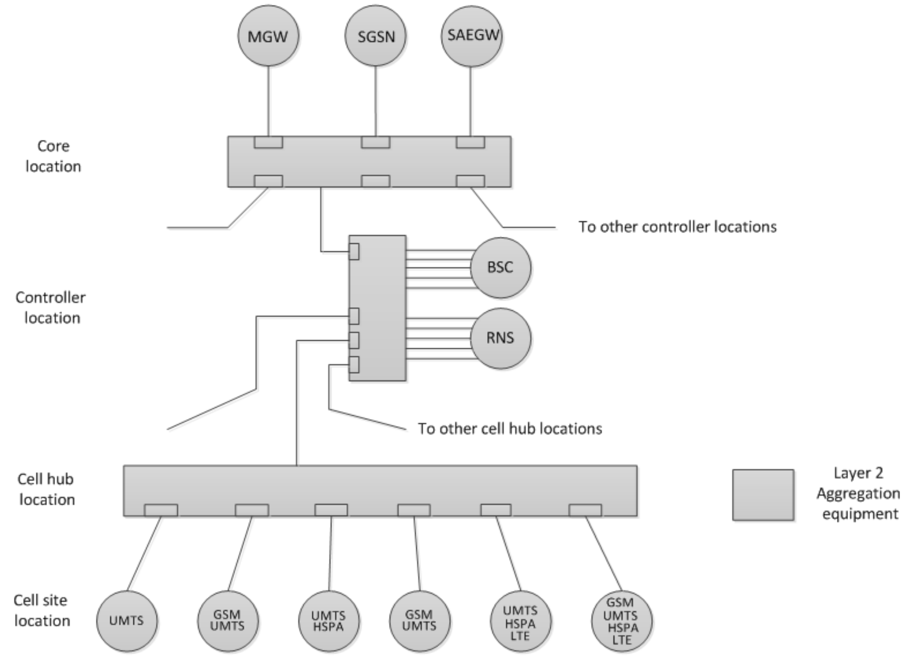


3.2.2.2 Dimensioning

Information about the required capacity over a star or tree topology and the lengths of the links are the main inputs for determining the type and number of systems with which the connections can be realised. In addition, layer 2 multiplex systems for traffic aggregation and disaggregation (typically carrier grade Ethernet) must be dimensioned, both at the level of the cell-hubs and at the level of the controllers.

The dimensions of the connections are determined by two parameters: the traffic flow, which is measured by the bandwidth, and the distance. For the connections between the cell-hubs and the controllers, the model takes into account the specific values (flow and length) for each individual connection. For the connections between the base stations and the cell-hubs, the model calculates average values for the distance, having in mind that the sites of the individual base stations are only approximately determined in the model (which has a negligible impact on the level of the cost). The traffic flow parameters from the base stations to the hubs vary according to whether only GSM or also UMTS or HSPA traffic must be carried; they will be described in the following subsection. Figure 3-11 shows the three main components of a mobile network in terms of the equipment of layer 2 and the connections between them.

Figure 3-11: Main components of an aggregation network based on the 3GPP Release 8



The dimensioning and the allocation of the systems are carried out in the following steps:

- Dimensioning of the links from the individual cells / base stations to the cell-hubs and the assignment of the corresponding transmission systems,
- Dimensioning of the connections from the cell-hubs to the controller locations and the assignment of the corresponding transmission systems, and
- Dimensioning of the aggregation systems (Ethernet switch) both at the cell-hub locations and the controller locations, as well as the dimensioning of the controllers for both GSM (BSC) and UMTS (RNC).

Details are presented in the following sub-sections. Generally, it can be seen that the dimensioning of the facilities is expressed in terms of generic parameters so that different types of network realization (leased lines or own infrastructure in form of microwave links) are made possible.

3.2.2.2.1 Dimensioning and system assignment for the connections between cell sites and cell-hub locations

From the cell deployment, the following data, required for the dimensioning of the systems to be installed in each zone and its corresponding sub-areas, is available:

- Number of pure 2G, pure 3G and hybrid cell site locations for areas with high, medium or low user density, and
- Cell ranges in the various areas.

This information allows for each sub-area of a zone to calculate the average length of the links connecting the cell sites with the cell-hub location.

The transmission systems can differ according to whether they connect BTS or node B base stations with the hub, and therefore their bandwidth requirements can also be different. However, common transmission systems are used for the bandwidth requirements of hybrid cells.

It is assumed that the interfaces for 2G BTS equipment are based on E1 signals, and that those for 3G node B equipment on IP/Ethernet cards, at 10 Mbps or 100 Mbps, if HSPA or HSPA+ is used. The corresponding interfaces may already be integrated in the base station equipment or require an adapter. In case of hybrid cell sites, an adapter is always required to join the different signals from BTS and node B equipment on a common transmission system.

From the cell deployment follows for the BTS that the maximum number of TRX is 3 x 3 = 9, and hence one standard connection E1 provides always sufficient capacity for transporting the traffic of a base station to the cell-hub location. The aggregated traffic in a cell-hub location is the sum of the different BTS traffic volumes in a zone, and maximally corresponds to the capacity of an E1 connection multiplied by the number of cells.

Regarding the nodes B for UMTS, the model calculates the required capacities on the basis of the number of users and the total bandwidth resulting from the traffic and its average bandwidth for each traffic class, which arises from the services provided by the base stations deployed in the given cells.

The interfaces for 3G equipment are assumed to be based on IP/Ethernet and the corresponding interface cards are assumed to be integrated inside the node B equipment. The QoS requirements for the various traffic classes are expressed by the mean delay from entry of the signal into the network up to its exit. These delays are mainly caused by the layer 2 equipment and the transmission systems at the lower levels (especially from the cell sites to cell-hub locations), because these systems are dimensioned according to the required bandwidth and lie in the Mbps range, while the capacity of the higher levels, especially in the backhaul and core networks, lie in the Gbps range so that their contribution to delay is less significant.

The main approach of operators to meet the QoS requirements of the different traffic classes is to limit the average capacity utilization of the system at a particular level. Hence, the model considers for each network level above the radio access network a pre-defined utilization factor, to be set by the user as an exogenous parameter value. It follows that the aggregated bandwidth on each transmission link must be multiplied by a global mark-up factor, which is the inverse value of the selected utilization factor. The question of how in general QoS requirements are met will be taken up in Section 3.5.

As stated above, a pure star topology is implemented for the connections between the individual cells and the cell-hub locations. This is an approximation to reality which is justified by the following reasoning:

- The model does not determine the exact geographic locations of the cell sites, since this is not necessary for the purpose of the model. It is assumed that the sites are symmetrically distributed within each sub-area of a zone.
- It is obvious and has been confirmed by earlier application of the model that the differences in the locations of the base stations statistically neutralise each other and that the remaining cost difference is insignificant.
- Because of the assumption about the geographic distribution of base stations, any other topology than that of a star would be arbitrary. The contribution to cost of the transmission systems between the base stations and the cell-hub locations are only a small part of total costs, and, furthermore, while the cost of a star topology provides an upper bound, a fine-tuned optimization would not decrease this cost significantly.

The capacity of the links between base stations and cell-hub locations are provided by E1 systems for 2G GSM. For 3G UMTS / HSPA technologies, capacity is represented by equivalent bandwidths, which have been determined already in the dimensioning of the cell-hubs. The capacity for hybrid cells is aggregated by a corresponding layer 2 adapter which then provides the bandwidth of the common link to the cell-hub. The selection of the appropriate adapters is based on a table, the values of which (bandwidth required, number and type of ports) are input parameters.

The capacity of the connections from the base stations to the cell-hub locations can be realised either by microwave or leased lines. The user of the model can specify the transmission technology through a corresponding input parameter. In the case that a mix of microwave and leased lines should be installed, this can also be determined through input parameters, which stipulate the respective shares of the two technologies.

3.2.2.2.2 Dimensioning and system assignment for the connections between cell-hub and controller locations, and assignment of systems to these connections

As stated above, the required capacity for these connections are determined by the bandwidth requirements in the cell-hub locations. In respect of the topology of these connections, a star and a tree topology are available. As already mentioned, a star is a special case of a tree, where the selection between star and tree structure is determined by an input parameter (see Section 3.2.2.1). In case a star structure is chosen, the capacity of each connection of the star is equal to the capacity of the associated cell-hub location, and in case of a tree structure, the capacity of a tree corresponds to the sum of the capacity of the associated cell-hub locations.

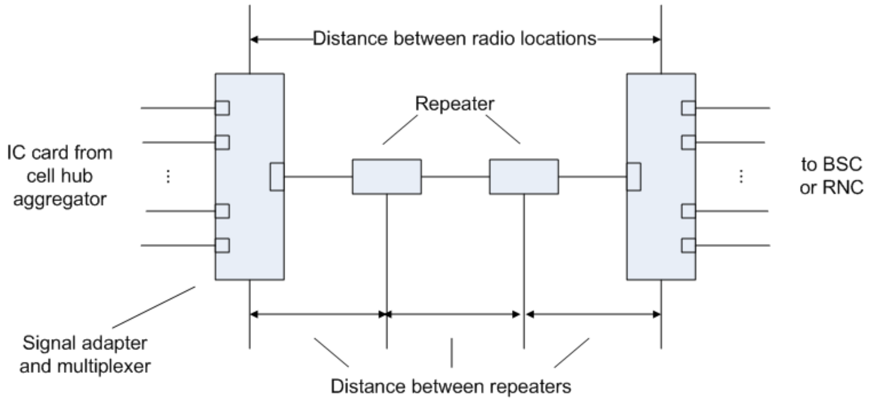
Once the capacity in form of equivalent bandwidth requirement has been determined for each connection in the topology, the model determines the systems for those connections in the same way as done for the connections between the base stations and cell-hub locations.

3.2.2.2.2.1 Dimensioning and system assignment for a star topology

In a star structure, the capacity between a cell-hub location and its corresponding controller location is determined as the sum of the capacities of the corresponding cell sites. The resulting average bandwidth is increased by a global mark-up factor, gMUF. This gMUF is necessary because in the fixed part of the network the information is transmitted based on a layer 2 frame, typically Ethernet. A too high utilization of the connections would lead to an increase of the delay time and/or to a buffer overflow.

For the realisation of the physical connections of a star structure, either leased lines or own-built point-to-point transmission systems can be used. When using dark fibre, a direct connection in the layer 2 plane (between the two ports of the corresponding layer 2 devices) is possible without the implementation of additional transmission systems. In a microwave radio transmission system, an adapter is integrated, converting the bearer signal into the signal required by the transmission system. In case that more than one bearer signal is transported, this adapter is integrated into the corresponding multiplexer. Figure 3-12 shows schematically the elements of such a physical connection.

Figure 3-12: Main components on the physical link of a star topology connecting a cell-hub location to the corresponding controller node location



The assignment of the transmission systems to the connections is carried out according to the same criteria as for the connections between the base stations and the cell-hub locations. The inputs, which are provided by the cell-hub aggregator equipment and which determine the system allocation, are:

- Total equivalent bandwidths to be transported between the cell-hubs and the corresponding controllers, and
- Lengths of the star connections between the cell-hub and the controller locations.

Table 3-1 shows the parameter values of a list of different system configurations that are eligible for the system assignment.

Table 3-1: Example of possible transmission systems for connecting cell-hub locations to the corresponding controller node

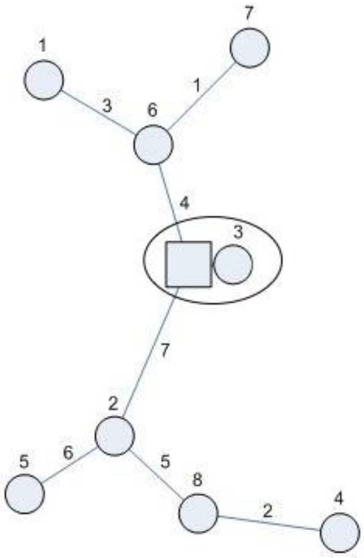
Features of the system	Index of system type			
	1	2	3	4
	Possible values of the characteristics			
Maximum net bandwidth (Mbps)	8	32	140	560
BWport [Mbps]	100	100	1000	1000
Maximum length (km)	50	50	50	50
Parameter providing a threshold which indicates the number of lower systems to be substituted for cost reasons by the next higher one	3	3	3	

3.2.2.2.2.2 Dimensioning and system assignment for a tree topology

In the case of a tree topology, the specific tree structure must be available, along which the transmission systems for the connection between the cell-hub and the controller locations have to be dimensioned. This structure is made available by the procedure described in Section 3.2.1.2.

Figure 3-13 shows an example of the application of the algorithm described in Section 3.2.1.2. In this figure the seven cell-hub locations (in zones) with the through a square box identified controller location – located in zone 3 – are connected through a tree structure. It follows from the figure that the location 4 is connected to the controller node with a depth of three edges, the locations 1, 5, 7 and 8 are connected to the controller with a depth of two edges, and cell-hubs 2 and 6 are connected to the controller with a depth of only one edge. The legend shows the data structure that is required to make the traffic routing from the cell-hub to the controller node. It shows that each zone is provided with a “pointer” both to the next zone and to the edge in the direction of the controller node assigned to it. From this follows that, for example, to route the demand from zone 7 to the controller node, first the edge number 1 is added, and the process continues in the next zone number 6 with the edge number 4. The next zone is number 3 where the controller node is reached, which is indicated by providing it with a “0” as the “pointer” to the next zone.

Figure 3-13: Example of a tree structure aggregation network with a controller location and the associated cell-hub locations and connections



Legend								
Index of the considered zone	1	2	3	4	5	6	7	8
Index of the next zone on the way to the controller	6	3	0	8	2	3	6	2
Index of the hop	3	7	0	2	6	4	1	5

The corresponding routing algorithm routes the traffic aggregated in the cell-hub locations in form of their bandwidth requirements over the connections of the tree to the controller location, which results, after the termination of the routing algorithm, in the bandwidth requirement at each edge of the tree.

The configuration of the cell-hub aggregation systems takes place in a similar way to that of a star topology where, however, the additional transit traffic, which is obtained from the routing algorithm, is taken into consideration. The allocation of the transmission systems to each edge of the tree is done in the same way as in the case of the star topology.

3.2.2.2.3 Dimensioning of the aggregation system and the controller

The dimensioning of the aggregation systems takes places on the basis of its drivers. For the aggregation systems these are the total bandwidth and the number of ports and their bandwidth.

3.3 Backhaul network

The backhaul network connects the controller node locations with the locations of the core network where the switching and routing systems are situated. The design of this network includes:

- Selection of the locations for the core network systems as a subset of the controller locations,
- Assignment of the controller locations to the locations of the core network, and
- Dimensioning and allocation of the systems.

3.3.1 Determination of locations for the core

The approach for selecting the locations of the core network and the assignment of the controllers to them is similar to the corresponding task in the case of the aggregation network (see Section 3.2.1). The same algorithms are used with similar adjustments regarding minimum distances between the different core network locations and regarding the capacity limits with respect to the number of controllers which can be assigned to one core network facility. For the prevention of failures and to increase availability, the model provides the option of assigning any controller node to two core network locations. In this case, the capacity for each of these connections can be set by a parameter between 50% and 100% if leased lines are used. If radio links over a ring topology are used, due to technical reasons only the options of 50% or 100% can be chosen.

3.3.2 Topology, dimensioning and transmission system determination

3.3.2.1 Topology

For the physical topology, the options of a star or a ring are available. If in case of a star topology the implementation is based on leased lines, the required bandwidth on the star links determines the type and number of leased lines. In the case that the backhaul locations are connected to two sites of the core network, the physical network is implemented either as a double star over leased lines or in the form of rings by microwave systems or leased lines with the corresponding ADM / ROADM devices.

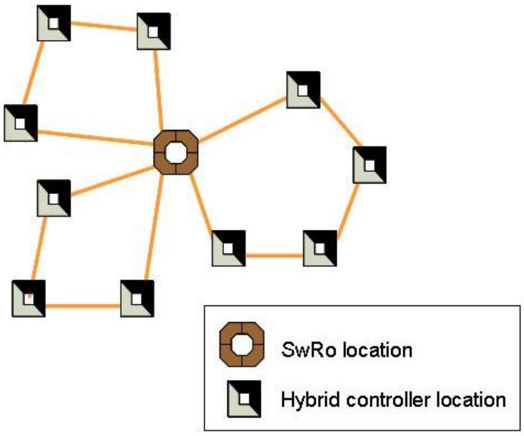
A ring topology can be implemented either via ADM / ROADM devices with a capacity in each of the two directions of either 50% or 100% of the total ring load and hence a corresponding protection, or based on Ethernet with a capacity for each direction between 50% and 100%. As physical systems either microwave or leased lines can be used.

The model considers for the ring topology those connections which minimise the length-dependent costs and calculates therefore a ring topology which minimises the total length. For this purpose, a heuristic algorithm for solving the so-called Travelling Salesman Problem is used[12]. In addition, the model considers that the number of locations in the ring is limited in order to minimise the risk of failures. The particular algorithm used for this is known as Shamrock Algorithm[13], and it consists of two steps:

- Determination of the clusters that are attached to the same ring, and
- Calculation of the topology for each ring.

Figure 3-14 shows an example for a backhaul network composed of three rings, wherein the number of controller locations in a ring is limited to four.

Figure 3-14: Example of a backhaul network topology



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[12] See Domschke (1982).
[13] See Silió et al. (2011).

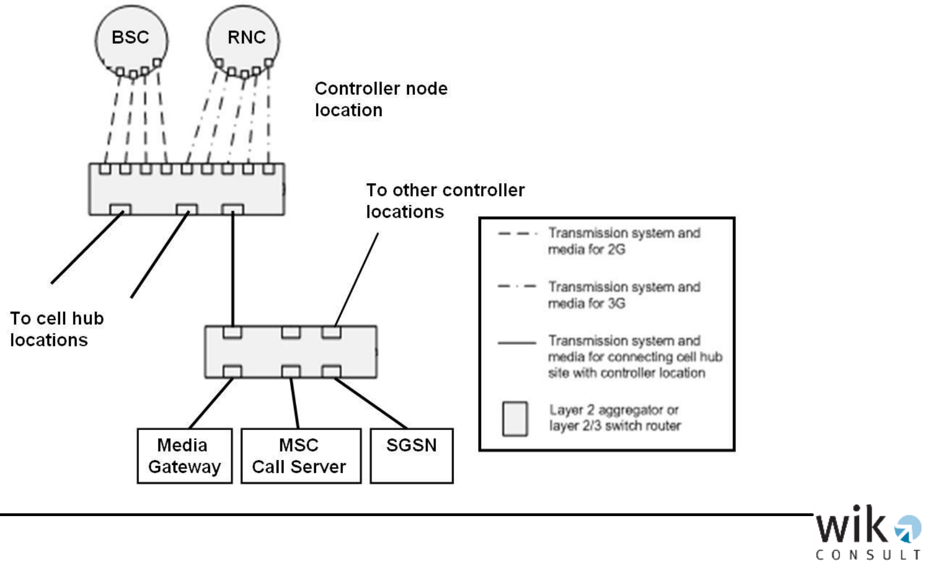
3.3.2.2 Dimensioning

The dimensioning of the backhaul network covers the following network components:

- The aggregators of the controller locations,
- The actual controller facilities, BSC for 2G GMS, and RNC for 3G UMTS, and
- The transmission systems connecting the controller node locations with the corresponding core node locations.

Figure 3-15 gives an overview over the essential components of the backhaul network. The model proceeds similarly to the aggregation network with information from tables to select the systems with the required capacity.

Figure 3-15: Backhaul network and its key components



3.3.2.2.1 Dimensioning of the BSC and RNC

Based on the traffic flows from cell-hub locations, the capacity requirements for the design of the controller units are determined. When dimensioning the BSCs or RNCs, a maximum utilization of the systems (utilization factor) is considered, since operators usually provide for extra capacity for unforeseen increases in traffic.

The dimensioning of the BSC for 2G GSM is based on a combination of the following cost drivers:

- The number of BTS which are assigned to a BSC
- Total number of aggregated users, which are provided to the corresponding base stations, and

- Maximum number of active connections (in slot units from the aggregated TRXs).

For each BSC, a PCU device is provided, through which the data traffic coming from the BTS is directed to the SGSN.

Table 3-2 shows the example of the dimensioning of a controller site, for which several units of the same type of BSC facility are available to cope with a given capacity. The four parameters that are used for the dimensioning are strongly correlated with each other. It may happen that for the different products not all parameter values are available. Parameters values which are not considered, e.g. because they are unavailable, should be set to a high value in order that these parameters do not influence in the dimensioning process.

Table 3-2: Example of dimensioning a BSC location, for multiple units of the same types of BSC available

Characteristics of a BSC location	BSC-Type		
	1	2	3
	Possible values of the characteristics		
Maximum allowed number of BTS	200	400	600
Maximum allowed number of users	$8.6*10^{5}$	$17.2*10^{5}$	$25.8*10^{5}$
Maximum allowed number of active connections	$1.44*10^{4}$	$2.88*10^{4}$	$4.32*10^{4}$
Parameter providing a threshold which indicates the number of lower systems to be substituted for cost reasons by the next higher one	2	2	

For UMTS, the dimensioning of the RNC follows the same approach as that of the BSC in GSM it considers the following cost drivers:

- Aggregated circuit-switched traffic (especially voice),
- Aggregated packet-switched traffic, and
- Aggregated number of ports for 10, 100 and possibly 1000 Mbps.

Table 3-3 shows the main cost drivers for the dimensioning of the BSCs and the RNCs, and the load factors with which they are set in the model.

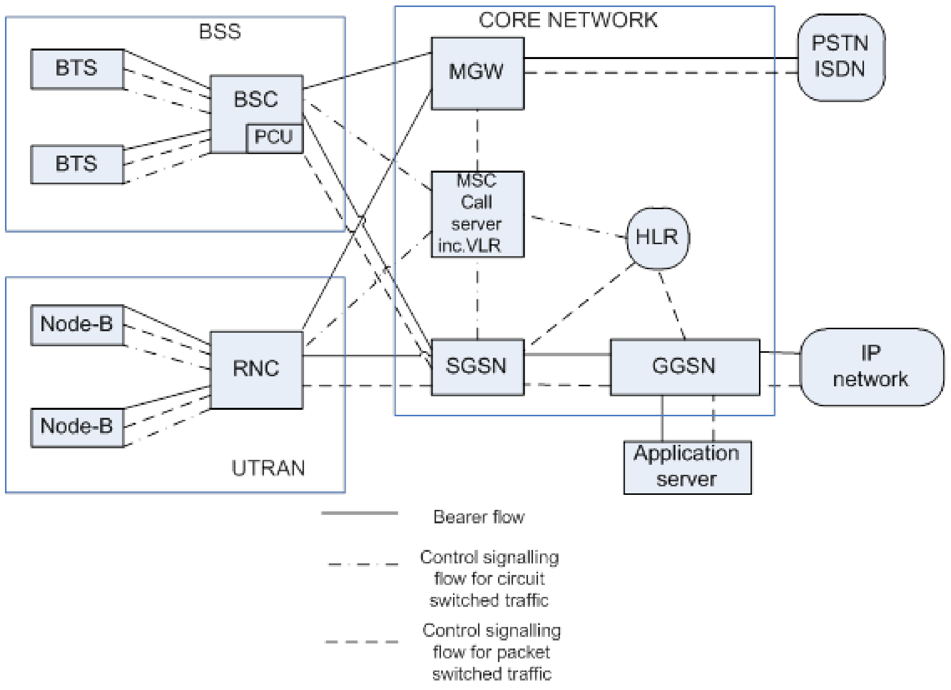
Table 3-3: Cost drivers for BSC and RNC and typical utilization factors.

Type of controller	Cost driver	Utilization
BSC	Number of TRX from all connected BTS	80 %
RNC	(a) Aggregated voice traffic during peak time (b) Aggregated number of 10, 100 and 1000 Mbps interfaces (c) Aggregated packet traffic performance in Mbit/s	80 %

3.3.2.2.2 Dimensioning of the connections between the controller locations with the core network locations

Concerning the dimensioning of the capacities for the logical connections to the core network, the model considers that the total GSM/UMTS traffic for circuit-switched services, mainly voice service, is directed to the media gateway (MGW) located at the corresponding core network site, while the signalling traffic is directed to the MSC call servers. Both user and signalling traffic of the 2G packet switched traffic is routed via the so-called Packet Control Units (PCU) of the BSC to the Serving GPRS Support Node (SGSN) and from there to the corresponding Gateway GPRS Support Node (GGSN). According to the UMTS Release 99, the same traffic flow applies for the 3G packet-switched traffic. For the 3G packet-switched traffic on HSPA, the model supports direct tunnelling whereby the SGSN is avoided and the traffic is directly routed from the RNC to the GGSN. The Figure 3-16 shows once again the appropriate functional blocks in the logical network. Concerning the dimensioning of the physical connections between the aggregation elements at the controller and the core network locations, the signalling traffic is neglected, due to the fact that its required bandwidth is small in comparison with the user traffic, and is covered by the proposed spare capacity based on the utilisation factors lower than 100%.

Figure 3-16: Logical connections between the functional blocks at the controller node locations and the locations of the core network based on specifications of the 3GPP Release 4 to 8



For determining the transmission systems for either a star or a ring topology, the same tasks have to be fulfilled and corresponding algorithms to be used as in the dimensioning and system allocation for the aggregation network (see Section 3.2.2.2).

For a star topology, the dimensioning includes the following tasks:

- Determine the total bandwidth requirement for each star or double star link;
- Increase this bandwidth by a mark-up factor which describes the limitation on the use of the systems and has been defined by the user for this network level;
- Calculate the mark-up factor (qMUF) and the equivalent bandwidth for the traffic of each traffic class based on the quality requirements (see Section 3.5);
- Provide the dimensioning of the star links based on a dimensioning table which contains the corresponding parameter values for each class, in the same way as it is done in the dimensioning of the aggregation network;
- Determine the appropriate transmission systems, as described for the aggregation network (see Section 3.2).

For a ring structure, the tasks are as follows:

- Determination of the total bandwidth requirement on the ring links, depending on whether the traffic in each direction is to be protected 50% or 100%;
- Increase this bandwidth with the mark-up factor which describes the limit in the utilization of the systems, which has been defined by the user for this network level;
- Determine the corresponding transmission systems, as described in the following.

The model implements ring topologies on the basis of well-known algorithms,[14] which have been used in previous analytical cost models[15]. Ring topologies are mainly used in the case that the operator constructs its own infrastructure for the transmission systems in the backhaul network. In this case the operator has to install on layer 1, so-called Reconfigurable Add-and-drop multiplexers (RADM) with which the traffic protection is carried out. The Ethernet ports in the aggregators at the controller and at the corresponding core network locations are linked with the corresponding Ethernet ports in the RADM. The network side ports of the RADM are connected to the ports of the corresponding transmission systems typically microwave. From the perspective of the model, an integrated equipment developing both functions (RADM and microwave) is assumed, as shown in Figure 3-17. Alternatively, leased lines with the corresponding bandwidth can be used instead of microwave equipment. The cost of the RADM hast to be included in the cost of the leased lines. Protection can be configured for values between 50% and 100% in both cases.

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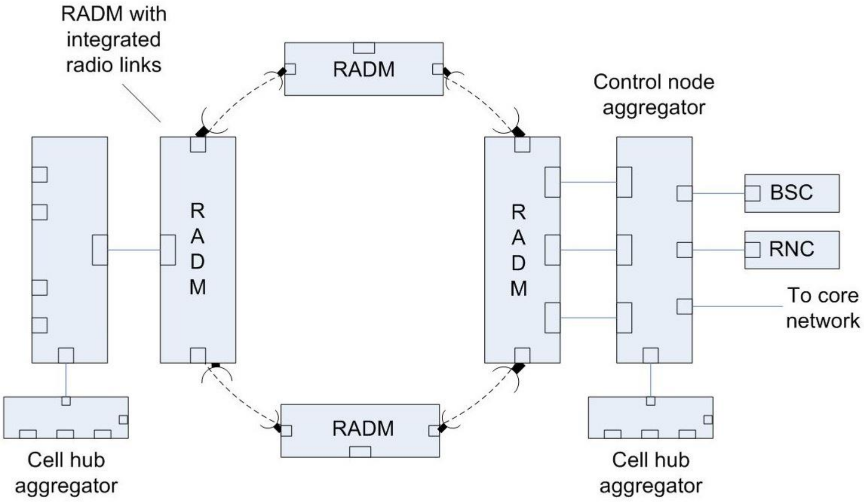
[14] See Lin et al. (1973).

[15] See WIK-Consult (2007, 2010).

Figure 3-17: Schematic representation of a ring topology on the basis of microwave with RADM



3.4 Core network

The core network consists of the functional units in the core node locations and the connections between them. In the core network, there are facilities that are dedicated to either voice or data as well as facilities that support both voice and data services. Due to the fact that the aim of this cost model is to determine the cost of terminating incoming voice calls, those facilities are primarily modelled to take over transport and switching functions for voice. However, facilities used for the control of data traffic are also dimensioned since these may affect the location of facilities used for voice. Facilities for data services that do not provide traffic control, such as the application servers, are not modelled. Below, in Section 3.4.4, Table 3-4 shows the complete list of facilities of the core network, which are considered by the model.

Voice traffic is possible both as circuit-switched and packet-switched traffic. In the case of circuit switched traffic, this traffic arises mainly in cell sites with GSM or UMTS equipment. In UMTS cell site locations with HSPA, voice traffic can also occur as packet switched VoIP traffic, which, as outgoing or incoming traffic, could be handed over at IP-interconnection points with IP-based networks (see Figure 3-15 in Section 3.3). Since this traffic is from a regulatory point of view not relevant, this type of voice traffic is not taken into account in the model for the estimation of the cost of termination.

The approach to the dimensioning of the core network differs according to whether GSM/UMTS circuit switched services or EDGE/UMTS packet switched services are to be handled. This is due to the fact that the model considers the corresponding GSM/UMTS circuit switched traffic in the form of fixed units (slots for GSM and voice quality line emulation for UMTS). For the transport of circuit switched traffic between the different locations of the core network, the circuit emulation is applied, given that all this traffic over packet switched facilities is, together with the pure packet switched data traffic, carried over the so-called Label Edge Routers (LER). It follows, that only the dimensioning of the circuit switched traffic, especially voice traffic, is dimensioned as a loss model, which is expressed by the classical Erlang loss formula. Note that GSM and UMTS voice traffic requires the same bandwidth (12,2 kbps) so that for dimensioning and cost purposes the two types of traffic need not to be distinguished. In the case of EDGE and UMTS, this packet traffic is expressed as the product of the packet rate times the packet length and the dimensioning is provided not by a loss model but by a queuing model where the delay and the packet loss limits are relevant.

3.4.1 Design of the core network systems for the GSM and UMTS circuit switched traffic

The core network locations (already determined as part of the modelling of the backhaul network) with their soft switch systems (media gateways) are the first points where traffic aggregation for GSM circuit switched services applies. This is important for the circuit switched services, given that the required bandwidth is dimensioned by the Erlang loss formula. Since the required capacity per traffic unit decreases in step with increasing traffic aggregation, it follows that in the case of high traffic aggregation for the Erlang traffic approximately one circuit per Erlang is required. The core network is dimensioned accordingly.

The two most important elements in the core network for circuit switched voice services are the media gateway and the MSC call server. The model assumes that the media gateway is installed in all core network locations, while the MSC call server is installed only in a limited number of the core network locations due to its high capacity in handling circuit switched connections. Anyway for protection reasons normally MSC call servers are installed at least two core locations. The dimensioning of the media gateway system in GSM and UMTS, as already shown, is based on the circuit switched traffic in the BH. In contrast, the dimensioning of the MSC call server is based on the BH calling rate due to the fact that they are only carrying out signalling functions. The traffic loads include all three types of voice traffic (on-net, off-net outgoing and off-net incoming).

For the circuit switched on-net and off-net incoming traffic, the model estimates a traffic matrix, which provides the corresponding traffic values routed between the different core node locations. The off-net outgoing traffic is not included in this matrix because it is assumed that it is routed by the base stations to the geographically nearest core node location which provides interconnection to other networks, where it then leaves the network.

The number of core node locations where interconnection with other networks is available is controlled by an input parameter. The locations with the highest traffic load are considered as candidates. For the off-net traffic, corresponding interface cards in the media gateways are installed. The model distinguishes between two types of cards according to whether they are cards for the part of the voice traffic handled by circuit switched technology, or for the part of the voice traffic that is handled by packet switched technology. The shares of the two types of traffic can be determined by a parameter.

The calculation of the traffic loads on the different links between the core node locations is carried out using relative traffic weights obtained from the traffic matrix. For clarification, Figure 3-18 shows an example for the on-net traffic distribution in three locations, through which an on-net traffic of 500, 300 and 260 Erlangs is routed.[16] In the case of 500 Erlangs, and assuming that the incoming and outgoing traffic are similar, 250 Erlangs of incoming traffic and 250 of outgoing traffic are distributed over the three locations based on their weights: 71 coming and outgoing Erlangs to the 300 Erlang location, 61 incoming and outgoing Erlangs to the 260 Erlang location, and 118 incoming and outgoing Erlangs to the 500 Erlang location, i.e. to its own location, for which no traffic arises that must be routed over connections. For the other two locations, the traffic distribution problem is solved in the same way.

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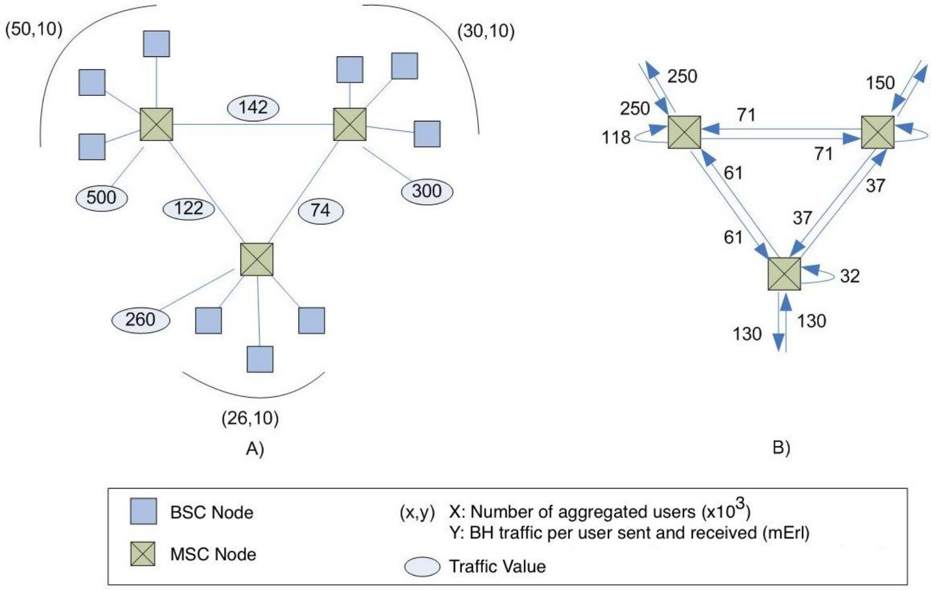
[16] Note that the model considers symmetry for on-net traffic due to the fact an outgoing on-net call from a cell phone causes always an incoming call to a cell phone in the same network.

Figure 3-18: Traffic distribution of the On-net traffic from three locations with 500, 300 and 260 Erlangs:
A) Traffic allocation to the sites
B) Traffic pattern after routing



The representation of the off-net incoming traffic, i.e. incoming termination traffic, on the transport routes of the core network would be analogous to those in Figure 3-18, with the exception that the incoming traffic does not come from the BSC locations, but it comes from other networks.

The core network treats the UMTS circuit switched services traffic in a similar way as the GSM traffic. For this purpose, both technologies use in the core network virtual connections based on MPLS tunnels applying similar bandwidths for voice connections from both UMTS and GSM units.

As already mentioned, the network's outgoing off-net traffic is routed to the nearest interconnection point with other networks. The number of interconnection points is set by an input parameter, while their locations are determined endogenously on the basis of relative traffic weights. The volumes of the incoming off-net traffic, which are the ones to be terminated, are assigned to the core nodes with interconnection facilities also on the basis of the relative traffic weights, and distributed from these again according to relative traffic weights to their receiver core locations.

3.4.2 Core network systems for the EDGE/UMTS data traffic

As already explained above, the packet switched traffic, consisting of data traffic and VoIP, is not dimensioned according to a loss model, but following a queue model.

The total data traffic consists of both data traffic generated in the BTS cells of the GSM/EDGE network and data traffic coming from the cells of the UMTS/HSPA network. Data traffic requires mainly connections from EDGE/UMTS/HSPA users to data applications, which are provided by so-called application servers located at core network locations of its own network or at locations of other networks.

The data traffic with destination to an application server in the own network is routed to the geographical nearest core network location where a corresponding server is installed, which is typically the core network location with the highest volume of traffic. The number of sites where the application servers are installed is determined by an input parameter, while for the locations the core nodes with the highest traffic loads are used. The data traffic with destination to an application server located in a different network is routed to the geographical nearest core node location with interconnection facilities. Its distribution is carried out in a similar way to that which has been described above for the off-net outgoing voice traffic.

The above specifications regarding application servers apply only to the volumes of data which are routed over the links connecting the corresponding network nodes, so that the links can be dimensioned properly; they do not apply to the determination of the capacity of the application server themselves, due to the fact that, as already mentioned, they do not carry out any functions for the voice traffic and are therefore not relevant for the determination of the cost of terminating calls.

3.4.3 Topology of the core network and dimensioning of the physical network

The model allows the selection of two different core network topologies, fully meshed or ring. In the case of a fully interconnected topology, both on-net traffic and off-net traffic are routed at most over two core network locations that are directly connected. In the case of a ring topology, both traffics, if necessary, are routed over one or more intermediate nodes.

The off-net traffic, to and from the interconnection points, as well as the on-net traffic between the core network nodes, are aggregated in the Label Edge Routers (LER), and routed over the Label Switch Routers (LSR) in the case of a ring topology. The interface cards of the physical layer depend on the type of implementation.

Regarding the physical layer, the model assumes that connections are implemented by one of the following options:

- Ethernet based leased lines (pseudo wire) that are directly connected to the LER routers with the corresponding interfaces, applicable in the case of a fully meshed topology, or
- Own-built physical infrastructure, such as RADM or ROADM, that have an Ethernet Interface to the LSR and are connected to the network through leased lines on an electrical or optical basis, applicable in the case of a ring topology.

In the case that the connections are implemented based on leased lines, a fully meshed topology with N*(N-1)/2 links is considered; further it is taken into account that the capacities of the physical links are symmetric. When the second option is chosen, a ring topology with exactly N links is implemented.

In the dimensioning process of the core network links, the capacity is increased by the global Mark-up-Factor, which is set by the user and which is also used in the aggregation and backhaul networks. The individual mark-up factors of the different service categories are calculated in the same way as for these two network parts.

Concerning the assignment of systems to the physical links for the first option, the model proceeds in the same way as in the case of the aggregation and backhaul networks. For the second option, LSR routers are used, which are connected by leased lines to a ring topology. Here again a protection of the ring capacity of either 50% or 100% can be selected. From this follows that the required bandwidth on the links of the ring is equal to the sum of the maximal bandwidth requirements on each of the asymmetrical logical connections.

3.4.4 Design of additional core network units

In addition to those already treated, the core network consists of the following facilities:

- Serving and Gateway Support Nodes (SGSN, GGSN),
- Different types of server, such as for SMS and MMS,
- Registers for the control plan (EIR, VLR, HLR), and
- Systems for IN network management functions, including STP functionalities.

Table 3-4 shows all the functional facilities considered for the core network and (in the second column) the cost drivers for their dimensioning. The third column indicates for the facilities needed for voice, with which utilization ratios they are installed, which through the corresponding mark-up-factors implicitly determine the required reserve capacities.

Table 3-4: Summary of the functional elements in the core network together with their driver units

Equipment	Driver for the dimensioning	Utilization ratio	Comments	Where installed
Media Gateway	Number of Ethernet ports, BH traffic	70 %		At all locations of the core network
MSC Call Server including VLR	BHCA	67 %		Input
HLR with Authentication Centre	Number of subscribers, BHCA	80 %		Input
EIR	Number of subscribers	80 %		Input
SMSC/MMSC	Number of SMS/MMS / s	80 %		Input
SGSN	(a) BHCA (b) Number of attached subscribers (c) Throughput, in Mbps	N/A		Input
GGSN	(a) Throughput, in Mbps (b) PDP context	N/A		All locations of the core network with IP interconnection
MGW Interface card to the PSTN/ISDN/PLMN for packet switched voice traffic	Number of Ethernet ports	80 %	The factor $1-\alpha_{cc}$ determines the relevant share	All locations of the core network with PSTN / ISDN interconnection
MGW Interface card to the PSTN/ISDN/PLMN for circuit switched voice traffic	Number of E1 ports	80%	The factor α_{cc} determines the relevant share	At all locations of the core network with PSTN / ISDN interconnection
Main connection devices (aggregators, Label Switch Router, Label Edge Router)	Required bandwidth	80%		At all locations of the core network
IN	(a) BHCA (b) Number of subscribers	80 %	Exerts control on the origination of the service and during the corresponding connection	Input
OAM	Considered in OPEX	N/A		N/A
Billing	Considered in indirect costs	N/A		N/A
Network management system (AAA, DNS, functions, etc.)	BHCA for all services	80 %		Input

The number of servers for EIR, HLR and SMS/MMS as wells as of application server locations is determined by the user of the model based on parameter values. The model assumes that the EIR and the HLR are installed at a subset of the core network locations, mainly the ones with the highest traffic load. For reasons of network availability, in case of partial failure of the network, at least two registers are used, where each of them can handle the total control traffic demand. The model considers that GGSN units are installed in all core network locations where interconnection to an IP network is provided, while the number of locations with SGSN facilities is an input parameter. In practice, the VLR is part of the MSC call server and is thus installed at all the core network locations where a MSC call server is installed. The driver units for their dimensioning are the BH call attempts.

3.5 Summary description of the concepts to ensure redundancy and QoS

Redundancy and QoS are related to each other but have logically to be treated separately. Redundancy allows avoiding the total loss of service in case that part of the network fails, while QoS aims at maintaining a constant quality even when traffic load fluctuates while taking into account the cost that go along with this. In practice, the two objectives overlap, because additional capacity must be considered to simultaneously serve both of them.

3.5.1 Implementation of redundancy and QoS guarantee in the model

The model provides the following options for redundancy and avoidance of congestion, which can be adjusted depending on the circumstances:

(1) Connection of controller locations to two core network locations (double star),

(2) In a ring topology, facilities with a protection of either 50% or 100%, and in a double star topology with a degree of protection between 50% and 100%, and

(3) Reducing the utilization degree of the equipment by over-dimensioning the global capacity of the transmission links.

The over-dimensioning option (3) serves on the one hand to guarantee a given grade of QoS, while on the other it also supports redundancy when in the case of failure of parts of the network, the amount of traffic routed over the alternative links in the options (1) and (2) also increases traffic in other parts of the networks. The option is available for the links between the nodes of the different hierarchical levels of the network, and is determined by the global mark-up factors for each level, determined by the inverse value of the maximum utilization factor. Our observation is that operators apply utilization factors between 0.65 and 0.85, which implies that the mark-up factors are in the range between 1.54 and 1.18. Table 3-5 shows the values of the mark-up factors implemented in the model for different levels of the network. If a certain degree of redundancy in the transmission systems is achieved, a corresponding degree is also obtained in the aggregation and routing server equipment.

Table 3-5: Values of the global Mark-up Factors to achieve redundancy at the various network levels

Connection Type	Global Mark-Up-Factor
Cell site – Cell-Hub	1,3
Cell-Hub – Controller	1,51
Controller – Core-Network node	1,51
Between Core-Network nodes	1,48

Regarding the redundancy approaches used for specific equipment, the model provides the options listed in Table 3-6.

Table 3-6: Approaches to achieve redundancy for the equipment on the different network levels

Network level	Approach to achieve redundancy
Controller	At least two BSC and RNC sites
Backhaul network	Assignment of the controller locations to two core network locations for those controllers that are not collocated with core network nodes (double star) and optional routing of 50% or 100% of traffic to each location. In the case of the implementation with own infrastructure, ring topology over microwave links or leased lines and traffic routing 50% or 100% in each direction.
Core network	At least two HLR and MSC Call Server, ring topology with 100% protection.

The model does not provide for any specific redundancy for the cells of the radio access network. This follows from the cost implications of redundancy in this part of the network. As the radio access network causes the largest share of total costs, redundancy would increase considerably the costs without any improvement in service availability. It is worth mentioning that redundancy has never been considered in the PSTN/ISDN subscriber access network.

3.5.2 Quality differentiation and equivalent bandwidth

The different quality requirements of the different services are expressed at the logical and physical levels by different bandwidth requirements and through different costs. In order to take into account the different quality requirements, different methods are used which are included in the dimensioning process of the model by corresponding approximations.

The model uses queue systems with Poisson packet flows and, therefore, the service-related QoS is modelled by a single parameter, namely, the average delay time of a packet between a terminal and the corresponding core node[17]. By means of internal parameters, this waiting time is distributed over the different network levels, and a corresponding dimensioning of the required bandwidth for the aggregated traffic of each service class is carried out. The sum of the bandwidths over all classes of services gives the required QoS bandwidth, also known as equivalent bandwidth. This bandwidth is larger than that resulting from the mean values of the services, that is, the coefficient between the mean and the QoS bandwidth is lower than one. However, experience with

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[17] See Akimaru and Kawashime (1999).

network dimensioning shows that the QoS bandwidth is lower than the mean bandwidth multiplied by the Global Mark-up-Factor, that is, the Global Mark-up-Factor is dominant in the dimensioning of the network.

For the modelling approach, these considerations result in the following situation: The starting point for the bandwidth requirements are the average traffic values of a service, given that they describe the minimum capacity requirement to be realised. However, these average values are not yet sufficient for the dimensioning of the network and need to be increased according to the two following considerations (of which only the dominant one is applied):

- In order to securing network operations against unpredictable short-term traffic peaks, the network facilities of the packet switched networks are not utilised to the full, i.e. utilization rates are set between 65% and 85%.[18] Note that congestion avoidance and control is mainly required in TCP/UDP/IP networks and requires often a network design where the equipment and transmission lines are dimensioned under a percentage between 60 and 80%,
- Due to both the traffic characteristics of the packet stream that the relevant service generates and the corresponding length of the packets, the bandwidth values that follow from the QoS requirements are, as shown above, usually above the mean values of the bandwidth. That is, the consideration of the QoS requirements, which minimise the average delay in the network elements, makes bandwidth values necessary which are above the mean values. However, it should be noted that for network elements with high traffic aggregation, large values of bandwidth arise which may be in the range from 100 Mbps up to the Gigabit range. Since the processing time of a packet lies in the range of micro or nano seconds, the delay in the buffer is also shorter than the maximum delay resulting from the QoS requirements. Therefore, from a QoS theoretical point of view, the relevant systems can be intensively used while nevertheless the quality requirements of each service remain fulfilled. This means that in this case the capacity increase due to the global utilization rates dominates and not the one resulting from the QoS requirements.

This interrelationship is taken into account when the individual utilization rates are specified for each network level.

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[18] For more details see RFC896 (1984); see also Jacobson (1988).

4 Determination of the cost of termination

4.1 The cost standard of Pure LRIC

The recommendation of the EU Commission of 7 May 2009[19] states that the determination of the cost of termination should be carried out on the basis of a “pure incremental costs approach” called “Pure LRIC”. Accordingly, the cost of termination to be determined is the cost that an operator would not incur if it did not offer the service of termination to third parties. This cost corresponds to the difference between the long-run costs of an operator when all services are provided and the long-run costs of all services without the provision of this service.

An important feature of the Pure LRIC approach to the determination of the cost of termination is that the inclusion of a general mark-up for enterprise-wide common cost is not allowed. This means that only those costs are recognised that are incurred when to the hypothetical case of the provision of all the services without termination, this service is also added. This may include cost elements of a common cost nature if it is evident that they have been caused by the fact that termination is provided.

The concept is illustrated in Figure 4-1 showing an example with the volumes of three services of a mobile operator, i.e. z = GB of data, y = billions of SMS and x = termination minutes. The incremental cost of the termination service arises from the difference between the total cost of all the services minus the total cost of all services without the termination minutes x.

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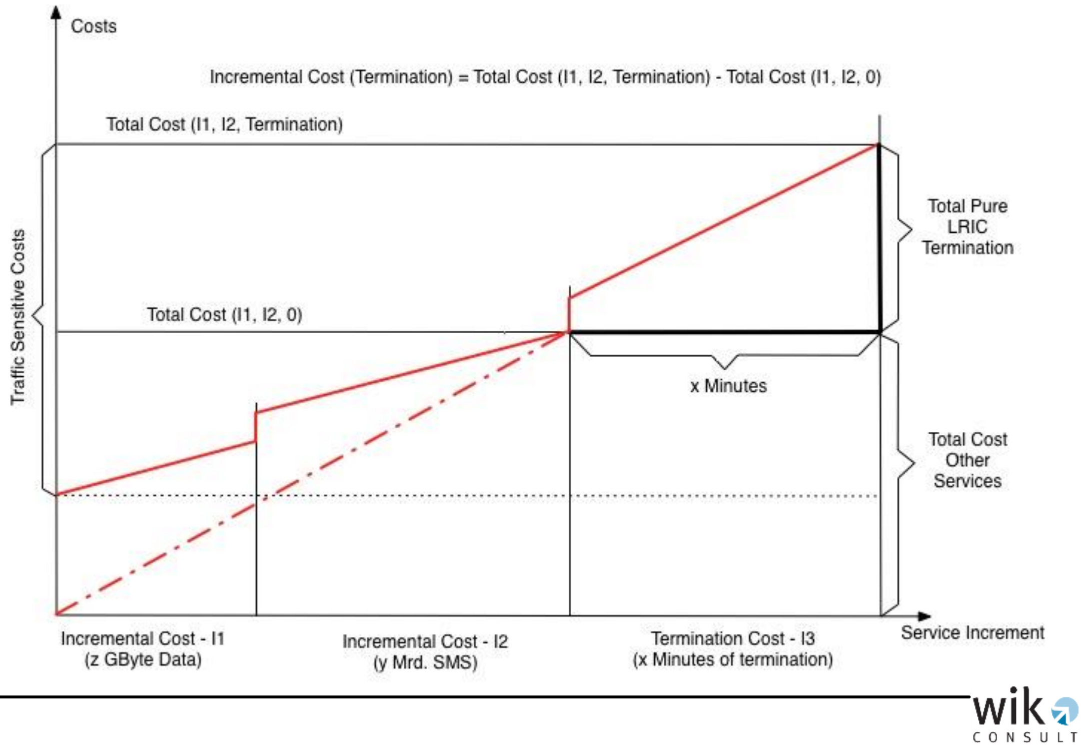
[19] See EU Commission (2009).

Figure 4-1: Pure LRIC of termination



4.2 Requirements for determining cost in the model

The starting point for the cost calculation process is the list of systems and facilities and their corresponding quantities, which has been determined within the network planning module. Network costs consist of the annualised CAPEX and OPEX values. In the case that the LRAIC approach is used, a general mark-up for overhead costs would be added, which, however, is not required when using the Pure LRIC approach. In the case that part of the capacity is leased, which mainly applies to transmission systems, corresponding rental amounts are applied instead of CAPEX and OPEX that would arise if the operator had installed its own facilities. In the following sections we will describe our approaches to determine these costs and the derivation of the applicable share for termination.

As far as information from the network planning tool is concerned, the volume of minutes of termination must also be provided by it. This information is obviously needed to determine the cost per minute, based on Pure LRIC, once the difference in total cost – with and without termination – has been calculated.

Additional input data that is required for the cost determination, and their sources are the following:

- Leased line prices – Source: ILR;
- Price of equipment and systems – Source: Operators and international benchmarks
- Lifetime of systems and equipment – Source: Operators, ILR and database of WIK
- Value of the WACC to determine the annualised CAPEX – Source: ILR
- Information on OPEX – Operators and database of WIK.

4.3 Annualised CAPEX

The first step to determine the annualised CAPEX in a bottom-up model is to determine the value of the network facilities determined by the network planning module. Due to the fact that this valuation is based on the current prices of the assets, the result represents the value of a completely new network. This is consistent with the conceptual approach according to which the costs of the network are to correspond to those that must be incurred by an operator newly entering into the market.

Derived from the investment values of the network assets, annual amounts for their amortization are calculated, where these amounts must cover both the depreciation and the interest of the capital provision. As it is standard in bottom-up models, the annuity approach as described below is used.

For each type of equipment it is proceeded as follows. We denote by I the investment value at the time of the installation, and with A the annual amount of revenue that must be generated for the amortization of I. Furthermore, we let i to be the interest rate, define $q = 1 / (1 + i)$, and denote by n the economic lifetime of the asset. The following relation must then hold in order to assure that both the amortization of the invested capital and the required interest is generated:

$$I \quad = \quad A * [q + q^2 + \ldots + q^n] \;.$$

For above the assumption is used that the residual value of the asset at time n is negligible. From the above formula it follows that

$$A \quad = \quad c * I \,,$$

where

$$c \quad = \quad 1 / [q + q^2 + \ldots + q^n] \quad ,$$

or by means of an algebraic transformation,

$$c \quad = \quad (1/q) * [1 - q] / [1 - q^n] \; .$$

For this calculation, the interest rate (usually in the form of the weighted average cost of capital, or WACC) and the expected life-time of the investment should be known. A particular property of this approach is that the amortization amounts A remain the same over the economic lifetime of the asset.

During the economic lifetime of a facility, two parameters usually change, which have a considerable impact on the levels of costs during this lifetime, i.e. the changing volumes of output determining the rate of utilization of the facility over time, and the prices for the facility changing over time. Insofar as these changes can be forecast, they are to be taken into account in the prices setting process. This is justified by the fact that a future potential competitor, whose price setting behaviour is to be anticipated, would base its decisions on these conditions. In the annuity formula, these anticipated developments are incorporated by redefining q as follows:

$$q \quad = \quad [(1+g)*(1+\Delta p)]/(1+i)$$

where

g = forecast average rate of change of the output volume of the system during the economic lifetime of the asset, and

Δp = average expected rate of change in the price of the facility (as a modern equivalent equipment) during the economic lifetime of the asset.

By replacing corresponding values for q in the equation

$$I \quad = \quad A * [q + q^2 + \ldots + q^n],$$

one obtains the amortization amounts A for the successive years, which change ceteris paribus from year to year according to the factors (1+g) and (1+Δp). That way, it is assured that the same amount of amortization is ascribed to every *future unit* of output as a *unit produced at present*, evaluated at the then current price of the input. From the above follows that the amortization amounts A of future periods can be larger or smaller than the present value depending on whether g and Δp take positive or negative values, or whether the value of $(1+g)*(1+\Delta p)$ is greater or smaller than 1. The value to be expected for Δp is negative in the case of equipment undergoing rapid technical progress, while in the case of facilities with a technical progress corresponding the economy at large it will rather be positive, in line with general inflation. In respect of g, when utilization is relatively low at the beginning of the investment cycle but increases with time, the value of this parameter will be positive; it will be negative if the time profile of utilization is the opposite, being relatively high at the beginning and decreasing with time.

The approach described above, taking into consideration the changes in the output and the development of the prices of the assets over time, corresponds to the economic depreciation since the amounts of amortization are determined in such a way that they correspond to the loss of value of the asset during each period of its economic life. At the same time, it also meets the requirement of being the basis for non-discriminatory prices. This last aspect results in particular also from the fact that the interest burden is calculated on the basis of the average of capital invested in the asset over its lifetime, which is the precondition that the cost of the asset include the amount of interest that in each year is proportional to the output quantity and the value of the investment used for it.

4.4 OPEX

In bottom-up cost models, this type of costs is usually not directly derived on the basis of the activities causing them, since the required information is as a rule not available to external observers. It is therefore common practice to determine OPEX in the form of a percentage mark-up factor on the investment value of the relevant facilities. For the values of these percentage mark-up factors, WIK relies on experience values that have been compiled in the course of previous projects.

OPEX is thus determined according to the following equation:

$$O_i = ocf_i \, I_i$$

where

O_i = OPEX for the type of asset i,

I_i. = Total investment of the asset type i,

ocf_i = Factor that determines OPEX as a percentage of the investment value of the asset type i, and

I = *Index of all types of assets.*

4.5 Special aspects of cost estimation

This section deals with the cost implications of four aspects that have so far not been specifically dealt with. These aspects arise (1) when capacity is externally procured (leased lines in particular), (2) when part of infrastructure is shared with other operators, (3) when additional spectrum is needed in the production of the termination service, and (4) due to the presence of termination-specific overhead:

(1) For the externally contracted capacities the corresponding rental amounts, which must be based on the specific rental rates in Luxembourg, are applied instead of the corresponding CAPEX and OPEX that would otherwise have to be determined, i.e. when own facilities are installed.

(2) In the cases where the assets of the infrastructure (for example the masts) are shared with other operators, the cost of the assets are assigned only partially to the modelled network. The shares to be applied in this case are derived accordingly to the given conditions of usage, for which experience values available in WIK's database can be used or information provided by the operators.

(3) Since termination of voice connections constitutes a relatively small part of the activity of a mobile network, in most cases no additional spectrum is needed for the provision of this activity. Therefore, in general there are no additional frequency costs caused by termination. However, should the case arise that additional spectrum for the provision of termination were required, that is, in addition to the situation where there is no termination, this additional spectrum would be added to the existing one and tagged with the relevant price. The resulting cost would be included in the model run for total output including termination so that it would also be reflected in the Pure LRIC determined for this service.

(4) The Pure LRIC approach does not foresee a general mark-up for company-wide overhead. However, overhead cost components that are directly associated with the provision of termination should be included in the cost calculation. The information for such termination-specific overhead cost is to be provided by the operators. As in respect of the preceding position, the resulting cost component would be included in the model run for total output including termination so that it would also be reflected in the Pure LRIC determined for this service.

4.6 Determination of the total costs and costs of a service

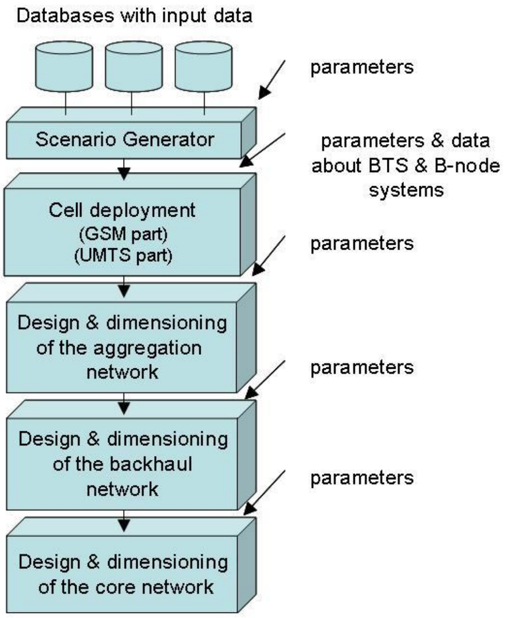
As already pointed out earlier, in the Pure LRIC approach the cost of terminating calls in the mobile network is derived by determining the difference of the total costs of providing services, on the one hand including the termination service and on the other excluding this service. In the case with termination the total cost consists of the sum of annualised CAPEX and OPEX of all the relevant assets used plus the termination-specific overhead cost, in the case without termination the total cost consists of the sum of annualised CAPEX and OPEX of the then relevant assets without adding any overhead costs. The difference between these two total costs is then the cost of this service, the cost per minute results from the division of this difference by the volume of termination in minutes.

5 Characteristics of the software tools

The model is provided in form of a software tool where all algorithms for network design are implemented by a high level programming language (C++) and compiled under the Microsoft Visual Net concept in form of separate modules for each of the blocks of functions. The C++ functional modules and their corresponding compiled DLLs (Digital Link Libraries) establish a direct communication with an MS Excel based master program (EXCEL-CP) which provides all the additional functionalities associated with an advanced user-friendly program interface with data analysis and management capabilities. The master program also contains the cost module which has completely been written in MS Excel.

The MS Excel master program controls the functional modules written in C++, which corresponds to the five major tasks of the network planning model. Figure 5-1 shows these five modules and the linear relationships between them.

Figure 5-1: Structure of the functional modules for the network dimensioning



Each module receives a set of data files and associated parameters that it needs to carry out its function. These sets are partly inputs from preceding modules while the rest are parameters required by the concrete module scenario. The MS Excel-CP solves all the interrelations between the DLL modules, manages the results from the previous modules and introduces the new parameters specifically related to the current module scenario. After having finished the calculations, all data which drive the corresponding cost calculation are provided to the cost calculation module. The calculations in the MS Excel-CP are linear – there are no loops or iterations – so that it could be programmed in MS Excel without any complications.

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Appendix: List of technical input parameters

The appendix shows the parameters which are used to design and dimension the modelled mobile network. The shown values for the technical parameters are accepted state-of-the-art standard values. For other values that are not of a strictly technical nature, sample values are shown. Examples are the frequency bands to be used, the volumes of demand for the different services per user, relative prices of equipment and facilities that enter into the decisions for a cost-effective deployment of equipment and facilities. In other cases, not even sample values are shown, given that only Luxembourg-specific values would make sense. Examples for this are parameters with which to determine the geographic location of motorways. In both cases, values specific to the Luxembourg market will have to be used in the actual application of the model.

The list is not necessarily conclusive. According to specific requirements in the case of Luxembourg, it may be necessary that additional parameters are used or that some of those shown are not needed. It also holds generally, that the shown values correspond to our current state of knowledge and that different values may be used in the completed model. For this, the operators will be consulted when the need arises.

Note that there is one difference in notation between this appendix and the text. For technical reasons of programming, the term “district” is used in the appendix instead of the term “zone” used in the text.

The appendix is subdivided as follows:

A-1 Cell deployment

A-1.1 Common files

<scenario_name>.fic

	Name	Comment
1	scenario_name	Scenario name
2	<scenario_name>_cities.txt	File containing areas parameters
3	<scenario_name>_BTS.txt	File containing BTS information for GSM deployment
4	<scenario_name>_general.txt	File containing general parameters
5	<scenario_name>_services.txt	File containing services parameters
6	<scenario_name>_mobile.txt	File containing mobile terminal parameters
7	<scenario_name>_NodeB.txt	File containing Node B information for UMTS deployment
8	<scenario_name>_3G_mobile.txt	File containing 3G mobile terminal parameters
9	<scenario_name>_3G_radio.txt	File containing UMTS radio parameters
10	<scenario_name>_harea.txt	File containing highways & roads parameters [OPTIONAL]

<scenario_name>_cities.txt

Name	**Type**	**Comment**
First Line		
n_cities	Integer	Number of areas
For each District		
First Line		
District_name	String	Name of the area
Second Line		
n_districtid	Int	Area identifier
n_hab	Int	Number of inhabitants of the area (≥ 0)
fl_ext	Float	Extension in Km^2 of the area (≥ 0)
fl_dutper	Float	Percentage of high dense populated terrain
fl_sutper	Float	Percentage of medium dense populated terrain
fl_restper	Float	Percentage of low dense populated terrain
fl_dupper	Float	Percentage of population in high dense populated areas
fl_supper	Float	Percentage of population in medium dense populated areas
fl_respper	Float	Percentage of population in low dense populated areas
fl_flattper	Float	Part of the area in a flat terrain (in Km^2)
fl_hilltper	Float	Part of the area in a hilly terrain (in Km^2)
fl_montper	Float	Part of the area in a mountainous terrain (in Km^2)
n_bheight_urb	Int	Average building height in high dense populated area (m)

Name	**Type**	**Comment**
n_bheight_sub	Int	Average building height medium dense populated area (m)
n_bheight_res	Int	Average building height low dense populated area (m)
Not used		**NOT USED**
n_districtproptype	Int	Type of area for radio propagation studies: 0 High dense, 1- Medium dense, 2 Low dense
fl_tLoss	Float	Terrain Loss by Orography. Range = (-1000, +1000) [dB]
Not used		**NOT USED**
fl_x	Float	X Coordinate in UTM or Degrees
fl_y	Float	Y Coordinate in UTM or Degrees
n_urb_GSM_UMTS	int	Deployed technology in high dense populated area (0=GSM/GPRS / 1=GSM/EDGE / 2=UMTS / 3=UMTS/HSPA / 4=GSM/UMTS / 5=GSM/UMTS/HSPA)
n_sub_GSM_UMTS	Int	Deployed technology in medium dense populated area (0=GSM/GPRS / 1=GSM/EDGE / 2=UMTS / 3=UMTS/HSPA / 4=GSM/UMTS / 5=GSM/UMTS/HSPA)
n_res_GSM_UMTS	Int	Deployed technology in low dense populated area (0=GSM/GPRS / 1=GSM/EDGE / 2=UMTS / 3=UMTS/HSPA / 4=GSM/UMTS / 5=GSM/UMTS/HSPA)
N_boundary_red	Int	TRXs Boundary reduction factor (0=0%; 1=25%; 2=50%; 3=75%)

<scenario_name>_services.txt

First Line	Type	Description	Value
Fl_MarketPenetration	Float	Market Penetration in the Country	
fl_MarketShare	Float	Percentage of Market Share	
Next Line			
fl_BsUrbPerc	Float	Percentage of Business users in high dense populated Area	
fl_BsSubPerc	Float	Percentage of Business users in medium dense populated Area	
fl_BsRurPerc	Float	Percentage of Business users in low dense populated Area	
fl_PrUrbPerc	Float	Percentage of Premium users in high dense populated Area	
fl_PrSubPerc	Float	Percentage of Premium users in medium dense Area	
fl_PrRurPerc	Float	Percentage of Premium users in low dense populated Area	
fl_CrUrbPerc	Float	Percentage of Customer users in high dense populated Area	
fl_CrSubPerc	Float	Percentage of Customer users in medium dense populated Area	
fl_CrRurPerc	Float	Percentage of Customer users in low dense populated Area	

Next Line			
n_serv	integer	Number of Services. Each Service is specified in a single line	
For each Service			
n_service_id	Integer	Service identifier	
sz_service_name	String	Service name	
Fl_sdensity	Float	Service penetration (%) [0-1]	
fl_BS_Traffic	Float	Traffic in Erlang of a Business User	
fl_PR_Traffic	Float	Traffic in Erlang of a Premium User	
fl_CR_Traffic	Float	Traffic in Erlang of a Customer User	
fl_AcBW_UL	Float	Average bandwidth required for the service in the fixed network for Uplink (in Kbps)	
fl_AcBW_DL	Float	Average bandwidth required for the service in the fixed network for Downlink (in Kbps)	
fl_mLUL	Float	Average data packet length in bytes in Uplink	
fl_mLDL	Float	Average data packet length in bytes in Downlink	
fl_avsessiontime	Float	Average service session duration in minutes	
fl_m2m	Float	On-Net traffic ratio of the service	

fl_m2f	Float	Off-Net outgoing traffic ratio of the service	
fl_f2m	Float	Off-Net incoming traffic ratio of the service	
fl_m2icip	Float	Mobile to External IP Networks percentage of the service traffic	
Fl_m2mobserv	Float	Mobile to Internal IP Mobile Services percentage of the service traffic	
Fl_m2voipic		Mobile to External VoIP Networks percentage of the service traffic	
Fl_voipic2m	Float	External VoIP Networks to mobile percentage of the service traffic	
Fl_GoS	Float	Blocking probability	
N_QosClass	Integer	Service QoS Class	
Next Line			
For Each Service		3G RAB Definition	
fl_vb	Float	RAB binary rate	
fl_Sp_perc	Float	Ratio of user with static profile	
Fl_Mp_perc	Float	Ratio of user with multipath profile	
Fl_EbNoULSP	Float	Eb/No UL for static profile	
Fl_EbNoDLSP	Float	Eb/No DL for static profile	
Fl_EbNoULMP	Float	Eb/No UL for multipath profile	

Fl_EbNoDLMP	Float	Eb/No DL for multipath profile	
Fl_actfact	Float	Activity Factor	
Fl_orth_fact	Float	Orthoganlity factor	
Next Line			
For each Service		GSM/EDGE	
fl_sreduction	double	Load reduction service % (0-1]. Always greater than zero	
dummy	-	Future uses	
dummy	-	Futures uses	
Fl_slotspeed	float	Binary rate per slot	
N_nslotsUL	Integer	Number of slots Uplink	
nl_nslotsDL	Integer	Number of slots Downlink	
Fl_hybrid_perc	float	Ratio of traffic carried by the 2G technology in case of hybrid sites	
Fl_UMTS_perc	Float	Ratio of traffic carried by UMTS technology	
Fl_HSPA_perc	Float	Ratio of traffic carried by HSPA technology	
Next Line			
For each Service		GSM/EDGE	
Fl_MUF27_an_ub	Float	Upstream bandwidth mark-up factor for layer 2 overheads in the aggregation network	

Fl_MUF27_an_db	Float	Downstream bandwidth mark-up factor for layer 2 overheads in the aggregation network	
Fl_MUF27_an_ul	Float	Upstream packet length mark-up factor for layer 2 overheads in the aggregation network	
Fl_MUF27_an_dl	Float	Downstream packet length mark-up factor for layer 2 overheads in the aggregation network	
Fl_MUF27_bn_ub	Float	Upstream bandwidth mark-up factor for layer 2 overheads in the backhaul/core network	
Fl_MUF27_bn_db	Float	Downstream bandwidth mark-up factor for layer 2 overheads in the backhaul/core network	
Fl_MUF27_bn_ul	Float	Upstream packet length mark-up factor for layer 2 overheads in the backhaul/core network	
Fl_MUF27_bn_dl	Float	Downstream packet length mark-up factor for layer 2 overheads in the backhaul/core network	

<scenario_name>_harea.txt

	Name	**Type**	**Comment**	**Value**
	First Line			
	B_hrconsidered	Bool	0=not considered; 1=considered	
	Highways_agg	Int	0= no aggregated; 1=aggregated	
1	n_highways	Int	Total number of highways and roads	
	Fl_lenght	Double	Total length of railway and highway section	
	Fl_hw_tunnel_lenght	Double	Total length of highways tunnel	
	Fl_railway_tunnel_length	double	Total length of railway tunnels	
	Second Line			
For each highway				
2	n_ID_HW	Int	Highway ID	
3	fl_x_coord	Double	Highway “x” coordinate	
4	fl_y_coord	Double	Highway “y” coordinate	
5	fl_lenght	Double	Total length (km)	
6	n_popkm	int	User density per km	
7	B_techtype	Bool	Type of technology for a highway (0=GSM; 1=UMTS/HSPA)	

A-1.2 2G Files

	Name	**Type**	**Comment**	**Value**
	First Line			
	n_models	Int	Number of BTS types	12
For each BTS				
	Sz_name	String	Name of the type of the BTS	BTS_Macrocell_1Sector_1T
Next Line				
1	n_btsheight	int	Base Station Height (m)	30
2	n_radioch	Int	Number of radio channels. (n_radioch-n_handover-n_signalling > 0)	8
3	n_handover	Int	Number of handover channels	1
4	n_signalling	Int	Number of signalling channels	1
5	fl_btspower_tx	Double	Transmission power (>0) [W]	28.75
6	fl _btsFnoise_rx	Double	BTS noise figure. Range = (-1000, +1000) [dB]	2.13
7	fl _Loss_tx	Double	Cable losses + NetworkEq + Combiner (Transmitter)	3
8	fl _Loss_rx	Double	Cable losses + NetworkEq + Combiner (Receiver)	3
9	fl _bts_gain_pre	Double	Pre-amplifier gain. Range = (-1000, +1000) [dB]	0
10	fl _bts_gain_rx	Double	Receiver antenna gain. Range = (-1000,	16.5

	Name	Type	Comment	Value
			+1000) [dB]	
11	fl _bts_gain_tx	Double	Transmitter antenna gain. Range = (-1000, +1000) [dB]	16.5
12	fl _bts_cost	Double	Cost factor of the BTS	126
13	fl_cost_increment	Double	Additional cost per TRX in the same site	2.269
14	n_sect	Int	Number of sectors. (>0)	1
15	n_trx	Int	Number of TRXs per sector	1
16	b_av_urb	Bool	BTS type available in high dense populated areas. (0:No, 1:Yes)	0
17	b_av_surb	Bool	BTS type available in medium dense populated areas. (0:No, 1:Yes)	1
18	b_av_res	Bool	BTS type available in low dense populated areas. (0:No, 1:Yes)	1
19	b_av_dualb	Bool	BTS type available for Dual Band. (0:No, 1:Yes)	0
20	B_av_increment	Bool	BTS type available for increment (0:No, 1:Yes)	0
21	fl_increment	Double	BTS site increment factor.	0
22	b_av_classicd	Bool	BTS type available for deployment in districts(0:No, 1:Yes)	1
23	b_av_hrway	Bool	BTS type available for highway and railway (0:No, 1:Yes)	0

	Name	Type	Comment	Value
24	b_av_mculayer_urb	Bool	BTS type available for high dense populated areas macrocell layer (0:No, 1:Yes) (only 1 type)	0
25	b_av_mculayer_surb	Bool	BTS type available for medium dense populated areas macrocell layer (0:No, 1:Yes) (only 1 type)	0
26	b_av_mculayer_res	Bool	BTS type available for low dense populated areas macrocell layer (0:No, 1:Yes) (only 1 type)	0
27	Fl_m_factor	Double	Mark Up factor to increase the number of units (only units are affected)	1

<scenario_name>_general.txt

	Name	**Type**	**Comment**	**Value**
	First Line			
1	fl_1bulf	Double	1st band uplink central frequency. (>0) [MHz]	897.5
2	fl_1bdlf	Double	1st band downlink central frequency. (>0). [MHz]. fl_1bulf & fl_1bdlf must be in the same band	942.5
3	b_2b	Bool	0: Single band ; 1: Double band	1
4	fl_2bulf *	Double	2nd band uplink central frequency. (>0). [MHz]	1747.5
5	fl_2bdlf *	Double	2nd band downlink central frequency. (>0). [MHz]. fl_2bulf & fl_2bdlf must be in the same band	1842.5
6	Fl_1bBw	Double	Available bandwidth in 900 Band	8.6
7	Fl_2bBw	Double	Available bandwidth in 1800 Band (only if 2 band is enabled)	18.6
8	N_urb_reusefactor	Integer	Reuse factor in high dense populated areas	4
9	N_sub_reusefactor	Integer	Reuse factor in medium dense populated areas	4
10	N_rural_reusefactor	Integer	Reuse factor in low dense populated areas	4
	Second Line			
11	fl_ffm	Double	Fast fading margin. Range = (-1000, +1000) [dB]	0

12	fl_lnm	Double	Log. Normal fading margin. Range = (-1000, +1000) [dB]	10
	Third line			
13	Fl_build_loss	Double	Building penetration loss in high dense populated areas. Range = (-1000, +1000) [dB]	20
14	Fl_sub_reduction	Double	Building penetration loss in medium dense populated areas reduction factor. (0-1)	0.75
15	Fl_rural_reduction	Double	Building penetration loss in low dense populated areas reduction factor. (0-1)	0.75
	Fourth Line			
16	fl_urbancovperc	Double	For internal Purposes	1
17	fl_suburbancovperc	Double	For internal Purposes	1
18	fl_ruralcovperc	Double	For internal Purposes	1
19	fl_minimum_density	Double	Minimum population density evaluative	0
20	fl_picocell_increment	Double	Increment over Picocell in dense urban areas.	0.5
21	b_urban_macrolayer	Bool	Macrocell layer available in high dense populated area	1
22	b_suburban_macrolayer	Bool	Macrocell layer available in medium dense populated area	0
23	b_rural_macrolayer	bool	Macrocell layer available low dense populated area	0

<scenario_name>_mobile.txt

	Name	**Type**	**Comment**	**Value**
	First Line			
1	fl_tx_power	Double	Mobile Terminal tx. Power	0.125
2	fl_mobile_height	Double	Mobile average height [m] (>0)	1.5
3	fl_rx_noise	Double	Mobile receiving noise figure [dB]	2
4	fl_gain	Double	Mobile Terminal Gain [dB]	0
5	fl_skinloss	Double	Mobile skin loss [dB]	4
6	fl_missmatch	Double	Mobile mismatch [dB]	2

A-1.3 3G and HSPA files

<scenario_name>_NodeB.txt

	Name	**Type**	**Comment**	**Value**
	First Line			
	n_NodeB	Int	Total number of Nodes B	9
	For each Node B			
	First Line			
1	Sz_name[]	Char	Name of Node B type	NodeB_Macro_1S
	Second Line			
2	Fl_nb_height	Double	Node B height [m]	34
3	Fl_nb_ptx	Double	Node B transmission power [W]	40
4	Fl_nb_gain	Double	Node B gain [dB]	17.7
5	Fl_nb_cableloss	Double	Node B cable loss [dB]	2.3
6	Fl_nb_noisef	Double	Node B noise figure [dB]	4
7	N_sects	Int	Number of sectors per Node B	1
8	B_urb_av	Bool	Node B available for high dense populated areas	0
9	B_sub_av	Bool	Node B available for medium dense populated areas	1
10	B_res_av	Bool	Node B available for low dense populated areas	1
11	Fl_cost	Double	Cost factor of Node B	132
12	Fl_cost_increment	Double	Additional cost per carrier in the same site	2.162
13	B_hw_av	bool	Node B available for highway deployment	0
14	Fl_m_factor	Double	Mark Up factor to increase the number of units (only units are affected)	1

<scenario_name>_3G_mobile.txt

	Name	**Type**	**Comments**	**Value**
1	Fl_mt_height	Double	Mobile average height [m] (>0)	1.5
2	Fl_mt_ptx	Double	Mobile Terminal transmission power	0.125
3	Fl_mt_gain	Double	Mobile Terminal Gain [dB]	0
4	Fl_mt_loss	Double	Mobile total losses [dB]	3
5	Fl_mt_noisef	Double	Noise figure [dB]	6

<scenario_name>_3G_radio.txt

	Name	**Type**	**Comments**	**Value**
1	Fl_lognormal	Double	Log Normal Fading [dB]	10
2	Fl_UL_ii	Double	Uplink interference Ratio	0.66
3	Fl_Dl_ii	Double	Downlink interference Ratio	0.66
4	Fl_MI	Double	Interference Margin [dB]	3.01
5	Fl_ffading	Double	Fast fading margin [dB]	0
6	Fl_softhHO	Double	Soft Handover Gain [dB]	3
7	B_hdp	Bool	Dense building area [0=Yes / 1= No]	1
8	B_lcity	Bool	Large city [0=Small / 1=Large]	1
Second line (for UMTS)				
9	Fl_WB_850	Double	Bandwidth in 850MHz frequency band [MHz]	0
10	Fl_WB_900	Double	Bandwidth in 900MHz frequency band [MHz]	0
11	Fl_WB_1800	Double	Bandwidth in 1800MHz frequency band [MHz]	0
12	Fl_WB_2100	Double	Bandwidth in 2100MHz frequency band [MHz]	15
13	Fl_WB_2600	double	Bandwidth in 2600MHz frequency band [MHz]	0
Third line (for HSPA)				
14	Fl_WB_850	Double	Bandwidth in 850MHz frequency band [MHz]	0
15	Fl_WB_900	Double	Bandwidth in 900MHz frequency band [MHz]	0
16	Fl_WB_1800	Double	Bandwidth in 1800MHz frequency band [MHz]	0
17	Fl_WB_2100	Double	Bandwidth in 2100MHz frequency band [MHz]	15

18	Fl_WB_2600	double	Bandwidth in 2600MHz frequency band [MHz]	0
Fourth Line (for UMTS and HSPA algorithm)				
19	Fl_down_850	Double	Central frequency for downlink in 850 frequency band	847
20	Fl_up_850	Double	Central frequency for uplink in 850 frequency band	806
21	Fl_down_900	Double	Central frequency for downlink in 900 frequency band	942.5
22	Fl_up_900	Double	Central frequency for uplink in 900 frequency band	897.5
23	Fl_down_1800	Double	Central frequency for downlink in 1800 frequency band	1842.5
24	Fl_up_1800	Double	Central frequency for uplink in 1800 frequency band	1747.5
25	Fl_down_2100	Double	Central frequency for downlink in 2100 frequency band	2140
26	Fl_up_2100	Double	Central frequency for uplink in 2100 frequency band	1950
27	Fl_down_2600	Double	Central frequency for downlink in 2600 frequency band	2655
28	Fl_up_2600	double	Central frequency for uplink in 2600 frequency band	2535
Fourth Line (for UMTS Algorithm)				
19	B_av_multiband_urb	Bool	Multiband case available for high dense populated areas	1

20	B_av_multiband_sub	Bool	Multiband case available for medium dense populated areas	1
21	B_av_multiband_res	Bool	Multiband case available for low dense populated areas	1
Fifth Line (for UMTS Algorithm)				
22	B_algorithm_selection	Bool	Selection of monoband/multiband algorithm to run (0=Monoband/Multiband time limited; 1=Monoband/Multiband time unlimited)	1
23	B_3GTechnology	Bool	0 = UMTS and HSPA technology installed in separated units 1 = UMTS and HSPA technology integrated in the same units	1
24	Fl_min	Double	Minimum value for the UMTS algorithm threshold	0.99
25	Fl_max	Double	Maximum value for the UMTS algorithm threshold	1.01
Sixth line (for HSPA and UMTS Algorithms)				
26	B_urbflag_UL	Bool	For urban areas with UMTS and/or HSPA technologies: 0 = UL propagation limit taken into account; 1 = UL propagation limit not taken into account	0

27	B_subflag_UL	Bool	For suburban areas with UMTS and/or HSPA technologies: 0 = UL propagation limit taken into account; 1 = UL propagation limit not taken into account	0
28	B_resflag_UL	bool	For rural areas with UMTS and/or HSPA technologies: 0 = UL propagation limit taken into account; 1 = UL propagation limit not taken into account	0

A-2 Aggregation network

Scenario File:

<scenario_name>.scnan

Name	**Comment**
<scenario_name>_AN_param.txt	File containing general parameters
<scenario_name>_AN_system.txt	File containing tables for systems assignation
<scenario_name>_service.txt	File containing service parameters
<scenario_name>_outputBA.txt	File containing 2G districts information
<scenario_name>_output_2G_traffic.txt	File containing 2G traffic distribution per district
<scenario_name>_output3GBA.txt	File containing 3G districts information
<scenario_name>_output_3G_traffic.txt	File containing 3G traffic distribution per district
<scenario_name>_output_2G_HLR.txt	File containing highways & roads 2G information
<scenario_name>_output_2G_HLR_traffic.txt	File containing 2G traffic distribution per highway
<scenario_name>_output_3G_HLR.txt	File containing highways & roads 3G information
<scenario_name>_output_3G_HLR_traffic.txt	File containing 3G traffic distribution per highway
<scenario_name>_output_HSPA_BA.txt	File containing HSPA districts information
<scenario_name>_output_HSPA_traffic.txt	File containing HSPA traffic distribution per district
<scenario_name>_link_def.txt	File containing parameters for link classification

Parameters File:

<scenario_name>_AN_param.txt

Name	Type	Comments	Value
ncon	Integer	Number of controller locations	6
csconmax	Integer	Maximum number of sites per controller location	9400
epsilon	Float	Distance increment factor for re-assignation	1
dmin	Real	Minimum distance between controller locations	115
Not used		NOT USED	
nlconmax	Int	Maximum number of links per controller location	300
nlchmax	Int	Maximum number of links per cell hub location	50
lmax	Real	=2: Tree topology/ =10000: Star topology	10000
Minmuf_0	Real	Minimum Mark-Up factor for site – hub links	1,3
Minmuf_1		Minimum Mark-Up factor for hub – controller links	1,51
Not used		NOT USED	
Not used			
Not used	Integer		

Link Classification File:

<scenario_name>_link_def.txt

Value	**Type**	**Comments**
dloc	float	Maximum length of a local link
dreg	float	Maximum length of a regional link

Systems File:

<scenario_name>_AN_systems.txt

Name	**Type**	**Comments**	**Value**
First line:			
Nidsys2gcsch		Table size for pure 2G site – hub transmission systems	5
For Nidsys2gcsch lines:			
Index	Integer	Index of the transmission system	1
Name	Char	Transmission system description	RF1
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
Spec [MHz]	Float	Spectrum (in case of radio links)	3.5
Thr	Integer	Threshold for using the next system type	2
First line:			
Nidsys3gcsch		Table size for 3G and 2G/3G hybrid site – hub transmission systems	5
For Nidsys3gcsch lines:			
Index	Integer	Index of the transmission system	1
Name	Char	Transmission system description	RF1
Systype	Integer	System type of the transmission system	1

Name	Type	Comments	Value
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
Spec [MHz]	Float	Spectrum (in case of radio links) (in MHz)	3.5
Thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsysch		Table size for hub systems	5
For nidsysch lines:			
Index	Integer	Index of the system	1
Name	Char	Transmission system description	A
Systype	Integer	System type of the system	1
maxBW [Mbps]	Float	Maximum bandwidth of the system	30000
Bwportt1[Mbps]	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	2
Bwportt2[Mbps]	Integer	Bandwidth of Type 2 ports of the system (in Mbps)	100
Bwportt3[Mbps]	Integer	Bandwidth of Type 3 ports of the system (in Mbps)	1000
Bwportt4[Mbps]	Integer	Bandwidth of Type 4 ports of the system (in Mbps)	10000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	4
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	4
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	2
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	10
Thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsyschconstar		Table size for hub - controller transmission systems in case of star topology	7

Name	Type	Comments	Value
For nidsyschconstar lines:			
Index	Integer	Index of the transmission systems	1
Name	Char	Transmission system description	LLE2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
maxnport	Integer	Maximum number of ports of the transmission system	1
Bwport [Mbps]	Float	Maximum bandwidth per port of the transmission system (in Mbps)	100
Maxlength [Km]	Float	Maximum length between regenerators (in Km)	1000
Spec [MHz]	Float	Spectrum (in case of radio links) (in MHz)	0
Thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsyschcontree		Table size for hub - controller transmission systems in case of tree topology	7
For nidsyschcontree lines:			
Index	Integer	Index of the transmission systems	1
Name	Char	Transmission system description	LL2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
maxnport	Integer	Maximum number of ports of the transmission system	1
Bwport [Mbps]	Float	Maximum bandwidth per port of the transmission system (in Mbps)	100
Maxlength [Km]	Float	Maximum length between regenerators (in Km)	1000
Spec [MHz]	Float	Spectrum (in case of radio links) (in MHz)	0
Thr	Integer	Threshold for using the next system type	2

QoS Input File:

<scenario_name>_qosin.txt

Value	Type	Comments	Value
First line:			
nqos		Number of QoS types	5
For nqos lines:			
id	Integer	Index of the QoS type	1
taut	Real	Maximum end to end delay (one branch, i.e. between end user and core segment)	15
rtau1	Real	Ratio of delay over network level 1 (aggregation network, site to hub location)	0.81
rtau2	Real	Ratio of delay over network level 2 (aggregation network, hub location to controller location)	0.14
rtau3	Real	Ratio of delay over network level 3 (backhaul network, controller location to core location)	0.02
rtau4	Real	Ratio of delay over network level 4 (core network, core location to other core location)	0.03

A-3 Backhaul network

<scenario_name>.scnbn

Name	**Comment**
<scenario_name>_an_con.txt	File containing controller locations information
<scenario_name>_BN_param.txt	File containing general parameters
<scenario_name>_service.txt	File containing service parameters
<scenario_name>_BN_systems.txt	File containing tables for systems assignation
<scenario_name>_an_conport.txt	File containing controller ports information
<scenario_name>_an_nod.txt	File containing district information

General Parameters File:

<scenario_name>_bn_param.txt

Variable	Type	Comment	Value
Nswro	int	Number of core locations	2
conmax	Int	Maximum number of controller locations per core location	50
epsilon	float	For internal use	1
dmin	float	Minimum distance between core locations (in Km)	5
dswro	int	Controller assignment to core locations: 0: single core location assignment / 1: double core location assignment	1
Prot	Int	In case of double core location assignment: Applied protection: 0: 50% protection / 1: 100% protection	1
Muf2	float	Mark-Up factor for backhaul network	1.51
aring	Int	0: Star topology / 1: Ring topology	1
maxringnod	Int	Maximum number of controller locations per ring	5
rprot	Int	Ring protection: 0: 50% protection / 1: 100% protection	1

Systems File:

<scenario_name>_BN_system.txt

Value	Type	Comments	Value
First line:			
NidsysBSC		Table size for BSC systems	3
For NidsysBSC lines:			
Index	Integer	Index of the BSC system	1
Name	Char	Name of the system	BSC_1
1	Integer	1 (Not used)	1
maxBTS	Integer	Maximum number of BTS per BSC system	800
maxtrx	Integer	Maximum number of TRX per BSC system	800
maxbw	Float	Maximum bandwidth of the system (in Mbps)	688
thr	Integer	Threshold for using the next system type	2
First line:			
NidsysRNC		Table size for RNC systems	3
For NidsysRNC lines:			
Index	Integer	Index of the RNC system	1
Name	Char	Name of the system	RNC_1
1	Integer	1 (Not used)	1
maxNB	Integer	Maximum number of Nodes B of the RNC system	640
Maxbw	Float	Maximum bandwidth of the system	640

Value	Type	Comments	Value
Bwportt1	Integer	Bandwidth of Type 1 ports of the system	2
Bwportt2	Integer	Bandwidth of Type 2 ports of the system	155
Bwportt3	Integer	Bandwidth of Type 3 ports of the system	622
Bwportt4	Integer	Bandwidth of Type 4 ports of the system	1000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	60
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	14
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	16
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	1
thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsysconna		Table size for controller node aggregator systems	5
For nidsysconna lines:			
Index	Integer	Index of the system	1
Name	Char	Name of the system	A
Systype	Integer	System type of the system	1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	30000
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	2

Value	Type	Comments	Value
Bwportt2	Integer	Bandwidth of Type 2 ports of the system (in Mbps)	100
Bwportt3	Integer	Bandwidth of Type 3 ports of the system (in Mbps)	1000
Bwportt4	Integer	Bandwidth of Type 4 ports of the system (in Mbps)	10000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	4
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	4
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	2
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	10
thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsysconswrostar		Table size for concentrator – core location transmission systems in case of star topology	7
For nidsysconswrostar lines:			
Index	Integer	Index of the transmission systems	1
name	Character	Name of the system	LL2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
maxnport	Integer	Maximum number of ports of the transmission system	1

Value	Type	Comments	Value
Bwport [Mbps]	Float	Maximum bandwidth per port of the transmission system (in Mbps)	100
Maxlength [Km]	Float	Maximum length between regenerators (in km)	1000
Spec [MHz]	Float	Spectrum (in case of radio links) (in MHz)	0
Thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsysconswroring		Table size for concentrator – core transmission systems in case of ring topology	7
For nidsysconswrostar lines:			
Index	Integer	Index of the transmission systems	1
name	Character	Name of the system	LL2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
Bwport1 [Mbps]	Float	Bandwidth of Type 1 ports (CNA sided) (in Mbps)	100
Bwport2 [Mbps]	Float	Bandwidth of Type 2 ports (CNA sided) (in Mbps)	100
maxportLC1	Integer	Maximum number of type 1 ports per line card	1
maxportLC2	Integer	Maximum number of type 2 ports per line card	1
maxLC	Integer	Maximum number of line cards	6

Value	**Type**	**Comments**	**Value**
Maxlength [Km]	Float	Maximum length between regenerators (in km)	1000
Spec [MHz]	Float	Spectrum (in case of radio links) (in MHz)	0
Thr	Integer	Threshold for using the next system type	2

A-4 Core network

<scenario_name>.scncn

Name	Comment
<scenario_name>_bn_swro.txt	File containing core locations information
<scenario_name>_CN_param.txt	File containing general parameters
<scenario_name>_services.txt	File containing service parameters
<scenario_name>_CN_system.txt	File containing tables for systems assignation
<scenario_name>_bn_port.txt	File containing core locations port information

General Parameters File :

<scenario_name>_CN_param.txt

Variable	Type	Comment	Value
Nsmsc	int	Number of Core locations with SMS center	2
Nmsccs	int	Number of Core locations with MSC Call Server	2
npoipstn	int	Number of Core locations with POI to PSTN/ISDN	2
npoiip	Int	Number of Core locations with POI to the IP network	2
napserv	int	Number of Core locations with application server facilities	2
nhlr	int	Number of Core locations with HLR	2
neir	int	Number of Core locations with EIR	2
nin	Int	Number of Core locations with Intelligent Network Platforms	2
nsgsn	Int	Number of Core locations with SGSN	2
bvintc	Float	Blocking probability for POI to PSTN/ISDN	0.01
maxcdsg	int	Maximum number of circuits per E1 group	28
Muf3	float	Mark up factor for core network	1.48
Maxuserhlr	int	Maximum number of users per HLR	2240000
Maxusereir	int	Maximum number of users per EIR	2240000

Variable	**Type**	**Comment**	**Value**
Maxnsmssmsc	int	Maximum number of SMS/s per SMS centre	4490
maxbhcamsccs	int	Maximum number of BHCA per MSC Call Server	3975333
maxuserin	Integer	Maximum number of users per Intelligent Network Platform	1751111
maxbhcahlr	int	Maximum number of BHCA per HLR	3401000
maxbhcain	int	Maximum number of BHCA per Intelligent Network Platform	688667
bhvf	float	Busy hour factor for voice traffic	1.18
nopcs	Int	Number of operators (interconnected with TDM based ports)	6
npoivoip	Int	Number of core locations with POI to the IP network for VoIP service	2
aring	Int	0=Fully meshed topology /1= Ring topology	1
rprot	Int	In case of Ring: Protection by overdimensioning of links 0: 50% protection / 1: 100% protection	1
nopps	Int	Number of operators interconnected with Ethernet based ports	6
roffnetpstn	float	Ratio of off-net traffic interconnected with TDM based ports	1

Variable	Type	Comment	Value
ebwpcv	float	Bandwidth for packet switched voice interconnection on layer 2 [Kbps]	95.2
muficmgw	float	Mark up factor for MGW IC Ethernet ports	1.25
Tauicmgw	Float	Mean delay allowed at the MGW for IC Ethernet ports [in ms]	0.1

Systems File :

<scenario_name>_CN_system.txt

Value	**Type**	**Comments**	**Value**
Next line:			
Nidsyscna		Table size for node aggregator systems	5
For nidsyscna lines:			
Index	Integer	Index of the system	1
Name	Char	Name of the system	A
Systype	Integer	System type of the system	1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	30000
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	2
Bwportt2	Integer	Bandwidth of Type2 ports of the system (in Mbps)	100
Bwportt3	Integer	Bandwidth of Type 3 ports of the system (in Mbps)	1000
Bwportt4	Integer	Bandwidth of Type 4 ports of the system (in Mbps)	10000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	4
Maxnportlct2	Integer	Maximum number of Type2 ports per line card of the system	4
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	2
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	10

Value	Type	Comments	Value
Thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsyscorelink		Table size for core network transmission systems for fully meshed topology	7
For Nidsyscorelink lines:			
Index	Integer	Index of the transmission systems	1
Name	Char	Name of the transmission systems	LL2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
maxnport	Integer	Maximum number of ports of the transmission system	1
Bwport [Mbps]	Float	Maximum bandwidth per port of the transmission system (in Mbps)	100
Maxlength [Km]	Float	Maximum length between regenerators (in km)	1000
Thr	Integer	Threshold for using the next system type	2
Next line:			
NidsysLER		Table size for LER systems	3
For NidsysLER lines:			
Index	Integer	Index of the LER systems	1
Name	Char	Name of the LER systems	LER1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	280000

Value	Type	Comments	Value
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	1000
Bwportt2	Integer	Bandwidth of Type2 ports of the system (in Mbps)	10000
Bwportt3	Integer	Bandwidth of Type 3 ports of the system (in Mbps)	10000
Bwportt4	Integer	Bandwidth of Type 4 ports of the system (in Mbps)	10000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	12
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	2
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	2
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	2
thr	Integer	Threshold for using the next system type	2
Next line:			
NidsysMGW		Table size for Media Gateway systems	3
For NidsysMGW lines:			
Index	Integer	Index of the Media Gateway systems	1
Name	Char	Name of the systems	MGW1
Bwportt1[Mbps]	Integer	Bandwidth of Type 1 ports of the system (for interfaces to the LER and node aggregator) (in Mbps)	100

Value	Type	Comments	Value
Bwportt2[Mbps]	Integer	Bandwidth of Type 2 ports of the system (for interfaces to the LER and node aggregator) (in Mbps)	1000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	8
Maxnportlct2	Integer	Maximum number of Type2 ports per line card of the system	2
MaxnportlcE1	Integer	Maximum number of E1 ports per line card of the system	63
Maxnlceth	Integer	Maximum number of line cards for Ethernet ports	24
Maxnlce1	Integer	Maximum number of line cards for E1	16
thr	Integer	Threshold for using the next system type	2
Bweicportt1	Integer	Bandwidth of Type 1 Ethernet IC ports of the system (in Mbps)	100
Bweicportt2	Integer	Bandwidth of Type 2 Ethernet IC ports of the system (in Mbps)	1000
Maxneicportlct1	Integer	Maximum number of Type 1 Ethernet IC ports per IC line card of the system	24
Maxneicportlct2	Integer	Maximum number of Type 2 Ethernet IC ports per IC line card of the system	24
Next line:			
NidsysSGSN		Table size for SGSN systems	3
For NidsysSGSN lines:			
Index	Integer	Index of the SGSN systems	1

Value	Type	Comments	Value
Name	Char	Name of the systems	SGSN1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	95
maxuser	Integer	Maximum number of users of the system	482760
maxpdp	Float	Maximum PDP context of the system	1000000
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	100
Bwportt2	Integer	Bandwidth of Type2 ports of the system (in Mbps)	1000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	48
Maxnportlct2	Integer	Maximum number of Type2 ports per line card of the system	8
Maxnlc	Integer	Maximum number of line cards	12
thr	Integer	Threshold for using the next system type	2
Next line:			
NidsysGGSN		Table size for GGSN systems	2
For NidsysGGSN lines:			
Index	Integer	Index of the GGSN systems	1
Name	Char	Name of the systems	GGSN1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	8000
maxpdp	Float	Maximum PDP context of the system	800000
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	100

Value	Type	Comments	Value
Bwportt2	Integer	Bandwidth of Type 2 ports of the system (in Mbps)	1000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	8
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	4
Maxnlc	Integer	Maximum number of line cards	2
thr	Integer	Threshold for using the next system type	2
Next line:			
Nidsyscorering		Table size for core network transmission systems for ring topology	7
For Nidsyscorering lines:			
Index	Integer	Index of the transmission systems	1
Name	Char	Name of the system	LL2
Systype	Integer	System type of the transmission system	1
maxBW [Mbps]	Float	Maximum bandwidth of the transmission system (in Mbps)	2
maxnport	Integer	Maximum number of ports of the transmission system	1
Bwport [Mbps]	Float	Maximum bandwidth per port of the transmission system (in Mbps)	100
Maxlength [Km]	Float	Maximum length between regenerators (in km)	1000
Thr	Integer	Threshold for using the next system type	2
Next line:			
NidsysLSR		Table size for LSR systems	3

Value	**Type**	**Comments**	**Value**
For NidsysLSR lines:			
Index	Integer	Index of the LSR systems	1
Name	Char	Name of the systems	LSR1
maxBW [Mbps]	Float	Maximum bandwidth of the system (in Mbps)	160000
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	1000
Bwportt2	Integer	Bandwidth of Type2 ports of the system (in Mbps)	10000
Bwportt3	Integer	Bandwidth of Type 3 ports of the system (in Mbps)	10000
Bwportt4	Integer	Bandwidth of Type 4 ports of the system (in Mbps)	10000
Maxnportlct1	Integer	Maximum number of Type 1 ports per line card of the system	12
Maxnportlct2	Integer	Maximum number of Type 2 ports per line card of the system	2
Maxnportlct3	Integer	Maximum number of Type 3 ports per line card of the system	2
Maxnportlct4	Integer	Maximum number of Type 4 ports per line card of the system	2
Maxnlc	Integer	Maximum number of line cards	3
thr	Integer	Threshold for using the next system type	2