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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

Version 2.0

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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-NB	Adaptive Multi-Rate Narrowband
AMR-WB	Adaptive Multi-Rate Wideband (AMR-WB)
BH	Busy Hour
BHCA	Busy Hour Call Attempt
BLER	Block Error
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
BW	Bandwidth
CAPEX	Capital Expenditures
CIR	Committed Information Rate
CSCF	Call Session Control Function
CSFB	Circuit Switched Fallback
DCH	Dedicated Channel
DL	Down-Link
DLL	Dynamic Link Library
DSG	Digital Subscriber Group
E1	Physical layer protocol for leased line transmissions for 2 Mbps
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data Rates for GSM Evolution
EIR	Equipment Identity Register
e-Node B	Evolved Node B
EPC	Evolved Packet Core
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
GSMA	Group Special Mobile Association
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IC	Interconnection
I-CSCF	Interrogating Call Session Control Function
IETF RFC	Internet Engineering Task Force RFC
IMS	IP Multimedia Subsystem
IMS-MGW	IMS-Media Gateway
IN	Intelligent Network
IP	Internet Protocoll
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ISUP	ISDN User Part
kbps	Kilobit per Second
kHz	Kilohertz
LAN	Local Area Network
LER	Label Edge Router
LRIC	Long Run Incremental Cost
LSR	Label Switch Router
LTE	Long Term Evolution

LTE-A	Long Term Evolution – Advanced
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
MMSC	Multimedia Messaging Service Center
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
OAM	Operation Administration Maintenance
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
PCRF	Policy and Charging Rules Function
P-CSCF	Proxy Call Session Control Function
PCU	Packet Control Unit

P-GW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
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
RCS	Rich Communications Suite
RB	Resource Blocks
RNC	Radio Network Controller
ROADM	Reconfigurable Optical Add-and-Drop Multiplexer
SAEGW	System Architecture Evolution Gateway
SBC	Session Border Control
ScenGen	Scenario Generation Modul
SC-FDMA	Single Carrier Frequency Division Multiple Access
S-CSCF	Serving Call Session Control Function
SDH	Synchronous Digital Hierarchy
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SINR	Signal to Interference Noise Ratio
SMS	Short Message Service
SMSC	Short Messaging Service Center
SRVCC	Single Radio Voice Call Continuity
STM	Synchronous Transport Module
STP	Signaling Transfer Point
TAS	Telephone Application Server
TBS	Transport Blocking Size
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TRX	Transceiver

UDP	User Datagram Protocol
UL	Up Link
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice Over Internet Protocol
VoLGA	Voice over LTE via Generic Access
VoLTE	Voice over LTE
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 ("demande d'avis") by the Institut Luxembourgeois de Régulation (ILR) on the development of a bottom-up mobile network and cost model. In the context of the 3rd round of electronic communications market analyses, this model will be used to determine the eventual price cap for the provision of mobile call termination. This cost of termination is generally determined based on a Pure LRIC methodology as recommended by the EC for termination services[1].

The purpose of this Reference Document is to provide a description of the structure of the modelled bottom-up mobile network as well as the related cost calculations, thus to enable stakeholders to comment on the methodology proposed.

This 2nd version of the Reference Document differs from the preceeding model, described in the Reference Document of 20th March 2014. It includes now the new technology of LTE (i.e. LTE-Advance functions of Multiple-Input-Multiple-Output (MIMO) as well as Carrier Aggregation (CA)) and the new voice service over LTE (VoLTE).

In order to implement a bottom-up model, different modelling processes are needed and integrated in the model. It starts with a demand and specification process defining the particular conditions and needs for the territory of Luxembourg. This is followed by the process of network planning where the resulting characteristics are considered. During 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. The cost per minute of termination is derived from the previously determined costs .

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

- Chapter 2 describes the national situation, requirements and specifications of the territory of Luxembourg;
- Chapter 3 describes the network planning process;
- Chapter 4 describes the determination of the cost of termination; and
- Chapter 5 describes the features of the software modelling tool.

Those sections in the above chapters that introduce the new features of the model will be marked in grey.

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[1] See EU Commission (2009).

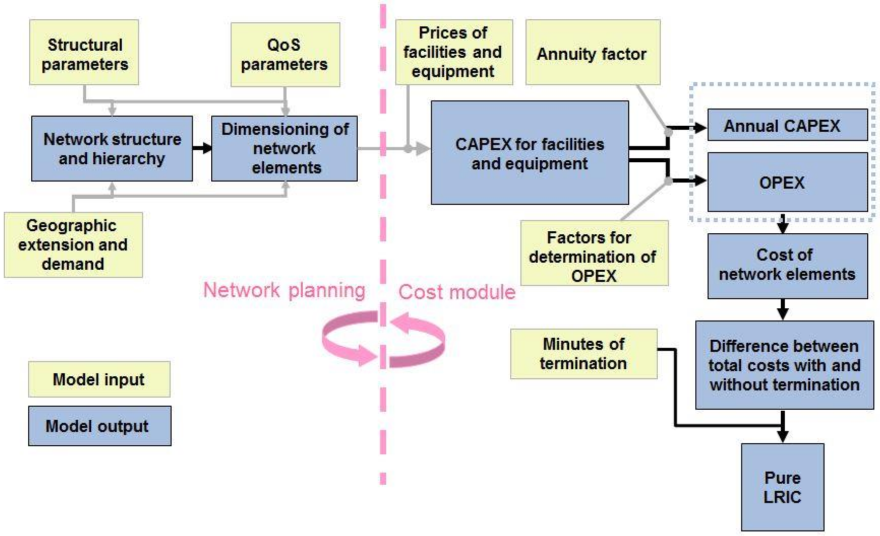
2 Background, requirements and specifications

2.1 Overview

The Bottom-Up Mobile Network and Cost Model (henceforth „the model“) performs the modelling of the network of an efficient operator (henceforth „the reference network operator“) that has a particular market share (determined by the ILR) of the demand in Luxembourg. At the same time it takes into account the conditions under which the existing operators are currently working. The said demand is determined via the regional population distribution, the location of the various work places as well as that of travellers. The model starts from this demand (which is based on an average profile of demand per user) and then follows on with the determination of the required mobile network according to the previously defined market share of the reference network operator. The next iteration is to calculate the total cost of the network based on the prices of the various inputs for this mobile network. The cost of termination of incoming calls on the modelled network is then calculated based on 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 functionally described in detail in Chapters 2 and 3.

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, UMTS with HSPA and LTE. The specification of the model will allow implementing networks based on pure technology choices, i.e. based on only GSM/EDGE, only UMTS, only UMTS/HSPA, or only LTE, 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 service categories actually taken into account cf. 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 has to be considered in the modelling process. The share of voice and data services (e.g. voice 80% and data 20%) determines the size of the cells of the modelled radio access network as well as the related fixed network parts.

Since the dimensioning of a network depends to a large extent on the frequency bands used, the model allows the use of 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. A schematic illustration of the network architecture is shown in Figure 2-2.

Figure 2-2: Architecture of the network to be modelled (LTE network elements highlighted)

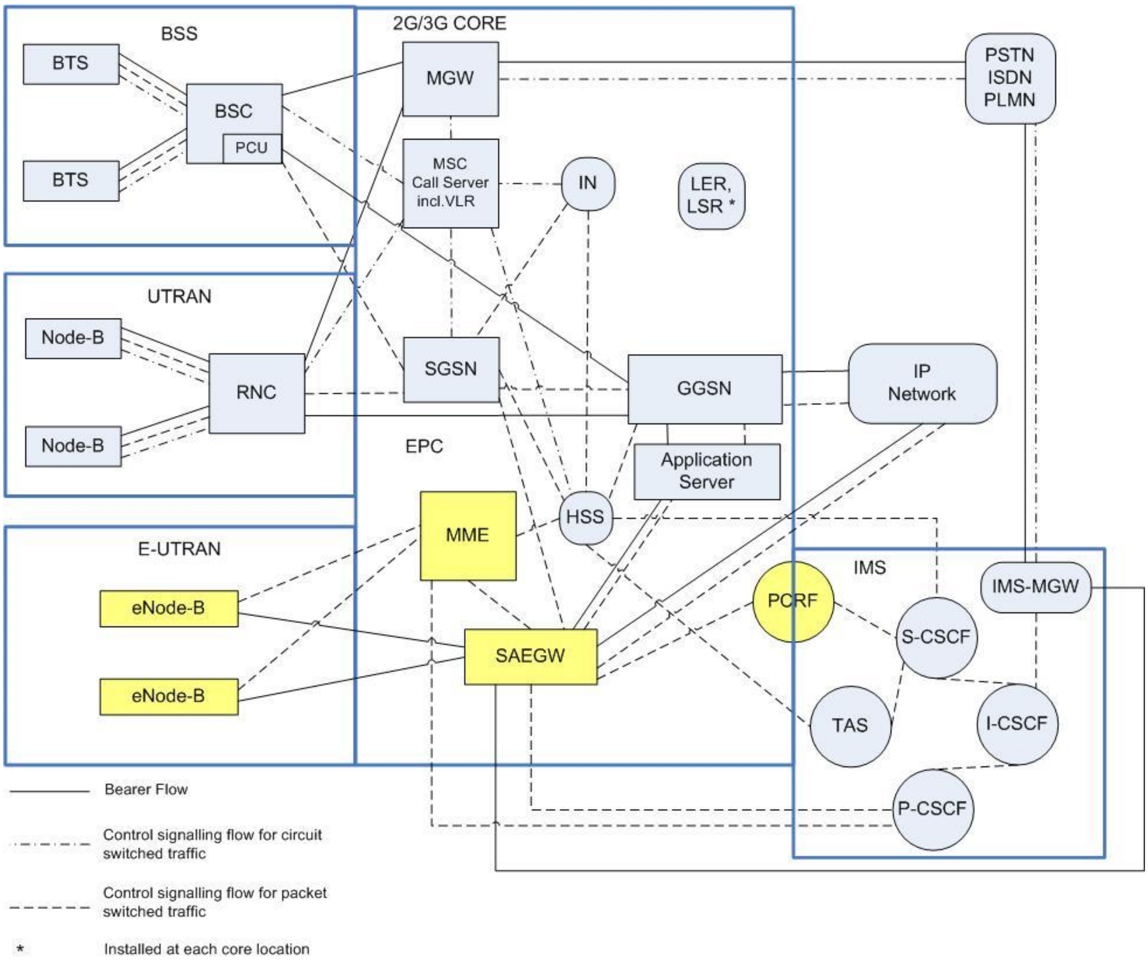


Figure 2-2 is based on elements defined by Releases 4 through 10 of 3GPP. Changes in comparison to the original version of the model are shown in the figure through the addition of the LTE radio access network (E-UTRAN), the evolved packet core (EPC) and the IP multimedia subsystem (IMS), which reflect the integration of the LTE technology and the new service VoLTE. As already mentioned, the network modelling process is described in detail in Chapter 2, and the cost determination process is described in Chapter 3. The remaining sections of this chapter cover the prerequisites for this modelling process in respect of the derivation of demand, the choice of technology combinations, the availability of frequencies as well as the 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 purpose of the model is to reflect as close as possible the 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 (e.g. capacity utilisation rates) that have proved to be reliable in generic planning and modelling practice.

2.2 Demographical and geographical input data

2.2.1 Definition of users

The network is modelled in order 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 including the travellers present. The relevant data are compiled from data on the local government areas in Luxembourg, providing the population and the geographical characteristics of each area. From the number of persons in each area, the number of modelled subscribers is derived using the country's average penetration rate and the market share assumed for the modelled 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.

The modelling process for the radio access network sketched in Section 2.1 requires that 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 is obtained.

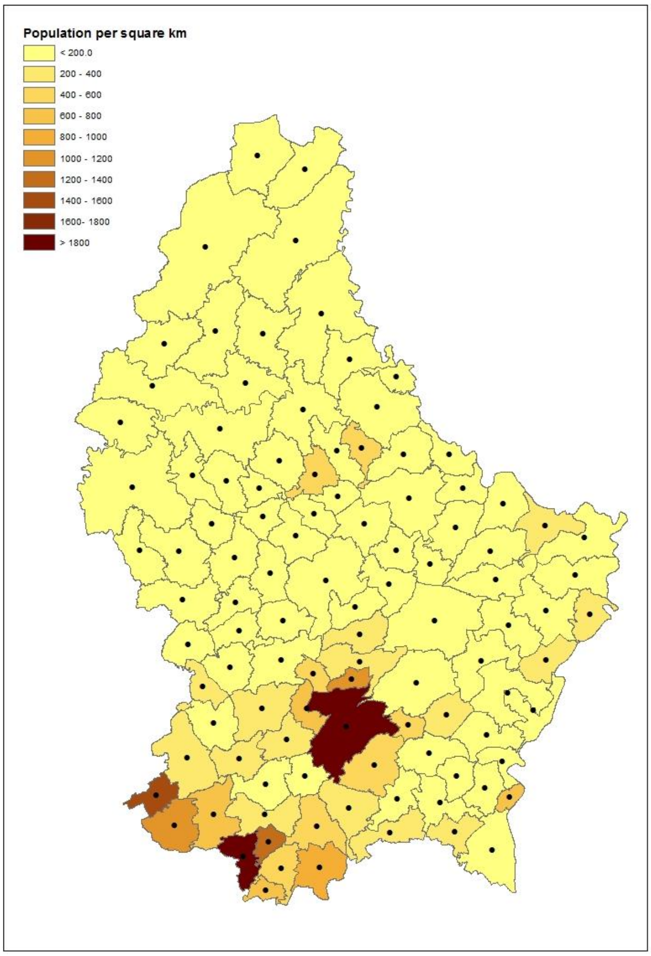
The basic data consists of the following categories:

- 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 comes from the government statistics service of Luxembourg “STATEC” as well as all GIS data 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, cf. Figure 2-3 infra) is this average demand multiplied by the total number of residents multiplied by the penetration rate multiplied by the market share of the operator.

Figure 2-3: Population density per local government areas of Luxembourg



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 in Luxembourg 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 commutes to their working places would, if there were no commuters moving in from neighbouring countries, be set equal to the number of available jobs.

- Given that there are workers moving in from neighbouring countries, the latters' number is deducted from the number representing what would otherwise be the local commuters.

- The balance is set equal to the number of local commuters.

- The resulting number of local commuters is 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 sum of local and visiting working people are assigned to their corresponding work places, which are known for each local government area.

Example: Assuming that there is a residential population of 500,000 in Luxembourg and that 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 occupied by residents from Luxembourg. The locations of the work places are known on the basis of concrete information received from ILR. To determine the number of people that remain in the various zones after working people have left in order to go to work, the residential population in each zone will be reduced by one fifth (=100,000/500,000) during the working day. It is not possible to carry out this calculation more precisely as the corresponding information is not available. Note that after carrying out the two operations (fill work places with workers in each zone, reducing the population in each zone by one fifth) a zone may either gain or lose in terms of number of users, depending on the number of work places in the particular zones.

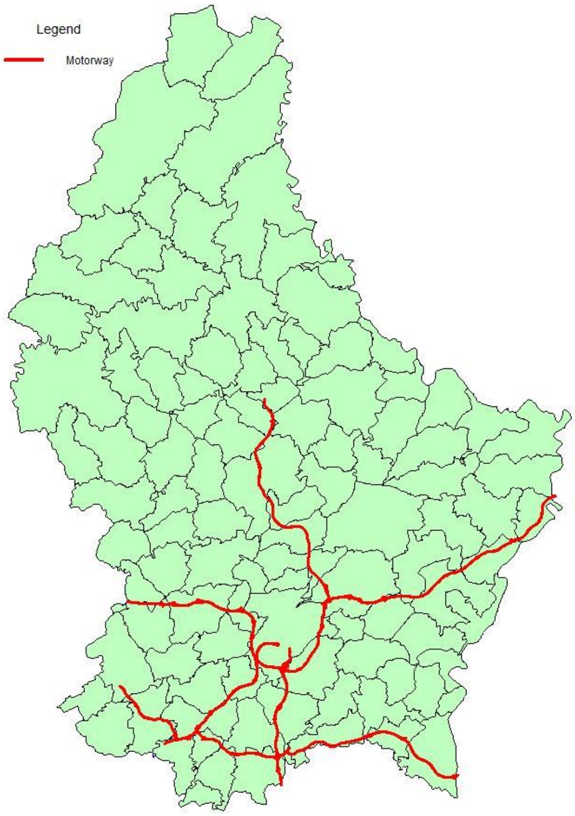
As a consequence of these movements, it can be expected that the peak load for the network in areas with a relatively small number of households but large number of enterprises, particularly in urban areas, happens during the day time, while in other areas (suburban and rural) the peak load is observed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

It must also be considered that local working people who are present at two different places during the various 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 users for the whole day.

Travellers, as distinct from working people moving to their respective places of work, are 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 relatively low number of households can still result in a larger number of users. This treatment of travellers implies that areas with a relatively low population may turn into high visitor regions during vacation time, which then in turn determines the peak period.

As it will be discussed in Section 2.3, the modelled network assures that the coverage of the area of Luxembourg with mobile services is largely guaranteed as it is dimensioned according to the adjustments described supra with regard to the geographical distribution of the population, employed people and travellers. In addition, however, it is assumed that particular coverage for mobile demand must be provided along the motorways and major railway lines. Along these traffic arteries, additional mobile base stations are installed to ensure this extra coverage. 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, i.e. Belgium, France and Germany. Section 2.3 describes how these users are addressed.

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 so that they can be provided with additional cell locations to accommodate the demand of the passengers passing through them. The consideration of these two places covers the vast majority of the demand of all airplane and train 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 of serving 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 one person, both being present 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 take off during the hour before, which is taken into account when determining the relevant amount of traffic.

On the other hand for 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 an overview of the different types of users whose movement are taking into account.

Table 2-1: Types of user movements

Type of user movements	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	Visitors 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 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 (e.g. Switzerland, Austria). Figure 2-4

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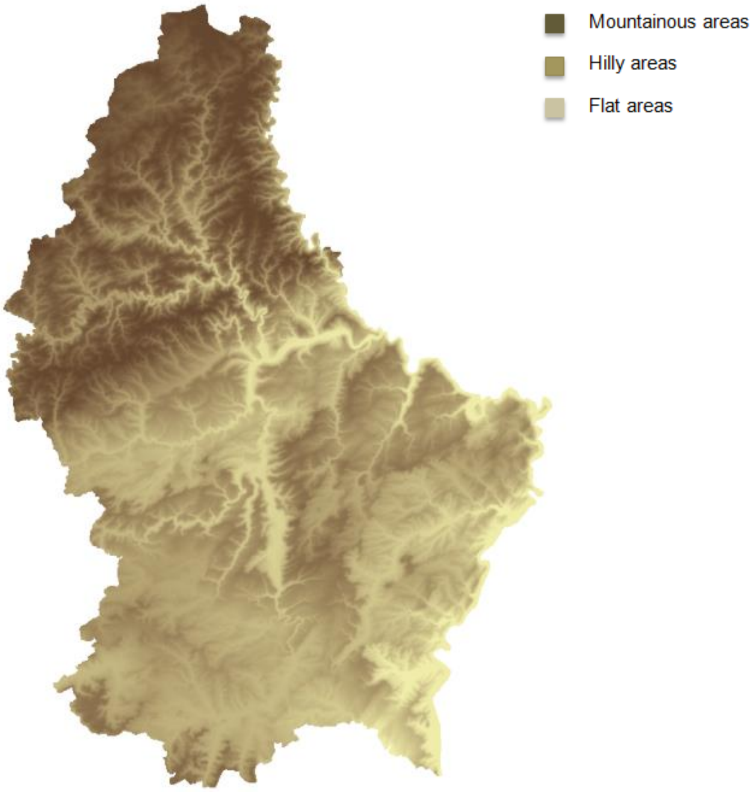
[2] These values are derived on the basis of simulations carried out by Prof. Portilla of the University of Alcalá (Spain) using the Friis equation. Regarding the Friis equation see Blaunstein and Christodoulou (2014).

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 (i.e. residents, work places, travellers, topography) are listed. The individual local government areas are sorted according to user density. The zones are formed – as described infra – starting with the most densely populated areas, to which the surrounding areas are assimilated according to a distance criterion.

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 next iteration continues with the one of the remaining (not yet aggregated) areas with the highest population density.
- The aggregated local government areas assimilate all other such areas that are located within a specific distance defined by a parameter (i.e. as criterion for the specific distance are taken the distances between the geographic centres of the areas).
- The distance thresholds depend on the type of the aggregated area, i.e. either high, medium or low density. The threshold for areas with high density is lower than the one for areas with medium density, which in turn 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

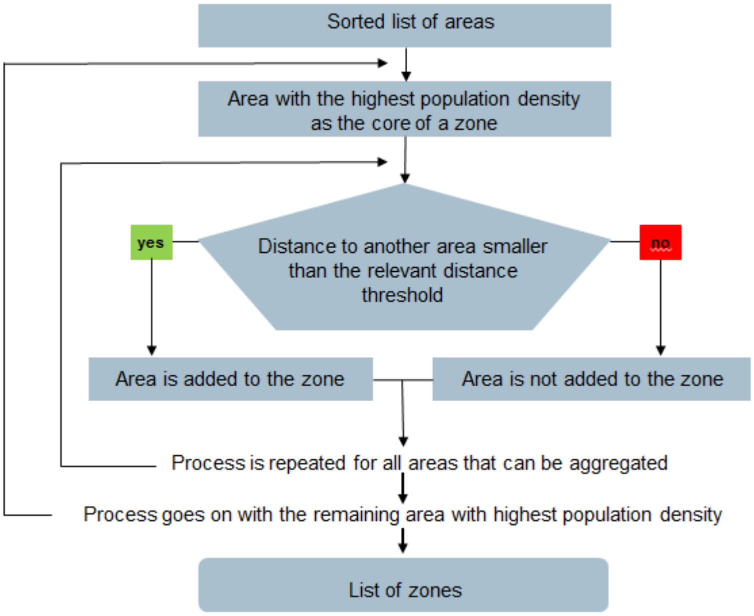


Table 2-3: Typical values of the parameters for the forming of the zones

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 that could aggregate 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. A 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 to ignore international roamers, based on the assumption that in each network the users temporarily lost and won compensate each other. In the first implementation/version of the model, ILR opted for this approach i.e. assuming a compensation of international roamers.

The foreign commuters coming to Luxembourg on a daily basis are not considered to be international users (roamers). It appears that the majority of these foreign commuters are customers of a Luxembourgish mobile operator. So those foreign commuters are not to be considered as part of international roamers.

With regard to cell planning, it is necessary to describe how this 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, another one to native UMTS, HSPA and/or LTE. This distribution will depend on parameters 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 of the network are deduced. This Reference Document is limited to the description of services at the upper level.

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

The description of services is based on studies of the UMTS Forum, the latest study[4] also includes the services made possible by LTE. Table 2-4 provides an overview over the corresponding services and their main features.

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

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. In an LTE environment, there is an increased potential for P2P file transfer, application sharing, M2M communication and access to mobile intranets and extranets.	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. It includes games, television, video on demand and music. Device development and the faster speeds of LTE make possible an enhanced entertainment-based content experience.	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. In an LTE environment this implies a development towards photo and video messages.	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. In an LTE environment, usage is likely to be closer to the PC experience, with super-fast browsing speeds and greater interaction with social networking.	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). With LTE this will move towards VoLTE and high quality video conferencing.	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 UMTS Forum (2003, 2011).

This model considers the services categories determined by the UMTS forum as a starting point, but it makes adjustments so that the definitions of the services are 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 noticed 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.
Voice over LTE (packet-switched)	Two way communication between to persons via a virtual connection
Streaming	E.g. 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 in different forums (e.g. GSM-Association), equipment providers (e.g. Ericsson), recent text books and earlier regulatory studies.

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[5] Rich voice service is defined by the UMTS Forum as a simultaneous voice and data service, e.g. 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	12.65	12.65	25	25	3	0.4	0.3	0.3	0	0	1	HSPA, LTE
Other real time (e.g. video telephony)	64	64	240	240	5	1	0	0	0	0	1	GSM
VoLTE	12.65	12.65	25	25	3	0.4	0.3	0.3	0	0	1	GSM, UMTS, HSPA
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	30	270	200	1150	5	0	0	0	0.4	0.6	4	GSM, UMTS
Mobile Broadband over LTE	500	1000	200	1150	5	0	0	0	0.4	0.6	4	GSM, UMTS

* In this table the Best Effort services of Table 2-5 are merged into a single category. The Best Effort category comprises also Machine to Machine services

The services in Table 2-6 represent the possible range of services. For the purpose of cost studies focusing primarily on voice services, it may be appropriate to consider fewer services, for which the model could of course be adapted. In some previous applications (e.g. studies for the regulatory authorities of Germany and Austria), only voice, SMS, MMS, a general category of data as well as mobile broadband access were implemented. In these previous applications, video telephony was 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 different types of user, e.g. the following three user types have been used in earlier cost models:

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

The model enables to define further user types, however in the previous implementation ILR used one average type of user.

2.5 Technology Mix

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

- GSM/EDGE (i.e. GSM with EDGE capabilities),
- UMTS,
- UMTS/HSPA (i.e. UMTS with HSPA capabilities) and
- LTE.

The version under review will also include LTE besides GSM and legacy UMTS in combination with HSPA. The model assumes a countrywide coverage of GSM/EDGE as well as a predetermined coverage of LTE and UMTS. There is no explicit modelling of GSM/GPRS as it is supposed that the services based on GPRS (e.g. machine to machine) can meanwhile be provided 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 hard-wired programming for the two equipment variants does not differ in the model since they are realised through different parameterisation.

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

- Only GSM/EDGE,
- Only UMTS/HSPA,
- Only LTE,
- UMTS plus GSM/EDGE,
- UMTS/HSPA plus GSM/EDGE,
- LTE plus GSM/EDGE,
- LTE plus UMTS/HSPA and
- LTE plus UMTS/HSPA plus GSM/EDGE.

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

In case of modelling a hybrid network, there will be areas with cells equipped with two or even three technologies implying the existence at some cell locations of radio facilities of different technologies. 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 2-7 shows two examples of technology configurations.

Table 2-7: Examples of thresholds for the determination of hybrid networks

Option	**Technology mix**	**Threshold for**			**Comment**
		very densely	**medium densely**	**sparsely**	
		populated zone			
		Population / km^2			
1	GSM/EDGE or UMTS/HSPA	0	0	100	Above this population density threshold UMTS/HSPA, below GSM/EDGE
	With LTE	0	0	200	Above this population density threshold LTE
2	GSM/EDGE or GSM/EDGE/UMTS/HSPA	0	0	100	Above this population density threshold GSM/EDGE/UMTS/HSPA, below GSM/EDGE
	With LTE	0	0	200	Above this population density threshold LTE

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:

- GSM/EDGE: 900 and 1 800 MHz-bands,
- UMTS/HSPA: 800, 900, 1 800, 2 100 and 2 600 MHz bands,
- LTE: 800, 900, 1 800, 2 100 and 2 600 MHz bands.

It is possible that at any given base station location different technologies, e.g. GSM/EDGE and UMTS/HSPA, may be deployed using spectrum from the same frequency band,

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) In the case of a GSM and UMTS network, the 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) In the case of a GSM and UMTS network, the backhaul network, which connects the controllers with the facilities of the core network,

(4) In the case of a LTE network, the transport network in lieu of the aggregation and the backhaul networks, and

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

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

- Network design,
- Dimensioning and
- System assignment.

A dedicated 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, UMTS with HSPA and LTE. 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, “nodes B” in UMTS networks and “e-nodes B” in LTE 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 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 UMTS and LTE networks are the following:

- Macrocells with up to three sectors,
- Microcells with up to three sectors, and
- Picocells with up to 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.

Base stations for macrocells are deployed in rural and suburban areas, base stations for microcells in suburban and inner-city areas, and base stations for picocells in urban areas. Moreover, base stations for macrocells 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, node B and e-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.

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 and e-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 selected. For this purpose, the information about the investment per base station is included in the list of parameters of the base station used by the network planning tool.

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 The significance of uplink and downlink traffic for planning the cells of the radio access network

The following sections will describe the planning of the cells of the radio access network under the conditions of the available technologies (2G GSM, 3G UMTS/HSPA and 4G LTE). The objective is each time to determine the size of the cell in the area under consideration, depending on the technologies and the conditions of demand. In each case it must be decided whether the cell size is to be determined on the basis of the propagation properties of the spectrum used or on the basis of available spectrum capacity. The propagation properties become relevant in the case of low demand, where it is the minimum acceptable signal strength at the edge of the cell,that determines its size. On the other hand, spectrum capacity becomes the determining factor in the case of strong demand when the available capacity is reached for each cell. For both considerations, propagation or capacity driven, there are two traffic streams through which the restrictive factor can become effective, the uplink traffic from the end user device to the base station and the downlink traffic from the base station to the end user device.

In case the size of a cell is determined on the basis of the propagation properties, i.e. the strength of the signal at the edge of the cell, the relevant traffic is the uplink traffic from the end user device to the base station, as this traffic must be supported by the signal strength of the end user device which is less than that of the base station and is therefore the restrictive factor. In contrast, in case the size of a cell is traffic driven, i.e. the available spectrum capacity is the restrictive factor, the relevant traffic is the downlink traffic, given that it is typically ten times larger than the uplink traffic which has to be supported by the spectrum capacity.

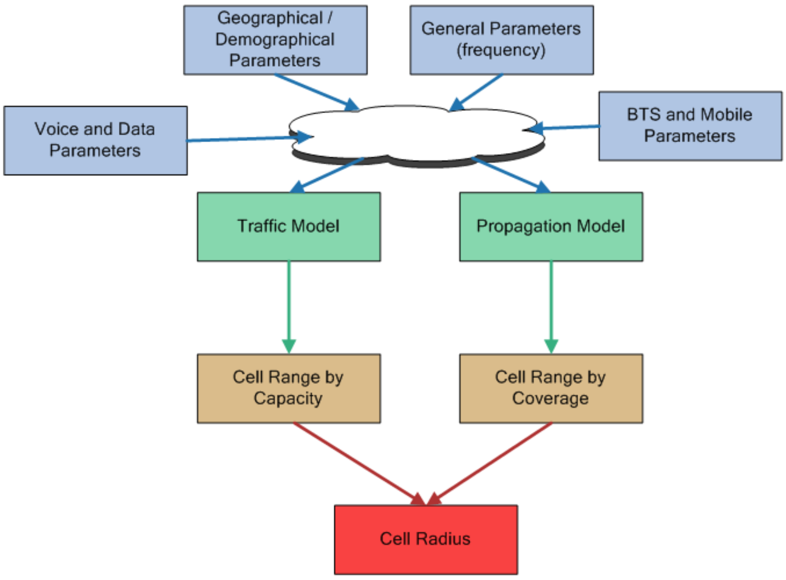
3.1.3 Cell deployment for 2G GSM

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. Here the 900 MHz and 1 800 MHz frequency bands can be 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 cf. infra). 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.

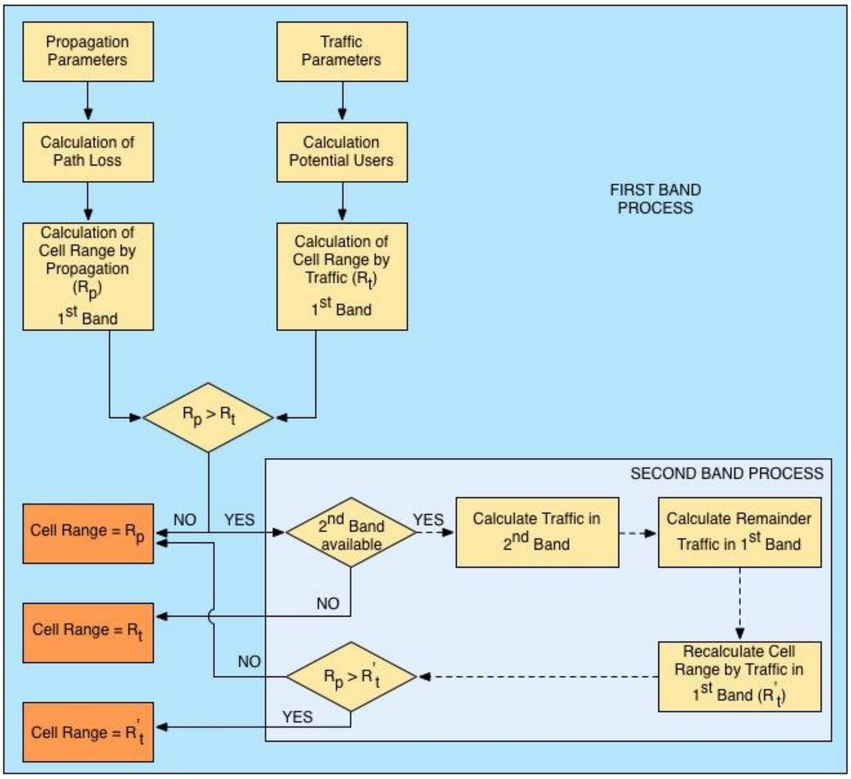
For a given cell range, determined on the basis of propagation limitations, the number of TRX available per sector increases with the volume of traffic. In case that the required number of TRX exceeds the maximum capacity, the cell range must be reduced. Thus, it follows that under high traffic conditions the sizes of cells are traffic driven, while under low traffic conditions cells are propagation driven. Figure 3-1 shows a schematic representation of the process followed to determine the cell range in 2G GSM networks.

Figure 3-1: 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 1 800 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 3-2 shows the flow chart of this algorithm.

Figure 3-2: 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.

3.1.4 Cell Deployment for 3G

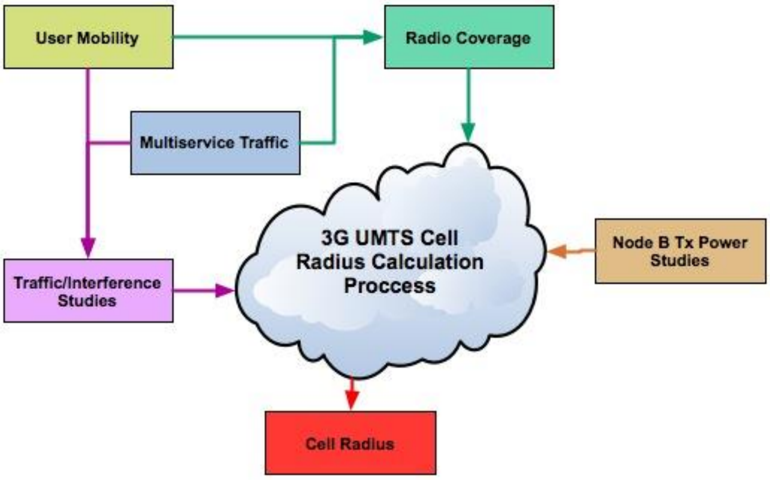
With the term “3G system” two standards, UMTS and HSPA, are meant. Both technologies are based on Wideband Code Division Multiple Access (WCDMA), which implies that the cell size depends on the amount of interference in the cell. This interference is generated by the users of the cell as well as system 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.

3.1.4.1 3G UMTS

3.1.4.1.1 Overview over the process for calculating the cell range of a 3G cell

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 (see Appendix A), 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 differs 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 3-3 shows a schematic representation of the process followed to determine the cell range in 3G UMTS networks.

Figure 3-3: 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 supra, 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.

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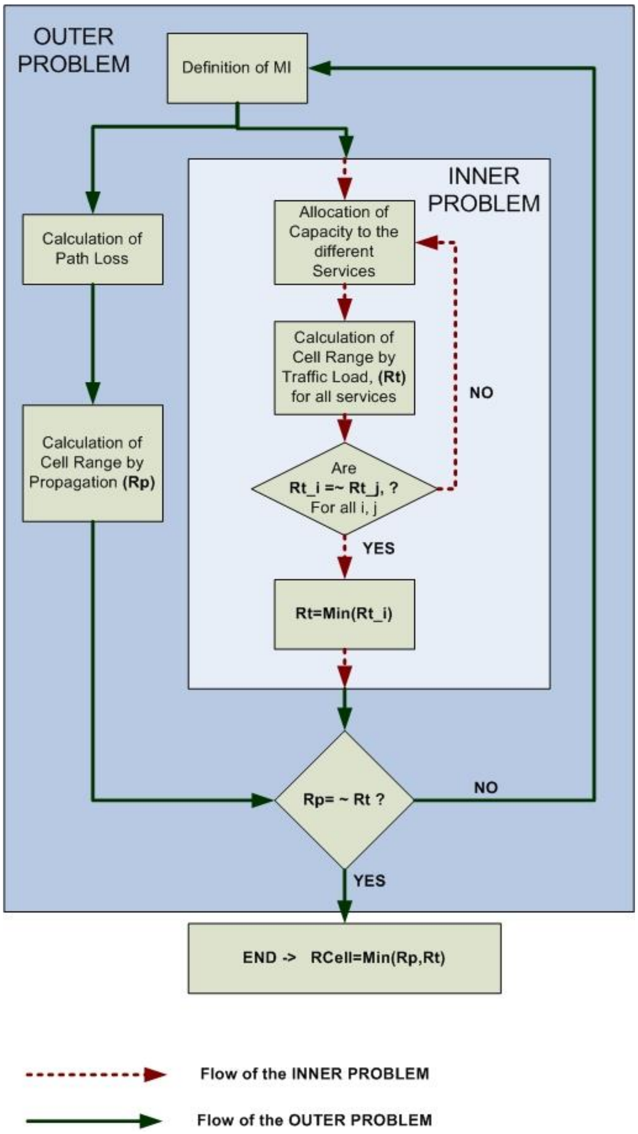
[6] See Portilla et al. (2009).

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 3-4. The detailed description of this cell range process is outlined in Section 3.1.4.1.2.

Figure 3-4: Flow chart for the calculation of the cell range in 3G networks



3.1.4.1.2 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 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 review, 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 number of channels is 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 predefined input parameters of the services considered (e.g. binary rate, bit energy over noise ratio) 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

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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).

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 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.

3.1.4.2 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 review 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 3-5 infra. From the technical information available for the services shown in Table 2-6, 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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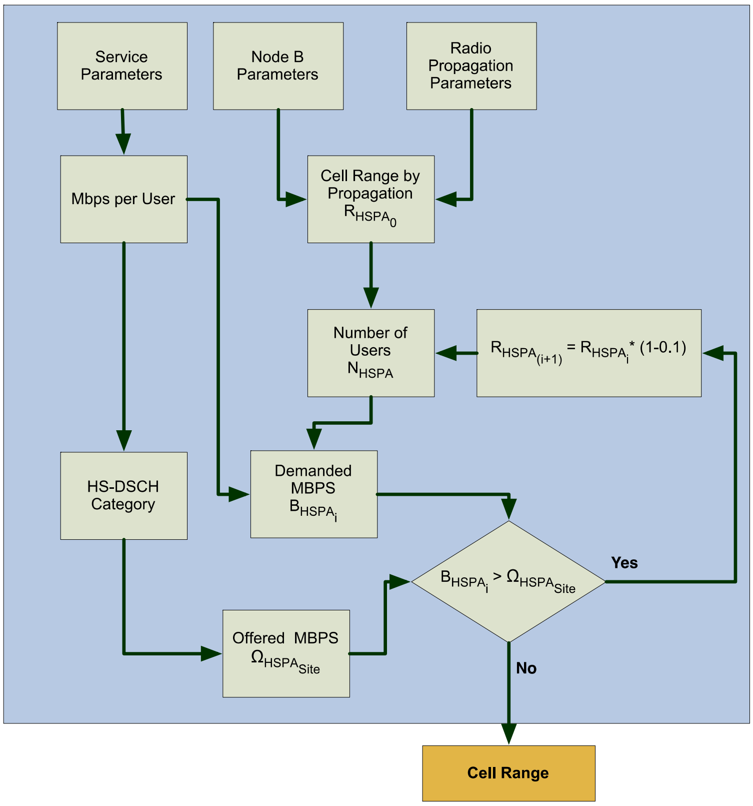
[9] For more details regarding the cell dimensioning under the Okumara Hata model see Chapter 8 in Holma and Toskala,(2010).

Figure 3-5: HSPA cell range calculation procedure



While the previous discussion has been in terms of HSPA, it can also apply to HSPA+. The use of the HSPA+ technology depends directly on the maximum required throughput per user, which determines the most suitable modulation and coding scheme among the existing possibilities. 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 supra.

3.1.5 LTE in the radio access network

The present section covers a brief description of the LTE technology and how it is implemented in the model. Part of the description are enhancements of the technology on the basis of two technical developments, Multiple-Input-and-Multiple-Output (MIMO) and Carrier Aggregation (CA). In a separate section, the provision of Voice over LTE (VoLTE) and its implementation in the radio access network is presented.

The order in which the various features of LTE are presented reflect the time path by which this new technology and its enhancements as well as the services made possible by it have been introduced onto the market.

3.1.5.1 A brief description of LTE

Long Term Evolution (LTE) is the further development of the 3G standards of the 3GPP which was first defined in Release 8. At the time an uplink bitrate of up to 50 Mbps and a downlink bitrate of up tp 150 Mbps was assumed, as well as a 2X2 MIMO configuration and the availability of type 4 end user device. In the meantime, uplink bitrates von 75 Mbps and uplink bitrates of 300 Mbps based on 4X4 MIMO configuations and type 5 end user devices have been defined. These speeds, however, must be considered as theoretically achievable maximum values for a given spectrum of 20 MHz, for which the end user devices are still to be brought onto the market. LTE-Advanced was introduced by 3GPP’s Release 10. It presents improvement for the MIMO applications with configuration of up to 8X8 in the downlink and 4X4 in the uplink, as well as Carrier Aggregation (CA) and the introduction of voice services over LTE (VoLTE).

Both LTE and LTE-Advanced are based on two new technologies in the radio access network: Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink. In the downlink, the transmission between the base station and the end user device takes place over separate sub carriers of 15 kHz each, where the number of sub carriers depends on the bandwidth of the spectrum that is available: there are 72 sub carriers in case of a bandwidth of 1.4 MHz and 1,200 in the case of a bandwidth of 20 MHz.

In the LTE system, the allocation of resources takes place dynamically through the scheduler, whose corresponding function is an integral part of the e-nodes B. The allocation is based on the concept of resources block (RB) where a RB is the smallest unit of resource that can be assigned to a user and which is the result of the aggregation 12 sub carriers. Each RB consists of these 12 sub carriers in the frequency domain (180 kHz) and a slot in the time domain (0.5 ms). The number of RBs that is assigned to a user depends on the selected modulation and coding schem (MCS) as well as the quality of the connection between the end user device and the e-node B. For this purpose the model selects from the 29 different MSC options the one which is best able to bring the two cell sizes, the one based on propagation properties and the one based on capacity requirements, in agreement with each other.

3.1.5.2 The determination of the size of an LTE cell

This section covers the determination of the LTE radio access network, which in most instances is also relevant for LTE-Advanced and when VoLTE is part of the services portfolio. Particular features regarding LTE-Advanced and VoLTE will be covered in the sections dedicated to these topics.

The dimensioning of an LTE access network in a given sub-area of a zone consists of two steps, i.e. the determination of the size of the cells on the basis of

- Propagation properties and
- Available spectrum capacity.

As in the case of UMTS/HSPA, these steps are not independent of each other, as shown in Figure 3-6.

Figure 3-6: Approach to determining the radius of an LTE cell

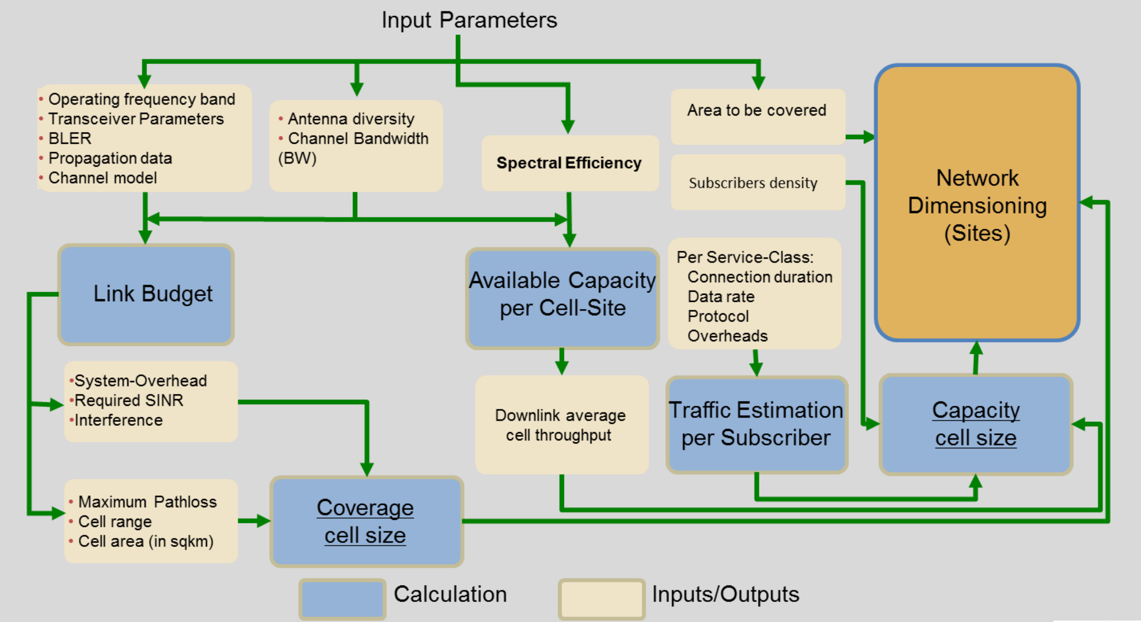


Figure 3-6 illustrates the two approaches that, as in the case of GSM and UMTS/HSPA, are used to determine the cell size. In the approach based on the propagation properties, the link budget is specified which provides the maximum distance from the base station by a signal of sufficient quality and which enables to derive the maximum radius of the cell (i.e. which is represented by the two blue boxes on the left hand side). In the second approach, the size of the cell is determined on the basis of the number of users, which can be served with the available spectrum capacity, given the demand of each user (cf. the three blue boxes on the right side of the figure). As is the case for the other two technologies, that result providing the smaller cell size is selected. Below the two approaches are discussed in more detail.

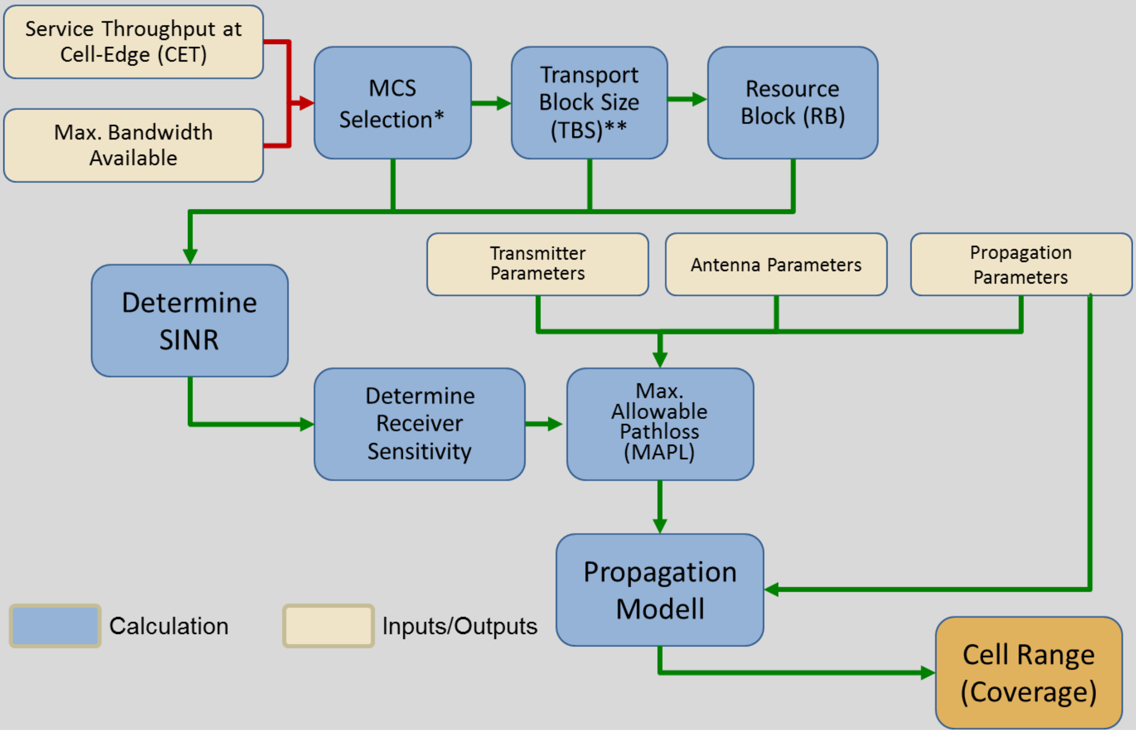
The process by which the cell size is derived on the basis of the propagation properties of the spectrum is graphically shown in Figure 3-7. Following the order of the boxes marked in blue, first the modulation and coding scheme (MCS), which assures the best coverage and fulfils the requirements in terms of the bitrate at the edge of the cell, is selected. For this the model considers 29 different MCSs on the basis of look-up tables. Each MCS is associated with a particular transport block size (TBS) and accordingly with a corresponding number of resource blocks (RB). The look-up tables used by the model contain the information necessary for the dimensioning of the cells enabling the coverage of relevant area. This information concerns the number of RBs and the signal to inference noise ratio (SINR) that correspond to the given bandwidth of the channel.

Then the maximum allowable path loss (MAPL) is determined using the following parameters:

- the required bitrate at the edge of the cell (where this bitrate corresponds to the SINR),
- the propagation properties of the channel,
- the fading margin,
- the building penetration losses,
- the clutter type,
- as well as some technical parameters (e.g. antenna sensitivity, power, antenna gain and loss),
- as well as some other ones (e.g. thermal noise, receiver noise figure, MIMO gain).

The value of this path loss is then used by the model to determine the distance that a sufficiently strong signal according to the propagation properties of the used spectrum can travel (see Cost 231 Okumura Hata model), from which in turn it derives the radius and the surface area of the cell. By dividing the total surface area of the zone to be provisioned by a single cell’s surface area, the number of e-nodes B is calculated.

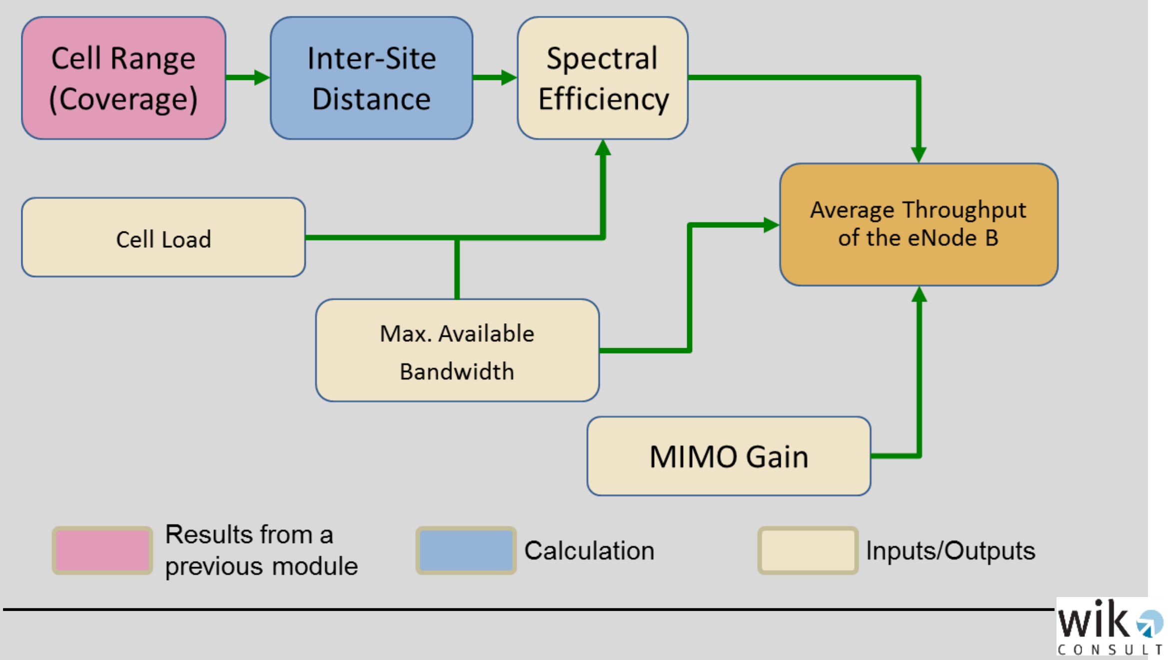
Figure 3-7: Calculation of the cell radius according to propagation properties of the spectrum



* MCS: Modulation and Coding Scheme; Selected from a set of 29 different options.
** TBS: Transport Block Size; defined as the number of bits that can be sent in one milisecond, which is determined by the type of MCS used.

The next step consists in the calculation of the cell size that corresponds to the available system capacity. Given that LTE is an interference restricted system, the capacity of an e-node B is calculated on the basis of the available bandwidth, the antenna configuration and the traffic load. The demand required for carrying out the dimensioning is obtained from the average demand per user. The dimensioning is then carried out using this average demand and the capacity of the e-node B. When as a result of the capacity calculation the average load of an e-node B is known, the number of e-node B will be determined in order to serve the demand in the zone under consideration. Figure 3-8 contains the detailed graphical description of this process.

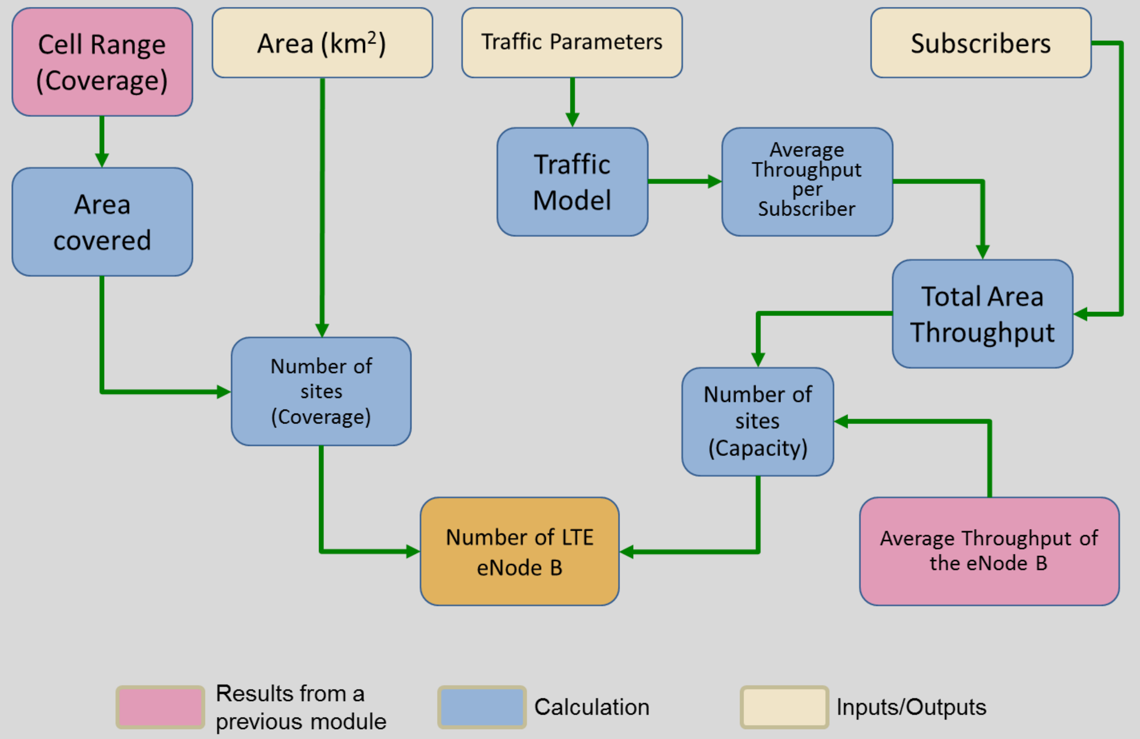
Figure 3-8: Capacity calculation



As shown in the Figure 3-8, the cell range that assures coverage, being based on the propagation properties of the spectrum, is an input parameter for this calculation (see pink box in the upper left corner of Figure 3-8). This range implicitly determines the distance between adjacent base station locations, i.e. the distance that plays a role in the ensuring calculations. First the capacity available in the cell needs to be calculated. The spectral efficiency of a resource block as well as the number of resource blocks (depending on the bandwidth of the available spectrum) determine this capacity. The spectral efficiency is obtained through simulations taking into account the distances between adjacent base station locations. For this we use the results from Elnashar (2014) which lead to average capacities in the range between 1 Mbps for 1,4 MHZ and 17,5 Mbps for 20 MHz, assuming, again following Elnashar (2014), that only 70 % of the maximum capacity is used. In case that the gain from MIMO is also being taken into account, the previous values are increased by the MIMO efficiency factor. Having thus determined the average – measured in Mbps – capacity of the cell (see blue box on the right side), the next task is to determine the average throughput per user, which is derived from the average volume demanded by a user. The number of users is then obtained by dividing the cell capacity by the traffic throughput per user (see beige box at the right).

In Figure 3-9 it is shown how the the cell size to be used for a particular sub-area of a zone is derived from the results obtained according to the two different criteria.

Figure 3-9: Calculation of the number of e-nodes B



The results from the two approaches are represented by the two pink boxes. The result according to propagation properties (upper left corner) is the maximum radius that a cell may have in the given sub-area. From it the maximum size of the cell is derived which is then divided into the total surface area to be covered to arrive at the number locations that are required to serve the given sub-area with this type of cell. The result on the basis of available spectrum capacity (lower right corner) is the average throughput of an e-node B. Taking the required throughput of the total surface of the sub-area, which has been obtained by multiplying the number of users in that sub-area by the average demand per user, provides the number of locations that are necessary to meet the demand in the sub-area. The number of locations implemented by the model is then the larger one from the two approaches.

3.1.5.3 MIMO

As already mentioned in the introduction to LTE in section 3.1.5.1, MIMO was first introduced with 3GPP Release 8. The defining feature of MIMO is that a radio station is equipped with more than one antenna that jointly perform the sending and receiving of two (or more) different data streams. Although Release 10 defines the possibility of up to 8 sender and 8 receiver antennas, in reality there are currently only the 2X2 configurations in operation, where 2X2 means that the configuration must also be available in the end user device.

There are two types of MIMO, single user MIMO (SU-MIMO) and multiple user MIMO (MU-MIMO). In the first case, the maximum bitrate of each user in the cell is increased, in the second case a larger number of users is made possible, without that their bitrate is being increased. The two types imply the same total increase in capacity available in the cell. The implementation of MIMO in the model aims at such a capacity increase which makes it possible that a larger number of users with the same given bitrate is being served.

Given the heavier strain on the battery of the end user device due to MIMO, such devices, although being equipped with two antennas over which to simultaneously receive signals, will in the near future only be able to use one of the antennas for sending signals. From this follows that MIMO is available only for the downlink and not for the uplink connection. This is also being implemented in the model.

From the circumstance that MIMO is available for the downlink connection only, and that the high bitrates made possible by it are realised on the downlink connection, it follows that MIMO serves to increase the capacity and therefore enables a larger cell size in case that spectrum capacity is the constraining factor. The cell size is not affected by MIMO in case it is determined on the basis of the propagation properties of the spectrum, as these become effective via the uplink connection providing a minimum signal strength at the edge of the cell.

The implementation of MIMO is carried out in the framework of the algorithm for LTE, as described in the previous section. This involves the equipment of the base stations with two antennas on the assumption that the end user devices served are also equipped with two antennas. The cell size is then derived based on the available spectrum capacity. Since the LTE algorithm is based on the *given* bitrate that is guaranteed to a user located at the edge of the cell, it follows that SU-MIMO as well as MU-MIMO increases this capacity. This increase in capacity derives from an improvement in the spectral efficiency that MIMO makes possible. The gain obtained thereby is expressed as a factor, which is to be introduced into the model as a parameter. Empirical studies have shown that in the case of a 2X2 configuration this gain generally amounts to 54%.[10] The model takes this efficiency gain into consideration by increasing the efficiency of each resource block. From this follows that if e.g. 50 RB are made available through a spectrum block of 10 MHz, the model proceeds as if the increase in spectral efficiency increases the number of RBs by 54% so that it dimensions the cell on the basis of the availability of 77 RBs instead of 50. Besides this change in parameterisation no change in the algorithm of the network planning tool is needed. In

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[10] See Kuipers and Correira (2008).

the cost module, positions must be introduced through which the investment into additional antennas are taken into consideration.

3.1.5.4 Carrier Aggregation

Carrier Aggregation (CA) was introduced with Release 10 of 3GPP. Using this new development, it is possible to aggregate blocks of spectrum from different frequency bands (also called component carriers) and thereby increase the capacity for providing services. There are two types of CA, Intra-band and Inter-band, where in the first case it is the question of separate blocks in the same frequency band and in the second case of separate blocks from different bands.

When Intra-band CA is employed, i.e. the different component carriers are in the same band, the same propagations properties of the spectrum apply. In respect of capacity for handling volumes of traffic, the sum of the capacities of the two components carriers can be regarded as one single carrier, From this follows that there is no need to change anything in the modelling itself. It is only necessary that in the relevant mask of the user interface the corresponding spectrum capacity is entered in the appropriate input field.

This is different fir Inter-CA. In this case component carriers from different bands having different propagation properties are joined. This is of relevance both in the case that the propagation properties are determining the cell size as well as in the case that the aggregated capacity of the component carries is the size-constraining factor, as will become apparent when describing in the following the implementation of this type of CA as part of the algorithm for LTE cell deployment.

It can generally be assumed that the operators use carrier aggregation, in particular Intra-band CA, if the capacity of the spectrum available from a single band is not sufficient to meet the demand for mobile broadband services. Thus CA will be implemented in the model for these cases, where then CA can be activated by a parameter provided by the model user. The modelling will be carried out in a way that also the case that the cell size, despite the generally prevailing large demand, is nevertheless determined by the propagation properties of the spectrum. This would normally not be expected but this possibility is included for the sake of consistency.

In the following we describe the various steps the model undertakes when determining the cell size under Inter-band CA, both for the case that it is the spectrum capacity that is the size-constraining factor and for the case that it is the propagation properties of the spectrum that determine the size of the cell:

(1) Determination of the cell size on the basis of the totally available spectrum capacity (using the methodology presented in Section 3.1.5.2). For this purpose, the spectrum capacities of the different component carriers may simply be added up.

(2) Determination of the cell size on the basis of the propagation properties of the spectrum from the higher frequency band (e.g the 2.6 GHz band in case there is also spectrum available from 1 800 MHz band). If this cell size is larger than under (1), the selection process is already terminated, given that in this case the demand is so large that the capacity of both bands is needed to serve users in a cell that is smaller than the one that would be based on the propagation properties of the higher frequency band (as the latter would be the smaller one of the possible two cell sizes based on propagation properties).

(3) In case the cell size under (1) is larger than the one under (2), it is determined which part of the capacity is needed in order to meet the demand in the cell area defined under (2), i.e. that part of the cell area, that can be served using spectrum from both frequency bands. There will be a remainder of capacity that comes from the lower of the two bands[11] and which can be used in the part of the cell where CA is not feasible any more. This remaining capacity determines the area in a ring around that area that is being served by the carrier components from both bands. The corresponding programming will again rely on the methodology developed in Section 3.1.5.2.

(4) If the test steps show that the cell size is to be determined on the basis of the propagation properties, the question arises whether this should be on the basis of the propagation properties of the higher or the lower frequency band. It can be demonstrated that the (better) propagation properties of the lower band, which enable a larger cell site, are the constraining factor. If this case arises the model determines the cell site based on the propagation properties of the lower frequency band.[12]

Figure 3-10 shows the flow chart for this modelling process.

Concerning the frequency bands from which the spectrum to be used for Inter-band CA are selected, it must be taken into consideration that for this selection altogether five frequency bands are available. In the model there will be a mechanism that selects for each zone the two bands out of the possible five bands. This is carried out by having the corresponding algorithm calculate the cell size for each possible combination of two bands. The spectrum combination that leads to cells with the lowest cost is then selected as the one to be implemented. From this follows that depending on the

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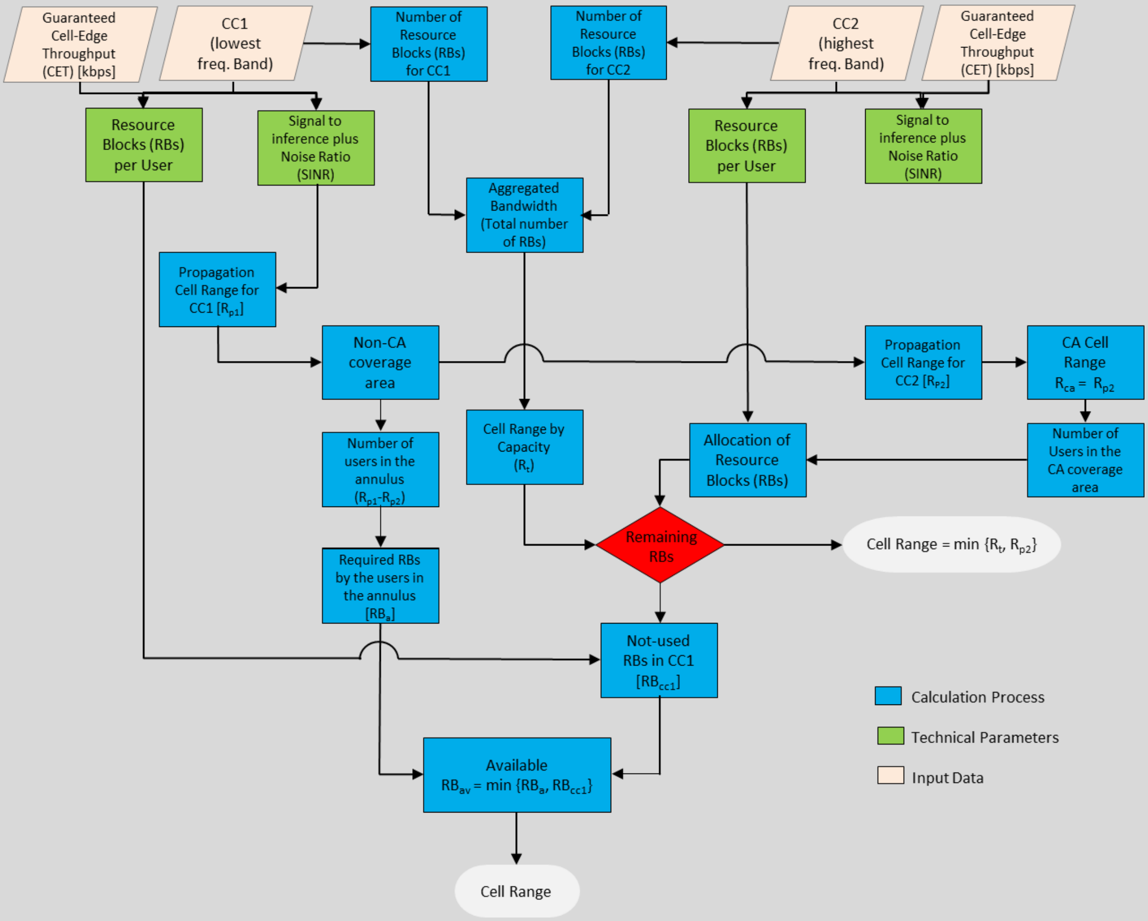
[11] The possibility should not be excluded that there remains the total capacity of the lower band together with a remainder of the other band. In this case, only the capacity from the lower band could be used, to meet additional demand (given that the propation properties of the remainder from the other band would not allow its utilization). However, this case would be in contradiction of the purpose of CA as the capacity of the spectrum further above would be sufficient, to meet the demand within the range defined by its propagation properties.

[12] The case is comparable to the one in the preceding footnote. In case of such a demand, the deployment of CA would not make sense.

demand and other features, in each given zone, different combinations of frequency bands may be implemented.

Figure 3-10: Calculation of the cell radius when Carrier Aggregation is used



3.1.6 Voice over LTE (VoLTE)

3.1.6.1 Overview over the developments regarding VoLTE

VoLTE means the delivery of voice service in the LTE network, based on VoIP by integrating voice services under the IP protocol. Currently, operators offer over LTE primarily data services taking advantage of the improved bandwidth of LTE, while voice services are still predominantly provided over UMTS and GSM. A more extensive migration of voice services on to LTE is to be expected with the introduction of so-called

Rich Communications Services (RCS),[13] i.e. when the facilities required for the provision of RCS – and VoLTE as part of RCS – appear to be justified.

A stepwise introduction of VoLTE is thus taking place. To facilitate this process, a number of special procedures have been developed and standardised, e.g.:

- Circuit Switched Fallback (CSFB) and
- VoLTE in connection with IP Multimedia Subsystem (IMS).

Of these, the second approach is the one that is most likely going to be adopted in future networks providing predominantly voice over LTE. In the current situation of stepwise introduction of VoLTE, both approaches are being used by operators. Accordingly, as described in the following paragraphs, the adapted version of the model will allow both approaches.

Besides CSFB and VoLTE over IMS, a further procedure, referred to as VoLTE over Generic Access (VoLGA), has been developed. VoLGA avoids the disadvantages of a relatively slow set-up of a connection when using CSFB, but would require considerable modifications in the end user devices as well as in the network. As VoLGA is currently not standardised by 3GPP and has not been successful in the market, VoLGA has not been implemented in this version of the model.

3.1.6.2 Meeting the demand for VoLTE – Possible implementations in the network planning module

Section 3.1.5 describes the implementation of LTE in the model without referring to any differences that may exist between the types of services provided over it. When in addition to data also voice services are provided over LTE, this implies at first sight simply that there will be a new service for which in the the radio access network capacity in terms of hardware as well as spectrum has to be made available. There is therefore no change in the planning and dimensioning of the LTE cells, except that this additional capacity has to be provided for. In this context, however, it has to be clarified what exactly constitutes the demand for VoLTE and how this demand has to be realised given different preconditions.

In the case that users have handsets that are LTE enabled, they would normally like to realise their demand for voice connections also over this technology, although the technical preconditions for genuine VoLTE may not yet exist in the network. In this case Circuit Switched Fall Back (CSFB) can be used. Already at the time of set-up of the connection in the radio access network, due to signaling, a connection over UMTS or

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[13] RCS is a standard defined by the GSMA that offers users enhanced communication services and is implemented under LTE by way of the IMS platform.
See GSMA website http://www.gsma.com/network2020/rcs/.

GSM is established and this type of connection will be maintained. This means that only the corresponding signaling for the set-up and dismantling of the connection in the UMTS or GSM networks has to be carried out over facilities of the LTE network, and the functions of the IMS are not required. The user initiating the call then gets virtual VoLTE service and will not be aware of this circumstance, except that he/she may notice the associated additional delay in the set-up of the connection. For a user logged in to the LTE network who receives such a call, the CSFB signaling assures that this user can receive the call over UMTS or GSM. As a precondition for this arrangement it is necessary that parallel to LTE there is also UMTS or GSM implemented, which is generally the case in practice as well as in the model.

The model realises a version of the radio access network, in which CSFB and genuine VoLTE based on IMS can be realised in parallel. The demand for genuine VoLTE is from the very beginning, i.e. when specifying the demand, constrained to include only that share of voice that from one end to the other, from the calling to the receiving party. is realised over the LTE network. For the share of voice that is realised over CSFB, it is also specified from the very beginning that it will be part of the volume of voice traffic that is either carried over UMTS or GSM. This is possible given that the realisation of these connections over the legacy networks is initiated by signaling which does not have any impact on the radio access network. For the part of VoLTE that actually runs over the LTE network, the following section will describe the consideration of VoLTE traffic in a LTE network. In case of a 100% LTE network, it should be noted that the model can accordingly be parameterised..

3.1.6.3 Cell planning in the radio access network in case VoLTE realised over IMS

The introduction of genuine VoLTE means that there is a second voice service in the model, i.e. one that is completely packet-switched. It is necessary to treat VoLTE in the model as a separate service from classical voice, since for the same volume of demand the capacity requirements differ from those of circuit-switched voice, in particular also because of the fact that different VoLTE may be realised by different versions of codecs. The codec is the mecanism used to transform the analog signals of a conversation into digital signals. It generates for each interval of 20 milliseconds, depending on the type used, a larger or smaller number of bits. The standard variant used for VoLTE is the AMR-WB voice codec with a bitrate of 12.65 kbps, which assures a quality that is equivalent to that of a circuit-switched voice service and is recommended by the GSM Association. Through an appropriate parameterisation it is also possible to implement further variants of the codec working with higher bitrates (e.g. 23.85 kbps).

The volume of VoLTE to be realised in the modelled network will, as it is the case for classical circuit-switched voice service, be introduced as an input into the model (i.e. a volume measured in minutes and then presented within the model as an Erlang value per user during the busy hours). In order to make the VoLTE service comparable to the other LTE services, this volume will then be transformed into kbit. For this, the voice volume expressed in Erlang is transformed into seconds and multiplied with the kbit rate of the particular codec used. (volume in Erlang*3,600) * kbps = (volume in kbit).

As mentioned, the standard voice codec used for VoLTE is the AMR-WB voice codec with a nominal bitrate of 12.65 kbps. Since VoLTE is packet-switched, and since each packet must be provided with an overhead, the nominal rate has to be augmented by this overhead. Taking this overhead into account leads to an actual bitrate of 15.85 kbps,[14] which is necessary to transmit with the appropriate quality the voice signals from one end to the other. If a codec with a higher bitrate is used, this will not affect the size of the overhead.

By dividing the volume in kbit – derived from the volume in Erlang – by the number of seconds in one hour, i.e. 3,600, we obtain the average bitrate that the cell must provide in order for it to be able to transport the voice signals. This bitrate will be added to the bitrate needed for data so that as a result there is one single bitrate. In other words, the system must be dimensioned in a way that the bitrate obtained by adding up the required bitrates for both voice and data can be realised.

There is, however, one important point that needs to be taken into account. As mentioned, the network will be dimensioned to meet the average demand and therefore also the average bitrate during the busy hour. Voice is, however, time sensitive which means that it is not sufficient to meet the bitrate requirement on average but as much as possible in real time. This in turn means that the packets for VoLTE need to be handled with priority. For this purpose, the capacity that in any case has to be available for VoLTE is increased by an additional capacity which can then be used to assure this priority treatment. The amount of the additional capacity can be controlled by the model user by specifying a given parameter.

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[14] The length of each of the packets which transmit VoLTE amounts to 20 milliseconds. From this follows that each packet carries 253 bits (12.65 bit/s * 20 / 1,000). The overhead of a packet, consisting of the requirements for header and further control functions, requires altogether 64 bits so that each packet consists of in total of 317 bits. From the fact that this number of bits is to be transmitted in intervals of 20 milliseconds follows the bit rate of 15.85 kbps mentioned above. The mentioned additional 64 bits correspond to the total length after application of the Robust Header Compression (RoHC) to a part of the headers. Before RoHC, the length of the headers for the Real Time Protocol (RTP) is 12 bytes, the ones for the User Datagram Protocal (UDP) 8 bytes and the one for the Internet Protocol (IP) 20 or 40 bytes, What value is used for IP depends on the IP version, for IPv4 the length is 20, for IPv6 it is 40 bytes. The maximum length of the header is then 40 or 60 bytes, depending on which IP version is used. In both cases, the header is longer than the payload of 253 bits (31.625 bytes). It is for this reason that the RoHC is used which is able to decrease the total length of the header on the average of a length of 3 bytes or 24 bits. Finally, the headers for the Packet Data Convergence Protocol (PDCP), the Radio Link Control (RLC) and the Medium Access Control (MAC) have to be considered, for which in the model 40 additional bits are added. All these components add up to a total length of the header of 64 bits.

Once, the required bitrate corresponding to the sum of the voice and data volumes, has been determined, the dimensioning of the LTE radio access network can proceed as discussed in Section 3.1.5.2.

For an adequate cell planning, the move of active users from a voice enabled LTE cell to a region without LTE has to be considered. Signalling makes sure that the switch to legacy networks takes place. This implies for modelling, that the volumes of demand used to dimension the network are based on empirically measured traffic volumes. No further adaption is necessary as the measured traffic volumes realised over the different technologies already take into account the connections requiring a change of technology .

3.1.7 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.

3.1.8 Considerations regarding motorways 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 features of these base stations are as follows:

- Type for macro cells in rural areas with a high tower enabling it to cover large distances;
- Large transmission power and
- Two sectors.

The tunnels on these traffic arteries will be equipped with repeaters that emit/receive the signals into/from inside the tunnels. The model takes into account that repeaters are limited in the distance they are able to cover, so that for longer tunnels more repeaters are needed.

3.1.9 Signalling

Besides the actual signalling functions, there are several internal control functions for which corresponding channels have 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 the case of UMTS/HSPA as well as LTE, no physical connections are reserved for signalling traffic. As the total available capacity of the cell is shared by the total traffic within the cell, the corresponding connections are provided only virtually. At the radio interface only a small part of the available spectrum capacity is assigned to the bearer traffic, so that for signalling always sufficient bandwidth is available. This is also true when increased signalling traffic for new services (i.e., “always online” for smartphones) must be met, for which a capacity reservation has to be considered simultaneously on the downlink and the uplink as well as in the core network.

In summary, always sufficient capacity for signalling traffic at the radio interface will be modelled. This kind of transmission capacity is neither taken into account in the backhaul nor in the core networks as the signalling capacity needed is relatively small compared to the user traffic. The model takes this into account through mark-up factors (see Table 3-5 in Section 3.6) which limit the rate of utilisation of the transport capacities and also provide sufficient capacity for the signalling traffic. For this version of the model, which includes virtual VoLTE using CSFB as a new function, the values of the mark-up factors that have so far been used may need to be adapted to meet the increased signalling requirements, where however these previous mark-up factors had already been set conservatively.

3.2 LTE transport network

Taking into account the LTE technology requires the modelling of a layer 1 and 2 transport network to carry LTE traffic to the facilities of the core network. This transport network will not need any controller functions as it is the case for legacy networks. In a hybrid network that integrates all three technologies, the traffic volumes of all three technologies are carried in a common transport network, respectively, the LTE transport works in parallel to the aggregation and backhaul networks installed to handle GSM and UMTS traffic. This implies that the LTE traffic has to be considered for the dimensioning of the aggregation and backhaul networks (see next sections). Reference will be made each time, when LTE traffic will be considered.

In a modelled pure LTE network, the LTE transport network will be built with concentration points that geographically are positioned between the e-nodes B and the core network. They are considered at locations corresponding to the locations in the legacy networks in line with the minimum transport cost considerations. As it is the case for the controller facilities in a GSM and UMTS network, the user of the model specifies the number of these concentration points taking over the aggregation function, but no investment is considered for controller facilities.

3.3 Aggregation network

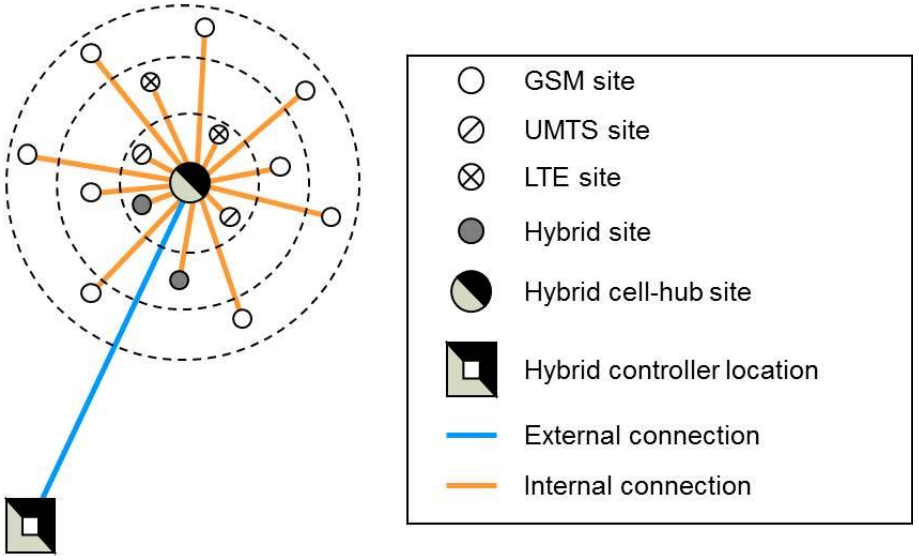
In both GSM and UMTS/HSPA networks, the aggregation network connects the base stations with the controllers. As previously discussed the functions of aggregation and backhauling of traffic are taken on by the LTE transport network. This section deals with the modelling of the aggregation network for a GSM and UMTS network including the transmission systems needed for LTE traffic. The concluding Section 3.3.3 describes which network elements are needed for this network segment in the case of a pure LTE network.

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, hereafter 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). Further, controller locations are considered a part of the aggregation network..

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 several types of bases stations, BTS node B or e-node B. Figure 3-11 shows a schematic example.

Figure 3-11: 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 (inclusive that for LTE traffic) over the corresponding links (blue line in Figure 3-11),

(4) Calculation of the required interconnection capacity (inclusive that for LTE traffic) between individual cells or base stations and their corresponding cell-hub (orange lines in Figure 3-11),

(5) Calculation of the required interconnection capacity (inclusive that for LTE traffic) 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[15]). The model's approach to these two problem is first taken up. Then follow the descriptions of the solutions to (4) through (6), i.e. the tasks for the determination of the transmission capacities and the assignment of the corresponding systems.

3.3.1 Determination of the controller locations

3.3.1.1 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

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

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.[16] 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 3-12 shows a flow chart for the algorithm.

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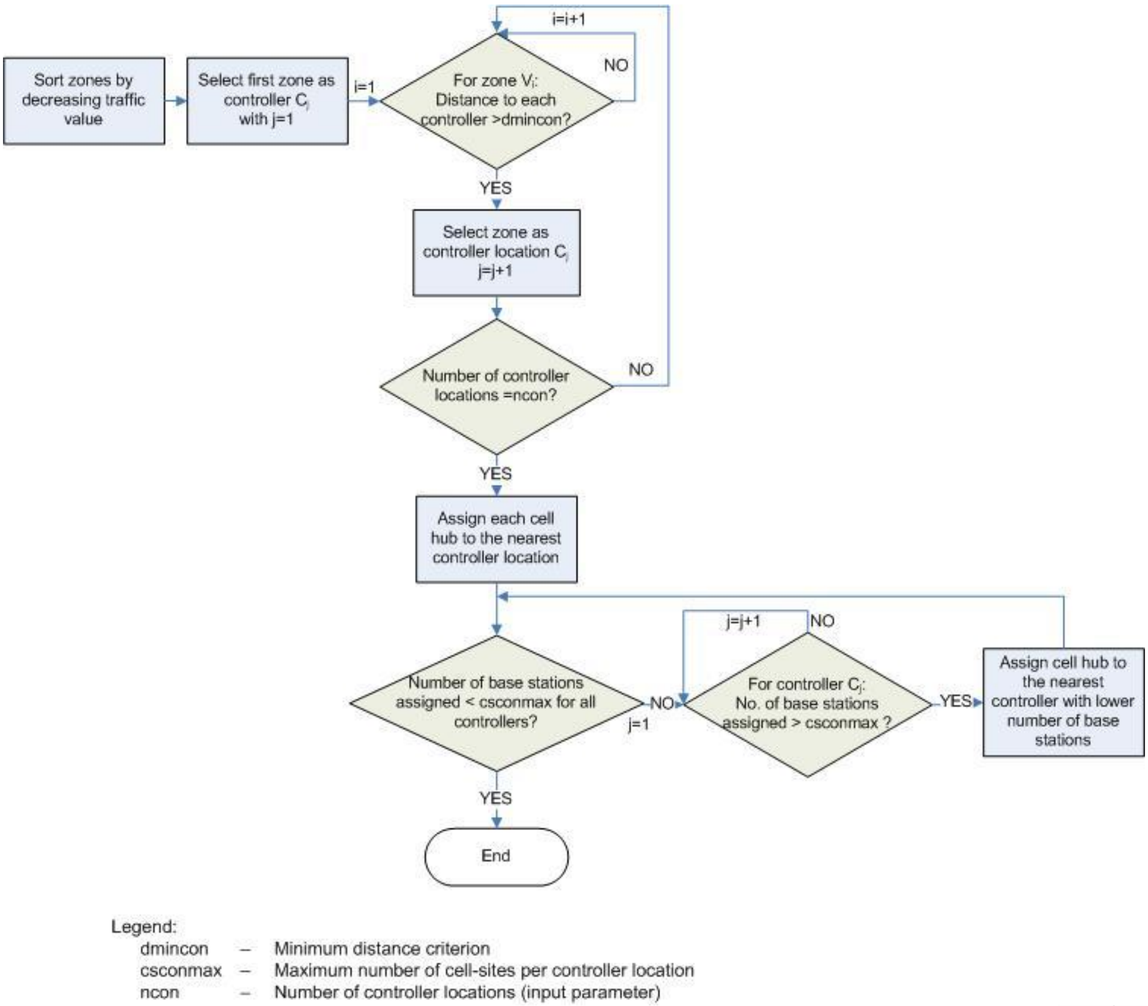
[16] For more details regarding the Depth First Search Principle see Cormen et al. (2001).

Figure 3-12: Flowchart for the determination of the controller stations and the allocation of the cell-hubs



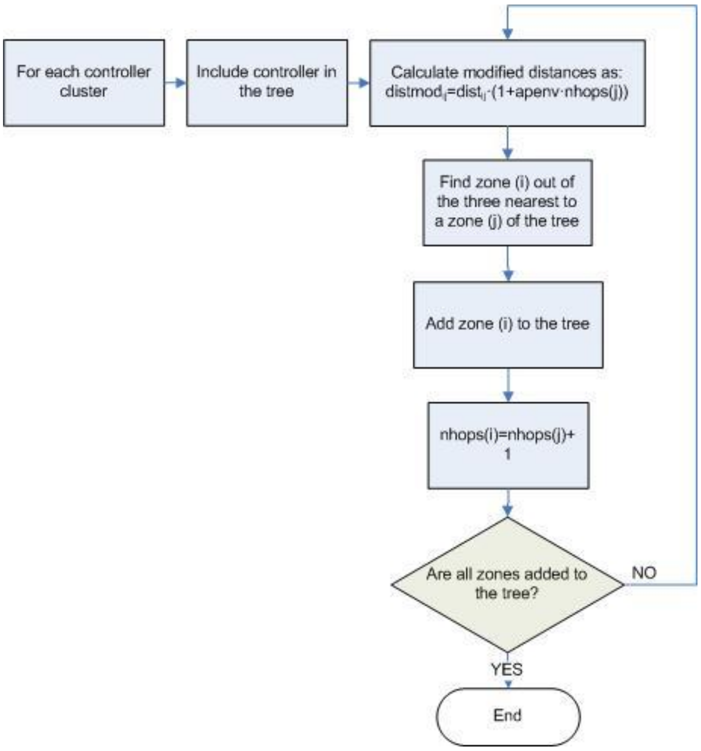
3.3.1.2 Algorithm for determining the links of cell-hub locations with controller locations

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 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 3-13 shows the flow chart of the process described above. In Figure 3-17 of Section 3.3.2.2.2.2 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 3-13: Flowchart of the calculations for determining the locations of the topology between cell-hubs and controllers



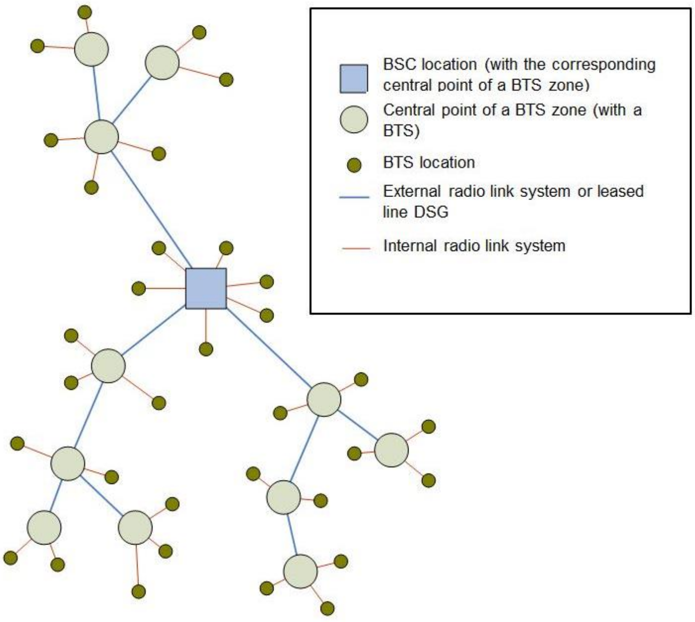
3.3.2 Topology, dimensioning of the capacity and determination of the systems

3.3.2.1 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 the other 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 3-14 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 3-14: Example of a tree topology for a cluster controller that connects the cell locations, cell-hubs and the controller locations in a GSM network

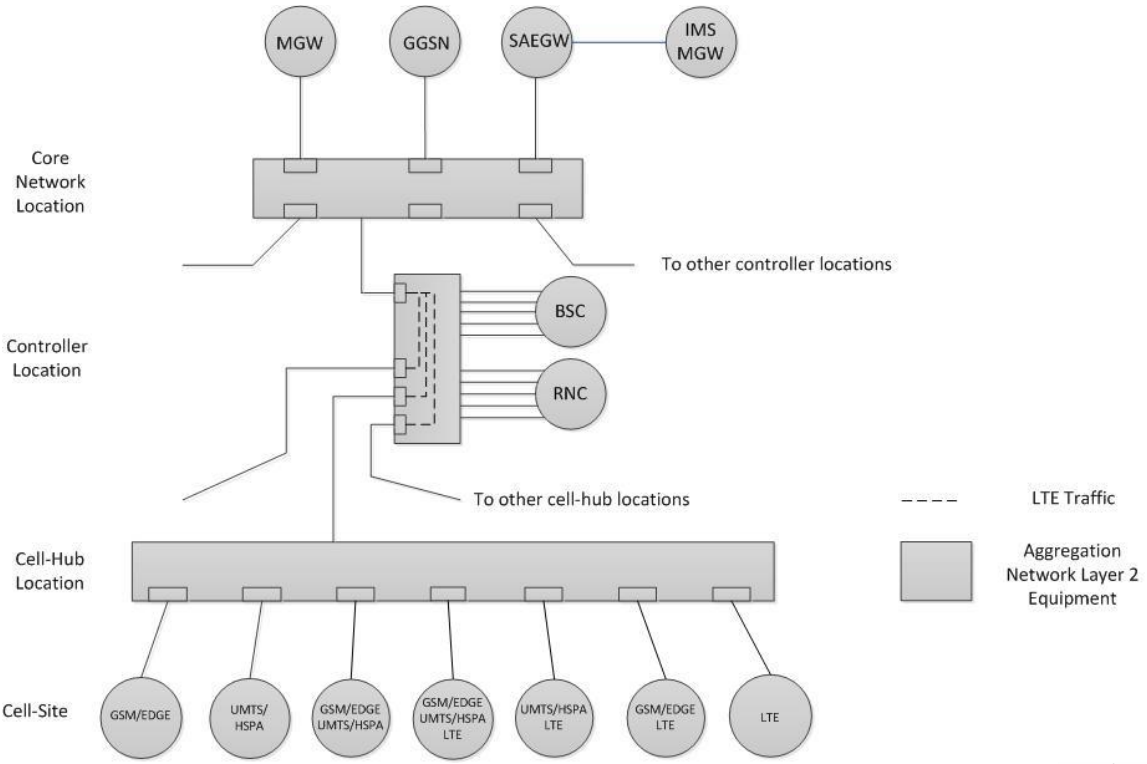


3.3.2.2 Dimensioning

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 what combination of GSM, UMTS, HSPA or LTE traffic must be carried; they will be described in the following section. Figure 3-15 shows the three main components of a mobile network in terms of the equipment of layer 2 and the connections between them.

Figure 3-15: 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 sections.

Later in the document it will be shown that the dimensioning of the facilities is expressed in terms of generic parameters so that different types of network realisation (leased lines or own infrastructure in form of microwave links) are made possible.

3.3.2.2.1 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 100 Mbps or 1,000 Mbps, if HSPA, HSPA+ or LTE 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 signals from the different base stations (GSM, UMTS/HSPA, LTE) 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 base stations for UMTS or LTE, 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 UMTS/HSPA and LTE equipment are assumed to be based on IP/Ethernet and the corresponding interface cards are assumed to be integrated inside the base station 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 utilisation of the system at a particular level. Hence, the model considers for each network level above the radio access network a pre-defined utilisation 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 utilisation factor. The question of how in general QoS requirements are met will be taken up in Section 3.6.

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 costs 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 optimisation 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 the UMTS/HSPA or LTE 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.

3.3.2.2.2 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 3.3.2.1). 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.

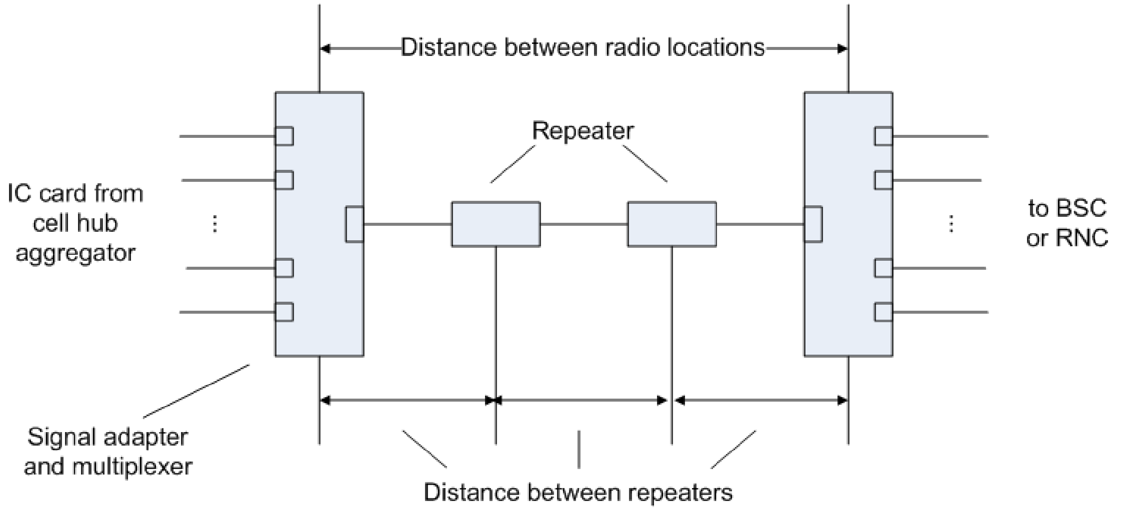
Once the capacity in form of equivalent bandwidth requirement has been determined for each connection in the topology, the model determines the systems for those connections in the same way as done for the connections between the base stations and cell-hub locations.

3.3.2.2.2.1 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 utilisation 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 3-16 shows schematically the elements of such a physical connection.

Figure 3-16: 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

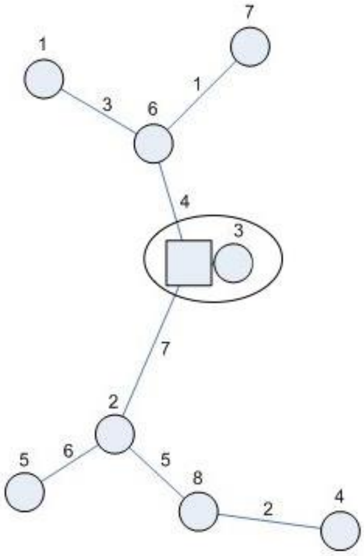
Features of the system	**Index of system type**			
	1	**2**	**3**	**4**
	Possible values of the characteristics			
Maximum net bandwidth (Mbps)	8	32	140	560
BWport [Mbps]	100	100	1000	1000
Maximum length (km)	50	50	50	50
Parameter providing a threshold which indicates the number of lower systems to be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

3.3.2.2.2.2 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 3.3.1.2.

Figure 3-17 shows an example of the application of the algorithm described in Section 3.3.1.2. 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, e.g. 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 3-17: 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.

3.3.2.2.3 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.

3.3.3 Aggregation in the case of a pure LTE network

As discussed in Section 3.2, a pure LTE mobile network requires here only the transport of traffic to the concentration points. As for the legacy networks, the number of locations for these concentration points has to be set by the model user, while their geographic positions are determined by the model. For this calculation, similar criteria are used to those for the controller locations. However, in a pure LTE network, only the transport network is optimised and not, as in GSM and UMTS/HSPA networks, the controller facilities. From a methodological point of view, the modelling of the aggregation and transmission systems is carried out according to the same planning and dimensioning rules as in the case of an aggregation network for a hybrid network. However, as pure LTE networks make only sense when an increased demand for bandwidth is required by the users' traffic, the transmission systems should be dimensioned accordingly. The model allows this, as appropriate transport systems can be selected with relevant model parameters. In a pure LTE network, the parameterisation would e.g. not include the operation of microwave systems but would predominantly be based on fibre systems modelled as leased lines.

3.4 Backhaul network

In a GSM and UMTS network, the backhaul network connects the controller node locations with the locations of the core network where the switching and routing systems are situated. In a LTE network, the comparable network segment is the transport network (see Section 3.2) transporting the LTE traffic between the concentration points and the facilities of the core network assuming a hybrid network collocation of the concentration points with the controller locations. This section deals with the modelling of the backhaul network of a GSM and UMTS network. As in the case of the aggregation network, when planning and dimensioning the backhaul network, the LTE traffic will also be included. In the concluding Section 3.4.3 points out which network elements are needed for this network segment in the case of a pure LTE network (without controller functions).

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.

3.4.1 Determination of locations for the core network

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 3.3.1). 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.

3.4.2 Topology, dimensioning and transmission system determination

3.4.2.1 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[17]. 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[18], and it consists of two steps:

- Determination of the clusters that are attached to the same ring, and

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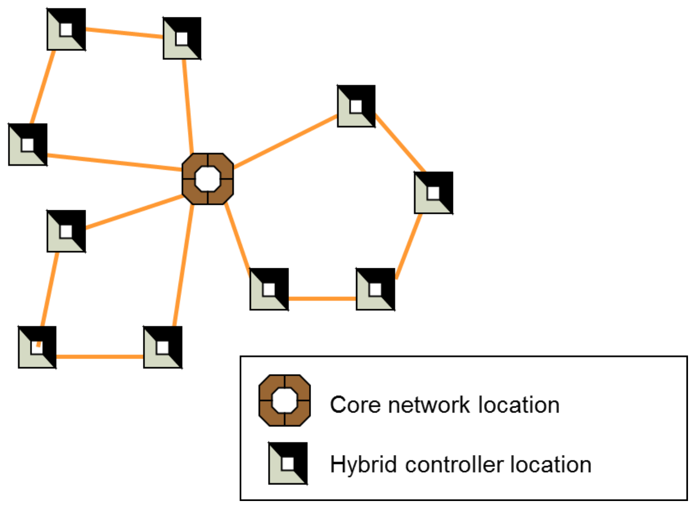
[17] See Domschke (1982).

[18] See Silió et al. (2011).

- Calculation of the topology for each ring.

Figure 3-18 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 3-18: Example of a backhaul network topology



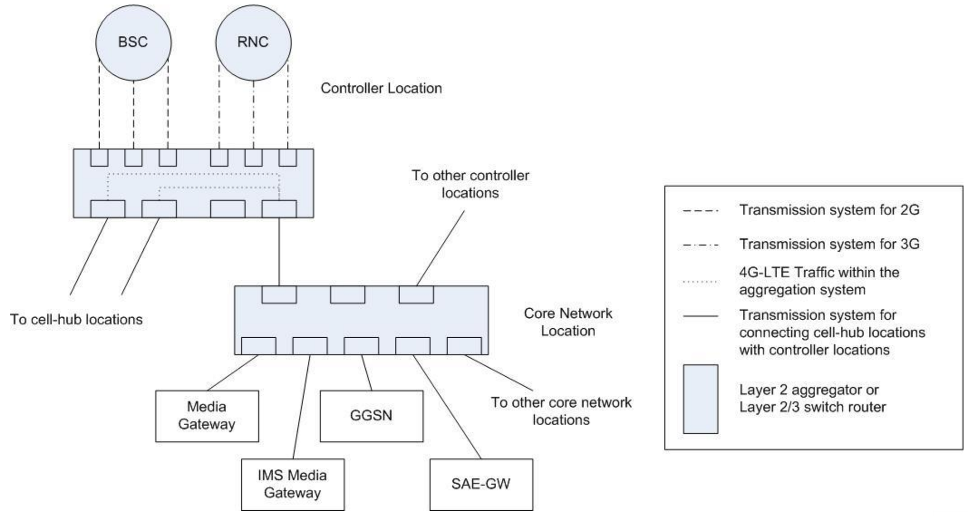
3.4.2.2 Dimensioning

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 3-19 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 3-19: Backhaul network and its key components



3.4.2.2.1 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 utilisation of the systems (utilisation 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 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.

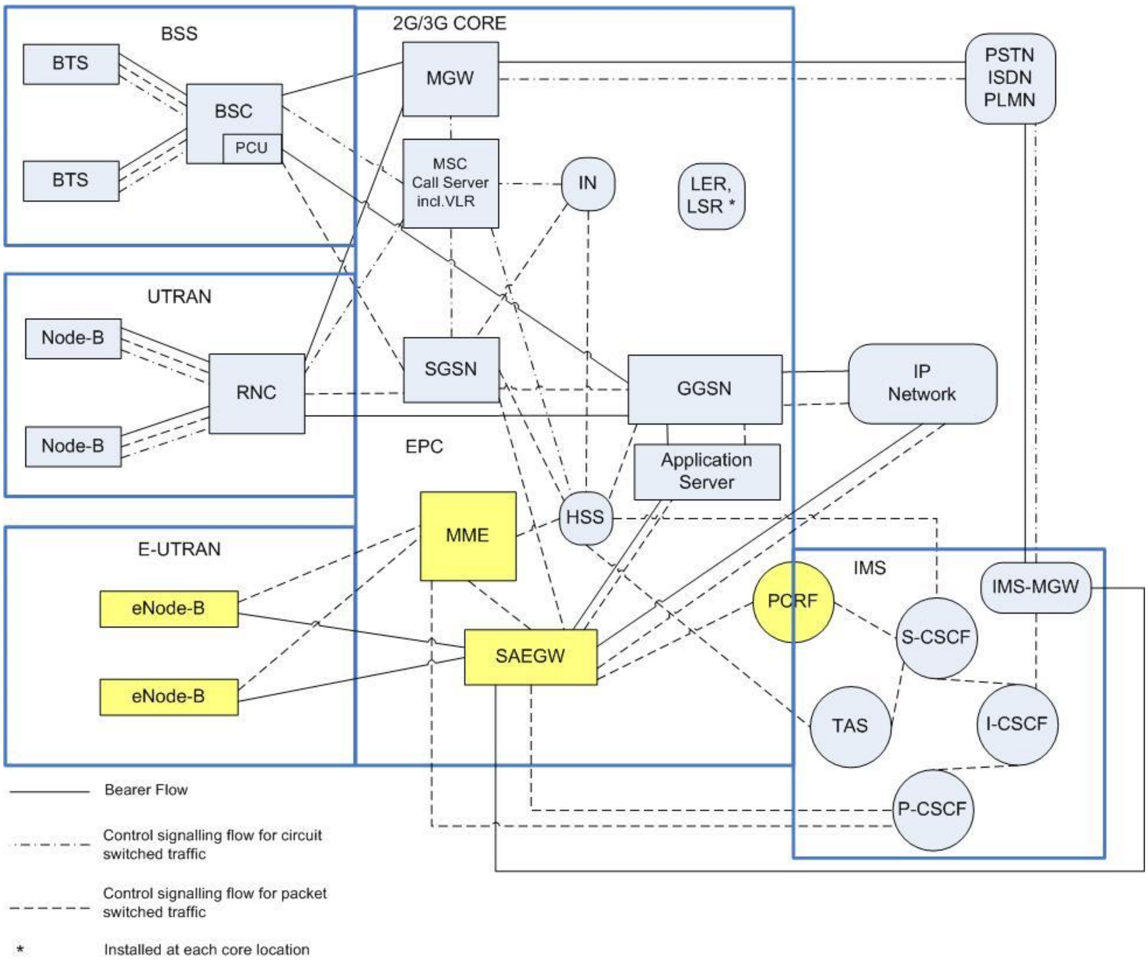
Table 3-3: Cost drivers for BSC and RNC and typical utilisation factors.

Type of controller	**Cost driver**	**Utilisation**
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 Mbps	80 %

3.4.2.2.2 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 6, 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 3-20 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%. The required bandwidth for LTE traffic are treated the same way as the bandwidths resulting from GSM and UMTS traffic.

Figure 3-20: Logical connections between the functional blocks at the controller node locations and the locations of the core network, based on elements of 3GPP Releases 4 to 10



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 3.3.2.2).

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[19] 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 3.6);
- 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 3.3).

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 utilisation 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,[20] which have been used in previous analytical cost models[21]. 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 3-21. Alternatively, leased lines with the corresponding bandwidth can be used instead of microwave equipment. The cost of the RADM has 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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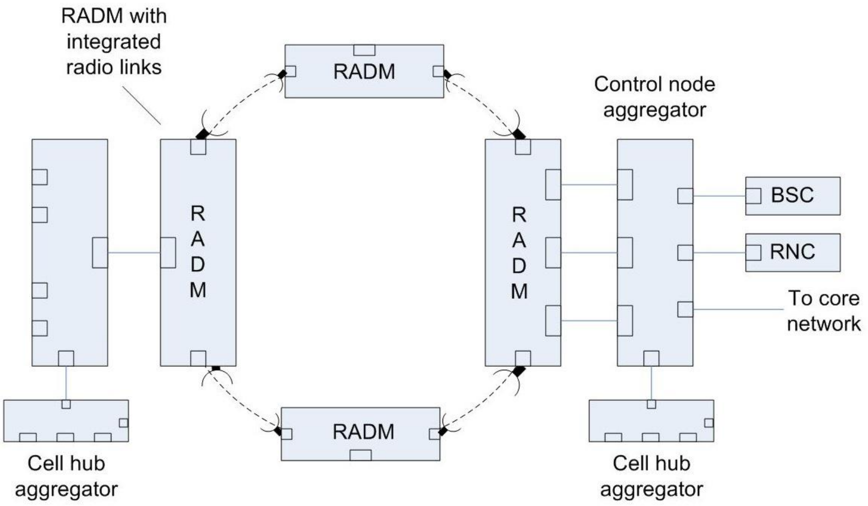
[19] For transmission systems of packet switched networks, there is a limitation on the utilisation of the systems which in the model is implemented through a relative utilisation factor. The value of this factor lies typically between 0.7 and 0.9, depending on network type (mobile or fixed) and the bandwidth that is aggregated on each of its network levels. This implies an overdimensioning, which in the model is expressed through mark-up factors for each level, that are determined as the reciprocal of the utitlisation rate. See the discussion regarding in Section 3.6.

[20] See Lin and Kernighan (1973).

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

Figure 3-21: Schematic representation of a ring topology on the basis of microwave with RADM



3.4.3 Backhauling in the case of a pure LTE network

The function of this network segment in a pure LTE network remains the same as in the backhaul network for a hybrid network. However, a network of concentration points is planned instead of controller locations. The planning and dimensioning rules for the aggregation and transmission systems remain the same, except that these systems are to be used for LTE traffic. The same observations apply to the relevant types of transmission systems as were made in Section 3.3.3 when discussing the aggregation segment of the network in case of a pure LTE network.

3.5 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, the focus is on those facilities related to the 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, as well as other core network facilities influencing the routing of voice services. Since the model implements all current technologies, facilities for the traditional core network (2G/3G core) for GSM and UMTS traffic as well as the facilities for the Evolved Packet Core (EPC) have to be modelled. Facilities for data services that do not have a role in the routing of traffic, (e.g. applications servers) will not be modelled. Table 3-4 in Section 3.5.6 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 in cell sites with GSM or UMTS equipment. With packet-swiched LTE, voice over LTE (VoLTE) can now also be realised over the modelled network. For this the minimal necessary elements of an IMS platform must be modelled in the core network. If an operator realises only data traffic over LTE, the model will assume that the circuit-switched voice traffic initiated by LTE-enabled handsets is carried via CSFB by the facilities of one of the legacy networks (e.g. GSM network which has universal coverage) (see Figure 3-22 infra).

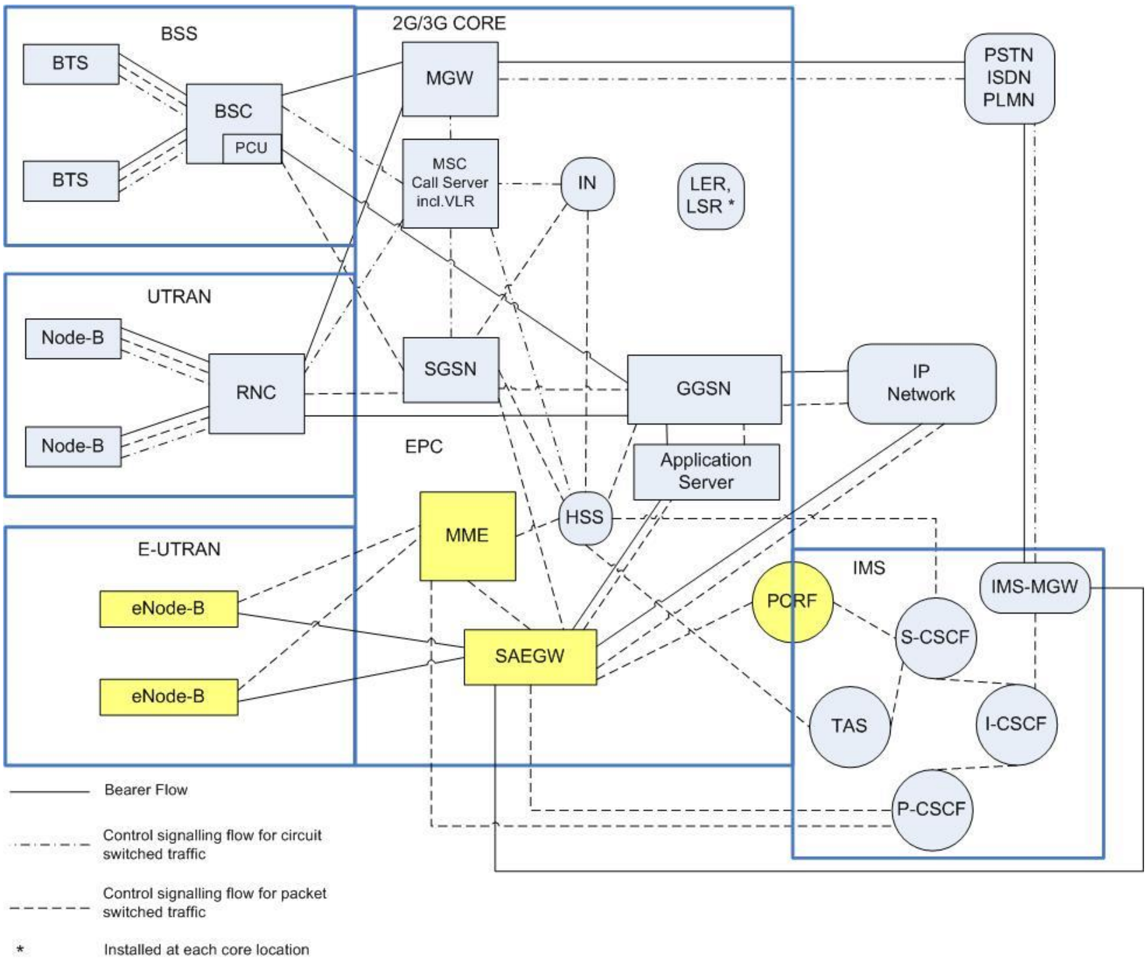
The approach to the dimensioning of the core network differs according to whether GSM/UMTS circuit switched services or EDGE/UMTS/LTE packet-switched services are to be handled. This is due to the fact that the model considers the corresponding GSM/UMTS circuit switched traffic in the form of fixed units (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 the dimensioning of the circuit switched traffic, especially classical voice traffic, is dimensioned as a loss model, which is expressed by the classical Erlang loss formula. In the case the traffic between two core network locations routed over more than one core location in between, one or more Label Switch Routers (LSR) are added. In the case of a fully meshed core network, however, LSRs are not necessary, since in this case the LERs are directly connected among themselves.

The capacity requirements of the packet-switched EDGE and UMTS traffic streams are derived from the corresponding values for packet rate and packet length. For this the model considers that the delay of the packets of an end-to-end connection on any of the different network levels depends on the capacity utilisation of the transport systems. The model user can control the degree of these delays for each network level through the use of appropriate mark-up factors. The actual delays resulting therefrom are calculated on the basis of a queue model for each of the service categories.

For LTE traffic, both data and voice traffic are handled in the EPC the same way as UMTS. Again packet rate, packet length and end-to-end delay are the relevant parameters, where for packets carrying VoLTE appropriate short delays are specified. The packet streams from LTE traffic are handled in the EPC locations by dedicated elements of the logical network (S-GW and P-GW), but in the transport network connecting the core locations they are handled by the same elements as in the UMTS network (LERs and LSRs as well as leased lines). The dimensioning of these network elements is carried out in a way that the end-to-end delays resulting from the QoS requirements of the various service categories, including those for VoLTE, are being maintained.

In summary, there are three different parts for the design and dimensioning of the core network: facilities for the circuit-switched traffic from the corresponding GSM and UMTS traffic shares, packet-switched data traffic from the EDGE and UMTS/HSPA cells and packet-switched voice and data traffic from the LTE cells. The corresponding modelling is described in the following three sections. The three-part division of the core network has already been shown in Figure 2-2 and Figure 3-20; to facilitate comprehension of the following discussion, it is presented here again in Figure 3-22 infra.

Figure 3-22: Logical connections between the functional blocks at the controller node locations and the locations of the core network, based on elements of 3GPP Releases 4 to 10



3.5.1 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 at 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 these 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, implying that the ports of each interface card are differentiated according to whether they are based on TDM or Ethernet technology. The shares of the two types of traffic can be determined by a parameter. In the case of voice interconnection that is based on Ethernet, the function of the Session Border Control is assumed to be part of the CS-MGW as well as the IMS-MGW.

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 3-23 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.[22] 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

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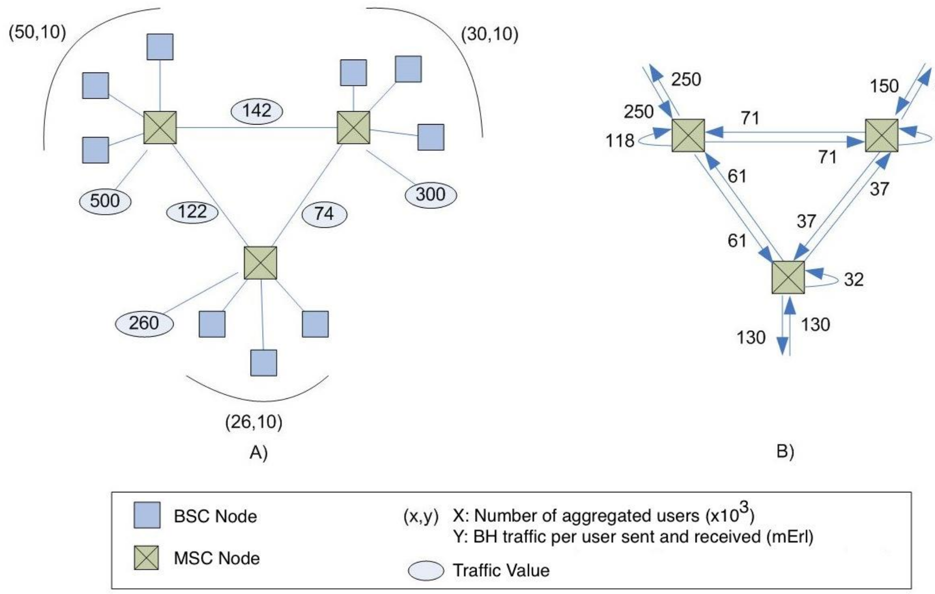
[22] Note that the model considers symmetry for on-net traffic due to the fact an outgoing on-net call from a cell phone causes always an incoming call to a cell phone in the same network.

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.

Figure 3-23: 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 3-23, 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.

3.5.2 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 over the local GGSN to the geographical nearest core network location where a corresponding server is installed. The model installs GGSN facilities at all core network locations where there is an interconnection with external IP networks and external servers, while the number of locations with SGSN facilities is set as a parameter by the model user. The number of sites where the application servers are installed is also determined by an input parameter, while the core nodes with the highest traffic loads are used for their position in the network. From this follows that the number of locations for application servers may not exceed that of IP interconnection points. 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.

3.5.3 Design of the core network systems for LTE traffic in the EPC

In the EPC essentially two network elements need to be implemented:

(i) The System Architecture Evolution Gateway (SAE-GW), encompassing the functions of the Serving Gateway (S-GW) and the Packet Data Network Gateway (P-GW);

(ii) The Mobility Management Entity (MME).

The function of the S-GW is the establishment of the connection with the e-nodes B and that of the P-GW is the interconnection with other networks. The MME is responsible for the controller signalling traffic. In addition, replacing the HLR, there is the Home Subscriber Server (HSS) that now serves LTE traffic as well as GSM and UMTS traffic.

The driver for the dimensioning or the SAE-GW are packet streams from all the services (data and voice) that result from the related busy hour traffic. For the MME, the driver is the number of e-node B connected LTE users. This follows from the fact that a switched-on LTE handset is always on-net and therefore there exists always a virtual connection independently whether it is carrying a service or not. For this, the model replaces the busy hour traffic parameter by the number of LTE users that are connected to a core network location, which is a realistic approximation, given that LTE users are usually on-line during the busy hour.

The number of core network locations at which both the SAE-GW and the MME are installed is determined through a parameter specified by the model user. For small networks with a low number of core network locations, we assume that both functions will be installed in all core network locations.

3.5.4 Design of the IMS platform for VoLTE

To start with, we refer back to the discussion in Section 3.1.6.2 according to which the demand for “genuine” VoLTE is limited to that share that is actually carried end-to-end on the LTE radio access network, and the demand for virtual VoLTE realised via CSFB is determined at the moment of initiation to be completely carried over the legacy networks. The following discussion of the modelling concerns the traffic that end-to-end remains in the LTE network.

In principle, the packets of the VoLTE traffic are routed in the same way as has been discussed in Section 3.5.1 for classical voice. The signalling for the set-up of VoLTE connections in the core network, however, requires additional facilities (e.g. EPC) whose design and dimensioning are discussed in this subsection.

As already discussed in the introduction to this Section 3.5, the traffic streams of all services carried over LTE are handled in the EPC by the same network elements. From this follows that an MGW is not needed for on-net traffic and that also an MSC Call Server is not needed, given that there is no circuit-switchend traffic. It must be ascertained, however, that transport systems (LERs, LSRs and leased lines) of sufficient capacity are installed so that the voice traffic is not hampered through the simultaneous handling of data and best-effort services with low QoS requirements (packet loss and delays). For this, 3GPP developed the concept of an IP multimedia subsystem (IMS) platform. The IMS platform provides the S-GW with the signalling that enables the transport facilities to assure the provision of the needed capacities. When dimensioning the capacities of the transport systems, the model therefore takes into account the QoS parameters of the traffic streams of the various services categories and determines the capacities for the tunnels corresponding to the services categories.

As shown by Figure 3-22, the IMS platform consists essentially of the three Call State Control Functions (S-CSCF, I-CSCF and P-CSCF), the Telephone Application Server (TAS) and the Policy and Charging Rules Function (PCRF). The driver for the dimensioning of the IMS platform are essentially the busy hour call attempts (BHCA) due to VoLTE. In the model, the IMS platform as a central control function is installed only in a limited number of core network locations, where this number is set by the model user.

For off-net VoLTE traffic between the LTE network and the external PSTN/ISDN, an IMS Media Gateway (IMS-MGW) is installed to transform the packet-based voice signals into circuit-based voice signals and vice versa, and the IMS signalling into the signalling of the ISDN (ISUP). The model installs this facility at all interconnection points of the EPC with a PSTN/ISDN. The dimensioning is based on the BHCA of the aggregated VoLTE off-net traffic.

3.5.5 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 Ethernet based leased lines. In the case of a fully meshed topology, there are N*(N-1)/2 connections, where N is the number of nodes. In case of a ring topology, the number of rings is determined by the number of controller locations. In the case of only one ring, which is realistic for a small country, the number of links is equal to N, i.e. equal to the number of nodes.

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, the model applies the same procedure as in the case of the aggregation and backhaul networks. In case of a ring topology, LSRs are installed that are connected via leased lines to form the ring. For this 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 maximum bandwidth requirements on each of the asymmetrical logical connections. In case of a fully meshed core network, the required bandwidth on each link corresponds to the traffic between the two linked nodes. In this case there is no need for additional protection, since in the case of a break-down it can always be assumed that the relevant traffic can be routed over the remaining links with one more intermediate node.

3.5.6 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 utilisation ratios are usually installed. For a conservative dimensioning, the reciprocal of the smallest of these utilisation rates is used to define the global mark-up factor by which the reserve capacities are determined that are maintained in case of special traffic occurences.

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

Equipment	Driver for the dimensioning	Utilisation 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 HSS 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	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-α_{cc} determines the relevant share	All locations of the core network with PSTN / ISDN /PLMN 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 / PLMN 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
SAE Gateway	(a) Throughput, in Mbps (b) PDP context	n/a		Input
Mobile Management Entity (MME)	Number of assigned LTE users	67%		Input
IP Multimedia Subsystem (IMS)	VoLTE BHCA			Input
IMS Media Gateway	VoLTE BH traffic and VoLTE BHCA	70%		Input
IMS-MGW Interface card to the PSTN/ISDN/PLMN based on Ethernet-Ports for VoLTE	Number of Ethernet ports	80%		At all locations of the core network with PSTN / ISDN / PLMN interconnection
IMS-MGW Interface card to PSTN/ISDN/PLMN based on TDM-Ports for VoLTE	Number of E1 ports	80%		At all locations of the core network with PSTN / ISDN / PLMN interconnection
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 well 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.

3.6 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.

3.6.1 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 utilisation 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 utilisation factor. Our observation is that operators apply utilisation 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.

3.6.2 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.[23]

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[24]. 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 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 secure network operations against unpredictable short-term traffic peaks, the network facilities of the packet switched networks are not utilised to the full, i.e. utilisation rates are set between 65% and 85%.[25] 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

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[23] See García et al. (2010).
[24] See Akimaru and Kawashime (1999).
[25] For more details see RFC896 (1984); see also Jacobson (1988).

> 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 utilisation rates dominates and not the one resulting from the QoS requirements.

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

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[26] 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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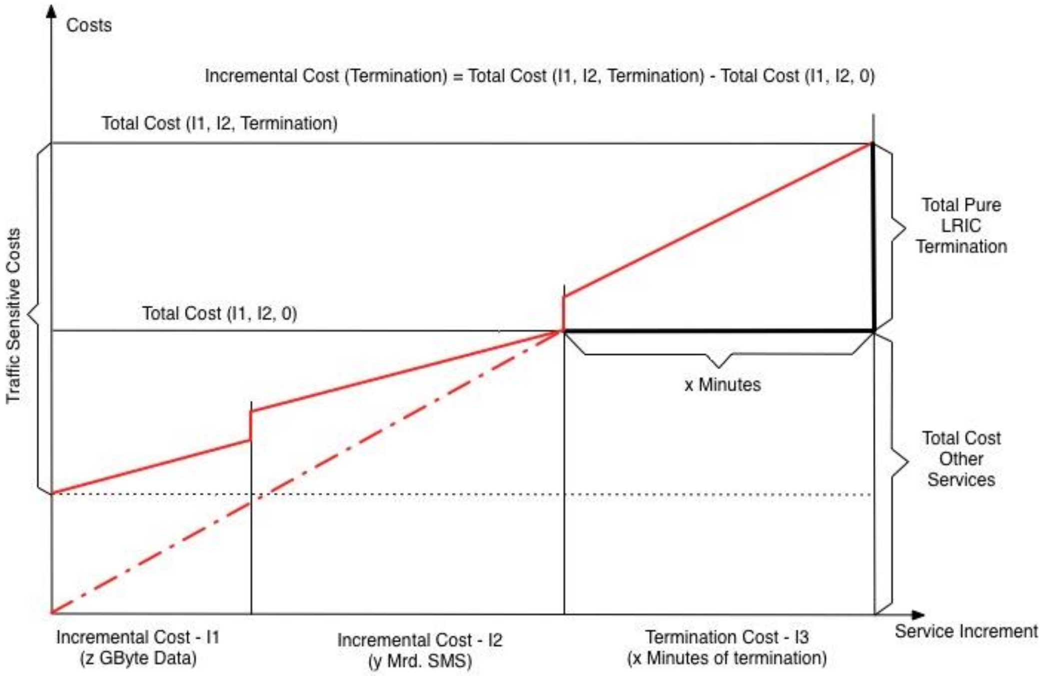
[26] See EU Commission (2009).

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, besides the list of facilities and systems, the volume of minutes of termination must be provided by it. This information is needed to determine the cost of termination per minute, as the latter is calculated by dividing the cost difference between a situation with termination and one without by this volume of minutes.

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 amortisation 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 amortisation 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 amortisation 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 utilisation 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:

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

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

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

one obtains the amortisation 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 amortisation 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 amortisation 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 utilisation 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 utilisation 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 amortisation 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 (e.g. 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

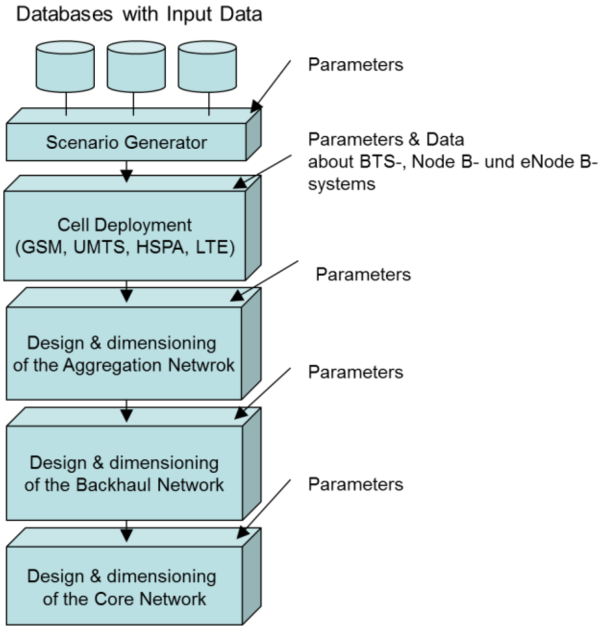
As already pointed out earlier, in the Pure LRIC approach the cost of terminating calls in the mobile network is derived by determining the difference of the total costs of providing services, on the one hand including the termination service and on the other excluding this service. In the case with 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.

References

A. E. García, L. Rodríguez de Lope, K. D. Hackbarth, "Application of cost models over traffic dimensioning with QoS restrictions", Annales of Telecommunication, Vol 65, Nº 3/4, 2010.

A. Elnashar, M. A. El-saidny, M. Sherif, “Design Deployment and Performance of 4G LTE Networks – A Practical Approach”, John Wiley & Sons, 2014.

A. Portilla-Figueras, S. Salcedo-Sanz, K. Hackbarth, F. López-Ferreras, G. Esteve-Asenisio, “Novel Heuristics for Cell Radius Determination in WCDMA Systems and their Application to Strategic Planning Studies“, European Journal on Wireless Communications, 2009..

B. W. M. Kuipers, L. Correia, “Modeling the Relative MIMO Gain”, IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, 2008.

EU Commission, Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU, 7 May 2009.

H. Akimaru, K. Kawashime, “Telegraffic Theory and Applications”, Second Edition, Springer, 1999.

H. Holma, A. Toskala, “WCDMA for UMTS – HSPA Evolution and LTE”, Chapter 8 – Radio Network Planning, John Wiley & Sons, Ed. 2010.

J. E. Sánchez-García, A. M. Ahmadzadeh, B. Saavedra-Moreno, S. Salcedo-Sanz, A. Portilla-Figueras, “Strategic Mobile Network Planning Tool for 2G/3G Regulatory Studies”, Mobile Lightweight Wireless Systems, 2012.

J. Silió, L. Rodriguez de Lope, K. Hackbarth, “An algorithm for the topology design of communication networks with multiple rings” (in Spanish language), Proc. of the X. Jornadas de Ingeniería Telemática JITEL 2011, Santander (Spain).

K. Lindberger, “Blocking for multi-slot heterogeneous traffic streams offered to a trunk group with reservation", in: M. Bonatti and M. Decina (eds.), Traffic Engineering for ISDN, Design and Planning, Proceedings of the 5th ITC Seminar, 1988, 151–160.

N. Blaunstein, C. G. Christodoulou, “Radio Propagation and Adaptive Antennas for Wireless Communication Networks”, John Wiley & Sons, Ed. 2014.

S. Lin, B. Kernighan, "An effective heuristic algorithm for the travelling salesman problem", Operation Research, Vol 21, 1973, 498-516.

T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, “Introduction to Algorithms“, MIT Press and McGraw-Hill, Second Edition, 2001.

UMTS Forum, "3G Offered Traffic Characteristics", UMTS Forum Spectrum Aspects Group Report, Nr. 33, November 2003.

UMTS Forum, "Mobile traffic forecasts 2010-2020", UMTS Forum Report Nr. 44, January 2011.

V. Jacobson, “Congestion avoidance and control”, ACM SIGCOMM Computer Communication Review, Vol.18, N. 4, 314-329, 1988.

V. Kevin, M. Whitney, “Minimal Spanning Tree”, Communications of the ACM, Vol. 15, N. 4, 273-274, 1972.

W. Domschke, “Logistik: Rundreisen und Touren”, Oldenbourg-Verlag, München-Wien, 1982.

WIK-Consult, "Analytisches Kostenmodell für das Breitbandnetz 2010", Reference Document, published on the website of the Bundesnetzagentur, 2010.

WIK-Consult, "Mobile Termination Cost Model for Australia", Report, published on the website of the Australian Competition & Consumer Commission, 2007.

Appendix A: Summary of features of the link budget

The link budget is an important part in determining the cell range in case this one is determined on the basis of the propagation properties of the spectrum. It is a mathematical expression that takes all the gains and losses between a transmitter and a receiver of a telecommunications system into account. The model determines two different link budgets, downlink and uplink. The main parameters of the link budget are:

- On the transmitter side, the most relevant parameter is the Equivalent Isotropic Radiated Power (EIRP) [in dBm]. It is based on the transmission power [in W], the transmitter antenna gain [in dB], and body losses [in dB].
- On the receiver side, the parameters that are taken into account are the receiver antenna gain and loss [in dB], and the receiver sensitivity [in dBm]. The receiver sensitivity depends in turn on:
  - Thermal noise [in dBm], which is based on the thermal noise density [in dBm/Hz] and the bandwidth of the channel [in Hz], i.e. 5MHz in WCDMA,
  - Receiver noise figure [in dB], and
  - Energy per bit over noise ratio $\left(\frac{E_b}{N_0}\right)$, or the corresponding Signal-to-Interference-plus-Noise ratio in HSPA and LTE

Additional parameters, such as the building penetration losses or in-car losses, in case of network deployment along highways, are considered. Finally, technology specific parameters, i.e. the interference margin [in dB], the fast fading margin [in dB], the soft handover gain [in dB], and the MIMO gain [in dB], are considered in the calculation process.

The value determined by the link budget is then combined with a given propagation model, which in our case corresponds to the Cost231-Hata model. The Cost231-Hata model takes the corresponding clutter correction factor for each area type into account, and defines a relationship between the maximum pathloss and the maximum coverage cell range.

Appendix B: 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:

B-1 Cell deployment

  B-1.1 Common files

  B-1.2 2G files

  B-1.3 3G and HSPA files

  B-1.4 4G files

B-2 Aggregation network

B-3 Backhaul network

B-4 Core network

B-1 Cell deployment

B-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>_LTE_NodeB.txt	File containing eNodeB info for LTE deployment
11	<scenario_name>_LTE_mobile.txt	File containing 4G mobile terminal parameters
12	<scenario_name>_LTE_radio.txt	File containing LTE radio parameters
13	<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)
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	GSM or UMTS in the area (0= Pure GSM/EDGE; 1= GSM/EDGE-UMTS/HSPA; 2= GSM/EDGE-LTE; 3= UMTS/HSPA; 4= UMTS/HSPA-LTE; 5= GSM/EDGE-UMTS/HSPA-LTE)
n_sub_GSM_UMTS	Int	GSM or UMTS in the area (0= Pure GSM/EDGE; 1= GSM/EDGE-UMTS/HSPA; 2= GSM/EDGE-LTE; 3= UMTS/HSPA; 4= UMTS/HSPA-LTE; 5= GSM/EDGE-UMTS/HSPA-LTE)
n_res_GSM_UMTS	Int	GSM or UMTS in the area (0= Pure GSM/EDGE; 1= GSM/EDGE-UMTS/HSPA; 2= GSM/EDGE-LTE; 3= UMTS/HSPA; 4= UMTS/HSPA-LTE; 5= GSM/EDGE-UMTS/HSPA-LTE)
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	
N_days_year	Int	Number of working days per year	250
Fl_BHvoice_net	Double	Busy Hour traffic ratio	0.1
Fl_unbilled_min	Double	Share of unbilled traffic	0.1
Fl_voice_min	Double	Billed minutes of voice	
Fl_volte_min	Double	Billed minutes of VoLTE	
Fl_vidtel_min	Double	Billed minutes of Video Telephony	
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			
Fl_voice_onnet	Double	Share of on-net voice traffic [in %]	
Fl_voice_offo	Double	Share of off-net outgoing voice traffic [in %]	
Fl_voice_offi	Double	Share of off-net incoming voice traffic [in %]	
Fl_vidtel_onnet	Double	Share of on-net video telephony traffic [in %]	
Fl_vidtel_offo	Double	Share of off-net outgoing video telephony traffic [in %]	
Fl_vidtel_offi	Double	Share of off-net incoming video telephony traffic [in %]	
Fl_volte_onnet	Double	Share of on-net VoLTE traffic [in %]	
Fl_volte_offo	Double	Share of off-net outgoing VoLTE traffic [in %]	
Fl_volte_offi	Double	Share of off-net incoming VoLTE traffic [in %]	

First Line	Type	Description	Value
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 corresponding units [minutes / GB] of a Business User	
fl_PR_Traffic	Float	Traffic in corresponding units [minutes / GB] of a Premium User	
fl_CR_Traffic	Float	Traffic in corresponding units [minutes / GB] 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 VoLTE Networks percentage of the service traffic	
Fl_voipic2m	Float	External VoLTE Networks to mobile percentage of the service traffic	
Fl_GoS	Float	Blocking probability	
N_QosClass	Integer	Service QoS Class	

First Line	Type	Description	Value
Next Line			
For Each Service		3G/4G RAB Definition	
fl_vb	Float	RAB binary rate (DL cell-edge bit rate for HSPA and LTE)	
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	
n_nslotsDL	Integer	Number of slots Downlink	
Fl_GSM_perc	Double	Ratio of traffic carried by the 2G technology in case of hybrid sites	
Fl_UMTS_perc	Double	Ratio of traffic carried by UMTS technology	
Fl_HSPA_perc	Double	Ratio of traffic carried by HSPA technology	
Fl_LTE_perc	Double	Ratio of traffic carried by LTE 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	

First Line	Type	Description	Value
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)	

B-1.2 2G Files

<scenario_name>_BTS.txt

	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, +1000) [dB]	16.5
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

	Name	**Type**	**Comment**	**Value**
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
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

B-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_800	Double	Bandwidth in 800MHz frequency band [MHz]	0
10	Fl_WB_900	Double	Bandwidth in 900MHz frequency band [MHz]	0
11	Fl_WB_1800	Double	Bandwidth in 1,800MHz frequency band [MHz]	0
12	Fl_WB_2100	Double	Bandwidth in 2,100MHz frequency band [MHz]	15
13	Fl_WB_2600	double	Bandwidth in 2,600MHz frequency band [MHz]	0
Third line (for HSPA)				
14	Fl_WB_800	Double	Bandwidth in 800MHz frequency band [MHz]	0
15	Fl_WB_900	Double	Bandwidth in 900MHz frequency band [MHz]	0
16	Fl_WB_1800	Double	Bandwidth in 1,800MHz frequency band [MHz]	0
17	Fl_WB_2100	Double	Bandwidth in 2,100MHz frequency band [MHz]	15
18	Fl_WB_2600	double	Bandwidth in 2,600MHz frequency band [MHz]	0
Fourth Line (for UMTS and HSPA algorithm)				
19	Fl_down_800	Double	Central frequency for downlink in 850 frequency band	806
20	Fl_up_800	Double	Central frequency for uplink in 850 frequency band	847
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

	Name	Type	Comments	Value
Fourth Line (for UMTS Algorithm)				
29	B_av_multiband_urb	Bool	Multiband case available for high dense populated areas	1
30	B_av_multiband_sub	Bool	Multiband case available for medium dense populated areas	1
31	B_av_multiband_res	Bool	Multiband case available for low dense populated areas	1
Fifth Line (for UMTS Algorithm)				
32	B_algorithm_selection	Bool	Selection of monoband/multiband algorithm to run (0=Monoband/Multiband time limited; 1=Monoband/Multiband time unlimited)	1
33	B_3GTechnology	Bool	0 = UMTS and HSPA technology installed in separated units 1 = UMTS and HSPA technology integrated in the same units	1
34	Fl_min	Double	Minimum value for the UMTS algorithm threshold	0.99
35	Fl_max	Double	Maximum value for the UMTS algorithm threshold	1.01
Sixth line (for HSPA and UMTS Algorithms)				
36	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
37	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
38	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

B-1.4 4G files

<scenario_name>_LTE_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	0.2
3	Fl_mt_gain	Double	Mobile Terminal Gain [dB]	7
4	Fl_mt_loss	Double	Mobile total losses [dB]	3
5	Fl_mt_noisef	Double	Noise figure [dB]	5

<scenario_name>_LTE_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_MIMOgain	Double	MIMO Gain Factor	1.54
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				
9	Fl_WB_800	Double	Bandwidth in 800MHz frequency band [MHz]	5
10	Fl_WB_900	Double	Bandwidth in 900MHz frequency band [MHz]	0
11	Fl_WB_1800	Double	Bandwidth in 1,800MHz frequency band [MHz]	10
12	Fl_WB_2100	Double	Bandwidth in 2,100MHz frequency band [MHz]	0
13	Fl_WB_2600	double	Bandwidth in 2,600MHz frequency band [MHz]	15
Third Line				
14	Fl_down_800	Double	Central frequency for downlink in 850 frequency band	806
15	Fl_up_800	Double	Central frequency for uplink in 850 frequency band	847
16	Fl_down_900	Double	Central frequency for downlink in 900 frequency band	942.5
17	Fl_up_900	Double	Central frequency for uplink in 900 frequency band	897.5
18	Fl_down_1800	Double	Central frequency for downlink in 1800 frequency band	1842.5
19	Fl_up_1800	Double	Central frequency for uplink in 1800 frequency band	1747.5
20	Fl_down_2100	Double	Central frequency for downlink in 2100 frequency band	2140
21	Fl_up_2100	Double	Central frequency for uplink in 2100 frequency band	1950
23	Fl_down_2600	Double	Central frequency for downlink in 2600 frequency band	2655
24	Fl_up_2600	double	Central frequency for uplink in 2600 frequency band	2535

	Name	Type	Comments	Value
Fourth Line				
25	B_MIMO_urb	Bool	Availability of LTE-MIMO in urban areas	1
26	B_MIMO_sub	Bool	Availability of LTE-MIMO in suburban areas	1
27	B_MIMO_res	Bool	Availability of LTE-MIMO in rural areas	1
Fifth Line				
28	B_CA_urb	Bool	Availability of Carrier Aggregation in urban areas	1
29	B_CA_sub	Bool	Availability of Carrier Aggregation in suburban areas	1
30	B_CA_res	Bool	Availability of Carrier Aggregation in rural areas	1

<scenario_name>_LTE_NodeB.txt

	Name	Type	Comment	Value
	First Line			
	n_NodeB	Int	Total number of eNodes B	9
	For each Node B			
	First Line			
1	Sz_eNBname[]	Char	Name of eNode B type	eNodeB_Macro_1S
	Second Line			
2	Fl_eNb_height	Double	eNode B height [m]	25
3	Fl_eNb_ptx	Double	eNode B transmission power [W]	40
4	Fl_eNb_gain	Double	eNode B gain [dB]	18
5	Fl_eNb_cableloss	Double	eNode B cable loss [dB]	3
6	Fl_eNb_noisef	Double	eNode B noise figure [dB]	2
7	N_eNb_sects	Int	Number of sectors per eNode B	1
8	B_urb_av	Bool	eNode B available for high dense populated areas	0
9	B_sub_av	Bool	eNode B available for medium dense populated areas	1
10	B_res_av	Bool	eNode B available for low dense populated areas	1
11	Fl_eNb_cost	Double	Cost factor of eNode B	132
12	Fl_eNb_addcarriercostt	Double	Additional cost per carrier in the same site	2.024
13	B_hw_av	bool	eNode 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

B-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
<scenario_name>_output_LTE_BA.txt	File containing LTE districts information
<scenario_name>_output_LTE_traffic.txt	File containing LTE traffic distribution per district
<scenario_name>_output_HS_HLR.txt	File containing highways/railways information
<scenario_name>_output_HS_HLR_traffic.txt	File containing traffic along highways/railways

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			

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	6
For Nidsys2gcsch lines:			
Index	Integer	Index of the transmission system	1
Name	Char	Transmission system description	RFMLE1
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	6
For Nidsys3gcsch lines:			
Index	Integer	Index of the transmission system	1
Name	Char	Transmission system description	RFMLE1
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) (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

Name	Type	Comments	Value
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
For nidsyschconstar 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
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
First line:			
Nidsysltecsch		Table size for pure 4G and 2G/3G/4G site – hub transmission systems	6

Name	Type	Comments	Value
For Nidsysltecsch lines:			
Index	Integer	Index of the transmission system	1
Name	Char	Transmission system description	RFMLE1
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

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

B-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
Systype	Integer	Sytem type	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
Systype	Integer	System type	1
maxNB	Integer	Maximum number of Nodes B of the RNC system	640
Maxbw	Float	Maximum bandwidth of the system	640
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

Value	Type	Comments	Value
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
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
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

Value	Type	Comments	Value
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
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

B-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
nhss	int	Number of Core locations with HSS	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
Maxuserhss	int	Maximum number of users per HSS	2240000
Maxusereir	int	Maximum number of users per EIR	2240000
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
maxbhcahss	int	Maximum number of BHCA per HSS	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
Nsaegw	Int	Number of Core locations with SAE-GW	2
Nmme	Int	Number of Core locations with MME	2
Mxusermme	Int	Maximum number of users per MME	1000000
Nimsmgw	Int	Number of Core locations with IMS-MGW	2
nIMS	Int	Number of Core locations with IMS-Platform	2
Maxbhcaims	Int	Maximum number of BHCAs per IMS-Platform	8000000

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
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
Bwportt1	Integer	Bandwidth of Type 1 ports of the system (in Mbps)	1000

Value	Type	Comments	Value
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
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
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

Value	Type	Comments	Value
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
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
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

Value	Type	Comments	Value
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
Next line:			
NidsysIMS-MGW		Table size for IMS Media Gateway systems	1
For NidsysIMS-MGW lines:			
Index	Integer	Index of the IMS Media Gateway systems	1
Name	Char	Name of the systems	IMS-MGW1
Bwportt1[Mbps]	Integer	Bandwidth of Type 1 ports of the system (for interfaces to the LER and node aggregator) (in Mbps)	100
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:			
NidsysSAEGW		Table size for SAEGW systems	1
For NidsysSAEGW lines:			
Index	Integer	Index of the SAEGW systems	1
Name	Char	Name of the systems	SAE-GW1
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
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

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