2G/3G-Connect: A Tool for Strategic Techno-Economical Studies on National-Wide Mobile Networks under a Hybrid 2G/3G Architecture

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Abstract. The current increment of the service portfolio for mobile communications and the related traffic load require an extension of the capacities in the mobile networks. As a consequence, mobile network operators have to replace part of the traditional equipment based on 2G GSM/GPRS by the 3G equipment based on UMTS and even start the path in direction to the 4G installing HSPA. This leads to techno-economical studies which require a corresponding service network model and its implementation in form of a computer support planning tool. This paper presents such a model and the structure and characteristics of the corresponding tool 2G/3G-Conncet. The paper also indicates corresponding applications.

Keywords: high-level Petri nets, net components, dynamic software architecture, modeling, agents, software development approach.

1 Introduction

The growing penetration of smart phones for mobile communication causes the necessity of increasing the capacities in the corresponding mobile networks which can't satisfy the additional demands by simple 2G technology based on GSM/GPRS and brings also to limits the GPRS improvement by upgrading them with equipment under the enhanced GPRS data rate for GSM evolution (EDGE). Hence, mobile network operators are accelerating the implementation of UMTS, currently envisaged in the 2100 MHz band. In some countries, mobile network operators offer so called broadband mobile access (BMA), mainly applied by end-user with laptop computers. This service by one side, offered in competition to fixed broadband access under corresponding xDSL technology, is based on the mobility paradigm mainly of the young generation. By the other side, it is applied for covering so called white areas where xDSL or future PON architecture can not be implemented by economic reasons, and hence broadband mobile access overcomes the so called digital division in rural area. It can

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be shown that for BMA the capacity offered by UMST is not sufficient and hence a corresponding enhancement is required and implemented by additional HSPA or HSPA+, see [7]. HSPA or HPSA + can be seen as a bridge technology for a smooth development in the direction of 4G under the long term evolution paradigm, see [14], similar as EDGE provided an enhancement of 2G technology in the direction of 3G one.

Similar changes happens in the fixed network part of the mobile network were traditional technology based on ATM and SDH equipment or corresponding leased lines for transport and mobile switching centres are replaced by technology either over Ethernet based radio links, or corresponding leased lines. For higher demands even leased dark fibre withEthernet over fibre technology might be applied in the BSS/UTRAN part, while the NSS part will apply full IP/MPLS systems. The classical mobile switching centres are hence substituted by corresponding Soft-switch equipment composed by Media Gateways and MSC call servers. Under the paradigm of Fixed-Mobile Integration (FMI) it can be expected that the BSS, the UTRAN and NNS will be at least partially integrated with infrastructure of the NGN in case that both networks are operated by the same operator, see [5].

As a consequence, current public mobile networks are strongly hybrid in the cell deployment where equipment ranging from simple GSM over GSM/GPRS or EDGE coexists with UMTS and HSPA or HSPA+. In the fixed network part current ATM-SDH transport paradigm is changed to carrier Ethernet and IP/MPLS. The cell deployment and the application of the corresponding technology mix depend strongly on the services offered by the public mobile network operator and the traffic requirement from the end users, see [8]. Hence, entities involved in the market place of mobile services and corresponding networks require strategic planning tools which allow to study the consequences of the increasing bandwidth demand by current and future applications from both, the technical implication but also the economical one.

This paper presents a computer tool for techno-economical studies in hybrid 2G/3G mobile networks based on a LRIC cost model and a scenario concept, which handles the required large parameters set, likethe number and distribution of potential end user in a country, the type of services to be integrated and the corresponding traffic demand, the applied range of technology and other parameters like radio spectrum in different frequency bands.

The paper provides in the second chapter a description of the model for the network design and dimensioning and provides in the third chapter an introduction to the applied TELRIC cost model for the economical analysis of the network configuration resulting form the network planning part. The fourth chapter outlines applications of the 2G/3G-Connect tool and the last chapter provides conclusions and indicates future extensions of the model and the corresponding tool.

2 Description of the Model for 2G/3G-Connect Tool

Telecommunication service and network models for strategic techno-economical studies are divided mainly into three main parts:

- Scenario generation
- Network planning, composed by:
  - Cell deployment
  - Fixed network design and dimensioning
  - System assignment to the network elements.
- Economical analysis by a corresponding cost model.

The model considers that current and mainly future PLMN has to support a strong set of applications and hence must provide a set of services supporting them. The services are differentiated not only by their bandwidth requirements but also by their quality of service (QoS) parameter. 2G/3G-Connect approximates QoS by three parameters: the accessibility to a service, expressed by a maximum value for the blocking probability under a traffic load in the common business hour (BH), the mean delay value for a connection between its source and destination location (end-to-end delay, e2e) and its jitter. The first parameter is considered mainly in the cell deployment applying an extension from the Erlang-loss model for multi-services, see [10]. The second and third parameters are applied mainly in the dimensioning of the output interfaces for the layer-2,3 equipment in the fixed network part and use a corresponding waiting model. For this purpose, the model for 2G/3G-conncet applies the concept of equivalent bandwidth requirement under a value which lies between the mean bandwidth and the maximum bandwidth of a service, see [6]. For this purpose 2G/3G-connect allows that each service gets associated a so called QoS class which describes the required QoS parameter.

Additionally, 2G/3G-Connect includes several options for improving the service availability which are:

- Doubling key network element and providing a traffic distribution on equal terms.
- Assignation of lower level nodes to two higher ones e.g. RNC locations to core network locations and providing a traffic distribution on equal terms.
- Congestion avoidance against unforeseen traffic loads by over-dimensioning of the transmission capacities. For this purpose 2G/3G-connect allows to provide corresponding parameters individually for each network level.

This chapter describes the main functions of the scenario generator and the associated network planning. Figure 1 shows the main functional blocks treated in this chapter implemented in the 2G/3G-connect tool by corresponding program modules.

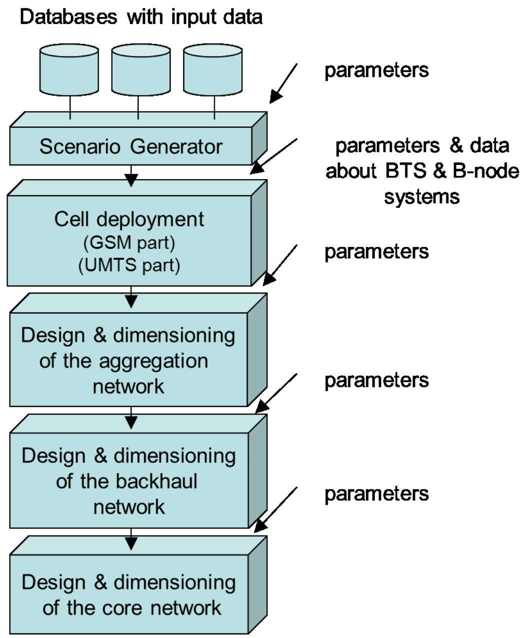

Fig. 1. Modules for the network planning implemented in 2G/3G-connect

2.1 Scenario Generator

The objective of the scenario generator is to provide the input data for a national mobile network planning. The model for 2G/3G-Connect is composed by the following scenarios:

– Geographical scenario, composed by geographical, topographical and population data.
– Service scenario, which defines the services set handled by the 2G/3G network.
– User and traffic scenario which considers different types of user and its traffic-service relation.
– Architecture scenario, defining the technology applied for the cell deployment and the fixed network part and its relation with the user and the geographical scenario.
– Frequency and spectrum scenario, indicating the frequency bands and the amount of spectrum associated to the applied cell technologies.

Geographical scenario. 2G/3G-Connect considers for the geographical scenario a list of small geographical units with their corresponding coordinates, topographical situation defined by three attributes (flat, hilly, mountainous) and the number of inhabitants; often these data are deduced from Postal Area Codes, see [2]. The geographical scenario includes also data about the road and the railway network of the country and data about special areas with high population concentration as airports, railway-stations, shopping malls etc.

Based on these data the scenario generator creates areas and joints adjacent areas to districts. The areas are then classified depending on their population density in rural, suburban and urban.

For considering mobility of the population and traffic estimation for roaming, the geographical scenario considers additional data about economical activities in the areas and classifies the areas as business or residential ones. For roaming, the scenario generator also considers data about hotels and its occupation.

Service scenario. The service scenario describes the characteristics of the different services offered by the considered network. The main parameters are:

- Mean packet length and mean bandwidth requirement separated for the uplink and downlink packet stream.
- Mean duration of the service.
- Parameters for the traffic distribution to different destinations.
- Assignation of the service to a QoS class.

Table 1 shows a corresponding example for the most important services considered by 2G/3G-Connect.

Table 1. Typical service scenario for 2G/3G mobile networks (M2M: relative traffic between mobile user in the same network, M2F: relative traffic from a mobile user of the considered network and a user in an other one, F2M: inverse from M2F, M2ICIP: traffic from a mobile user to an IP network over a corresponding interconnection point, M2 MobSer traffic between a mobile user and a server connected with the considered mobile network)

	Parameters for capacity requirement					Traffic distribution parameters					
service characteristics	Mean Bandwidth		Mean packet length		Mean duration	M 2 M	M 2 F	F 2 M	M2 IC IP	M2 Mob Ser	QoS class
	up link	down link	up link	down link							
Dimension	kbps	kbps	bytes	bytes	min	-	-	-	-	-	-
Real time voice	12.2	12.2	25	25	3	0.4	0.3	0.3	0	0	1
Other real time serv.	16	64	100	100	15	0	0	0	0.8	0.2	1
Streaming to content server	1	80	3.0	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	0.01	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	40	160	256	256	5	0	0	0	0.4	0.6	4

User and traffic scenario. The user and traffic scenario classifies the total number of users into three different categories: business, premium and standard, and associates them a traffic matrix which indicates the BH traffic of each user type to the corresponding services. As 2G/3G-connect considers hybrid sites, the corresponding scenario must provide for each service input data about the traffic distributions over different cell technologies installed in the same hybrid site; table 2 shows an example related with the service scenario shown in table 1.

Table 2. BH traffic values and their distribution over the different cell technologies in case of hybrid sites

Service and traffic per user	GSM traffic per user in hybrid sites	UMTS traffic replaced by HSPA	BH traffic per user (Erlang or messages		
			Business	Premium	Standard
real time voice	0.8	0	0.05	0.005	0.006
other real time services	0.2	0	0.01	0.0025	0
streaming to content services	0.0	0.5	0	0.005	0
guaranteed data with business server	0	0.5	0.002	0	0
best effort to general server	0	0.5	0.001	0.01	0.002
SMS	0.2	0.1	0.1	0.05	0.01
MMS	0.2	0.2	0.01	0.02	0
Mobile Broadband Access	0	1	0.01	0.005	0

Architecture scenario. 2G/3G-connect considers as network architecture the complete spectrum of technologies ranging from second generation GSM mobile networks, including GPRS and EDGE, up to third generation by UMTS including its extension to HSPA. For this purpose the scenario generator associates to each area a cell type depending on its type and user density. Table 3 shows the cell type and indicates the criteria for its selection.

Concerning the fixed network part 2G/3G-connect considers for bandwidth aggregation in the UTRAN/GERAN part layer-2 equipment based on carrier Ethernet and for the routing function concerning the traffic to be routed among the core network location layer-3 equipment based on IP/MPSL. For the transmission, 2/3G-Connect differentiate mainly between operators which provide a proper physical infrastructure, mainly based on radio links, and operators which use digital or optical leased lines from a different operator. The selection can be provided individually for each network level, e.g. an operator decides to implement proper radio links in the UTRAN/GERAN network part and use electrical or optical leased line for the core network part.

Table 3. Cell types consider by 2/3G-connect

Cell type	Identifier	Related parameters
GSM/GPRS	1	GSM “up to” user threshold for each area type
GSM/EDGE	2	As type 1
UMTS	3	GSM and GSM/UMTS “up to” user thresholds
UMTS/HSPA	4	As type 3
GSM/UMTS	5	GSM/UMTS “up to” user threshold for each area type
GSM/UMTS/HSPA	6	As type 5

Frequency and spectrum scenario. The frequency and spectrum scenario gives the frequencies associated to the different cell technology and the corresponding spectrum. 2G/3G-Connect allows a flexible frequency and spectrum assignment; table 4 shows an example. As a consequence, 2G/3G-Connect provides the possibility for studying the influence of different combinations of frequency and spectrum assignment to the network design and dimensioning and the corresponding economical implications.

Table 4. Example for a frequency and spectrum assignment

Frequency Band	GSM Spectrum (MHz)	UMTS Spectrum (MHz)
800	Not Applicable	0
900	8	0
1800	18	0
2100	Not Applicable	15
2600	Not Applicable	0

2.2 Network Planning

Strategic Telecom Network Planning studies the development of the corresponding telecommunication network under a medium up to long term development. For this purpose different scenarios, as shown in the last section are considered. Network planning is provided by two main steps, network design and network dimensioning. 2G/3G-Connect bases the network design on the set of districts and their corresponding areas which compose them, as shown in section 2.1, and determines the locations for higher level functions and for interconnection points with other networks.

Based on these locations, the network design determines the structure for the logical level and the topology of the physical one. 2G/3G-Connect considers the architecture as determined by the 3GPP under Release 4, see [1] and some extensions for HSPA considering the corresponding extensions from 3GPP in Release 5 and 6. Figure 2 shows the main functional blocks considered in the model for 2G/3G-connect.

The dimensioning corresponds to the traffic routing over the network structure and topology and provides the required capacity in each network element, mainly based on locations (nodes) and links connecting them. Finally, 2G/3G-Connect assigns corresponding equipment to each network element providing the bandwidth required for the capacities resulting from the network dimensioning.

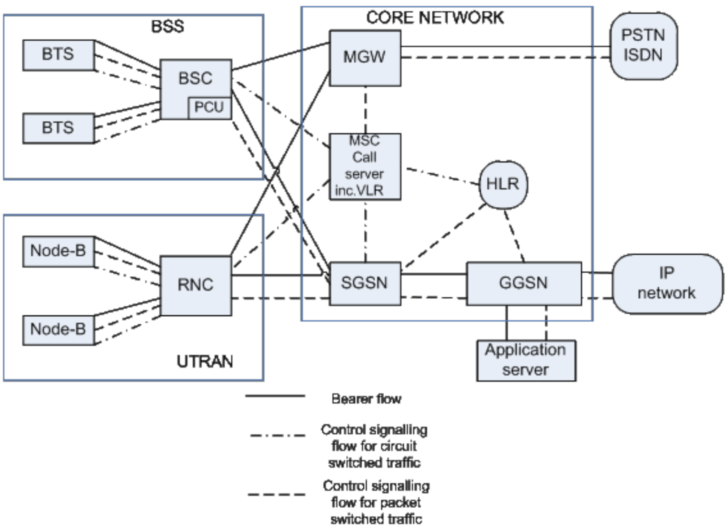

Fig. 2. Functional blocks of a 2G/3G mobile network

Cell deployment. 2G/3G-Connect receives from the scenario generator a list of districts with their corresponding areas, and for each area the required cell types. Based on these data the cell deployment determines for each area the number of sites, the required capacities and the corresponding radio equipment (BTS/node B/HSPA).

The cell deployment calculates for each area the amount of traffic, separately for each service, handled by the radio equipments under its corresponding QoS parameter determined by the QoS class associated to the service. These traffic values are then the main input data for the fixed network design and dimensioning.

Fixed network design and dimensioning. The fixed network part of a mobile network is composed by the following parts:

– Aggregation network part, covering the location of the base station sites up to the locations where the controller equipments (BSC, RNC) are installed.
– Backhaul network part, covering the controller locations up to the core network locations.
– Core network part, connecting the different core network locations and providing interconnection to other networks.

In both 2G as 3G mobile networks the traffic between the user equipment to other users, a server or a corresponding interconnection point with other networks must always be switched hierarchically up to the core network part. Only the core network part provides corresponding routing functions to distribute the traffic to other users inside the network, a proper server or to an interconnection point for users or servers connected in other networks. Hence, 2G/3G-Connect provides the corresponding network design starting from the site locations and the corresponding traffic demand up to the core network part.

Aggregation network part. The aggregation network connects the site locations in each area to a corresponding aggregation point (cell hub). 2G/3G-Connect considers the centre of each district as cell hub location and a pure star structure for these connections. Note that the cell hub location does not provide any traffic aggregation but only one for physical capacity requirements. Hence the layer-2 equipment in the cell hub location provides grooming of physical groups of lower capacity connections from the sites (E1 or 10Mb Ethernet) to higher ones (E3, STM-1, FE or 1GE).

Once the capacities requirements of the cell hub location are determined 2G/3G-Connect detremines the controller node locations taken the number of locations as an input parameter and assign each cell hub location to one controller location. For this purpose 2G/3G-Connect applies a heuristic algorithm based on p-median model resulting from graph theory and applied already in former network design and costing model, see [3]. Figure 3 shows the logical structure for this network part.

Concerning the topology for the physical layer between the cell-hub locations and the controller ones, 2G/3G-Connect considers a tree structure and applies an algorithm, already used in former network design models which allows calculating

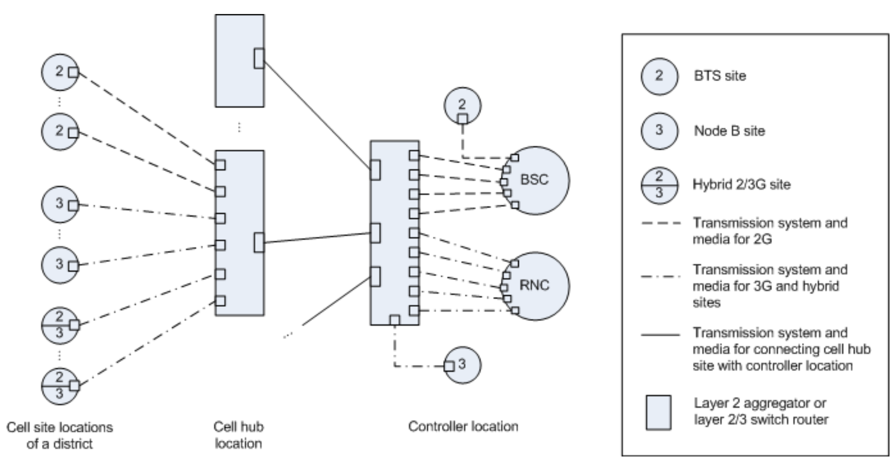

Fig. 3. Logical structure of the aggregation network for 2G/3G mobile networks

different tree structures, ranging from a pure star structure where the amount of traffic flow is minimised up to a pure tree structure which minimises the total geographical lengths (minimal spanning tree), see [2]. The optimal tree structure depends on the applied equipment and its length and capacity depending cost. From a practical point of view, a star structure is applied under leased line connections including dark fibre while radio link systems require a tree structure, minimising the number of radio link systems considering the distance limitations of the RF system (typically 50km). Fig. 4 shows an example for a tree structure.

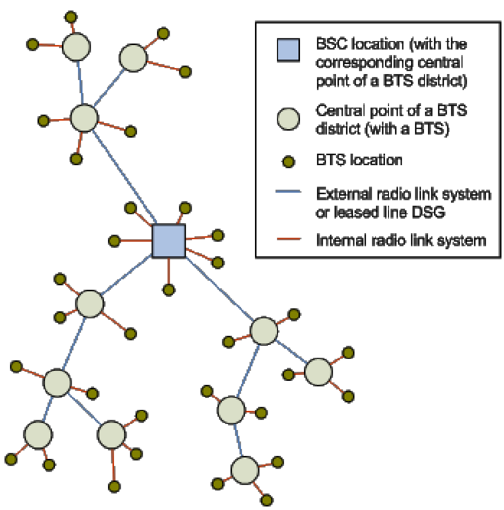

Fig. 4. Example for a tree topology in an aggregation network

Once the logical structure and the physical topology is calculated, 2G/3G-Connect provides the traffic routing up the controller node locations and the required capacities for the system assignment for the star links between the sites and the cell hub locations and the tree links between the cell hub locations and the controller node ones.

Backhaul network part. From the aggregation network design and dimensioning results the backhaul (controller) node locations and the corresponding traffics from the different services handled by the controller nodes. 2G/3G determines in the backhaul network part the location for the core node locations as a subset from the backhaul ones and assign each controller node location to one core node location; 2G/3G-Connect provides an option to provide an assignment to two core node locations for reasons of network availability. For this purpose 2G/3G applies a similar algorithm as in the design of the aggregation network part. Figure 5 shows the logical structure of the backhaul network.

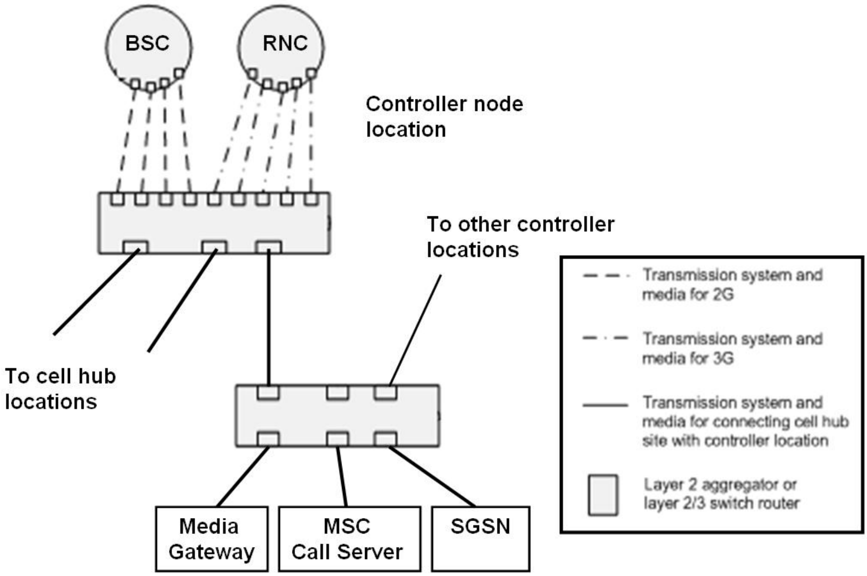

Fig. 5. Logical structure of the backhaul network for 2G/3G mobile networks

2G/3G-Connect considers for the physical topology again a star topology, and in case of applying double assignation a corresponding double star. Star- or double star structures are mainly applied for leased line including dark fibre. Due to the high traffic concentration in this network part 2G/3G-Connect considers in case that an operator implements a proper physical infrastructure a mapping of the logical star or double star structure into a set of ring topologies. The corresponding algorithm allows considering geographical obstacles and a limitation of the number of nodes which can be included into a ring; figure 6 shows an example. The calculation of the ring topologies is based on a heuristic algorithm for the travelling salesman problem; see [9].

Once the logical structure and the physical topology are calculated, 2G/3G provides the traffic routing from the controller node locations to the core nodes ones and determines the required capacities for the system assignment on the star or ring links.

Core network part. From the backhaul network design results the core network locations and the aggregated traffic from each service. Based on the total aggregated traffic in the core nodes, 2G/3G-Conncet selects the location of interconnection points to PSTN/ISDN&PLMN but also to IP based network and determines the locations where different types of servers and other central elements are installed. 2G/3G-Connect provides this selection based on the traffic weights of the core nodes, while the number of core nodes over which these elements should be distributed is given as an input parameter. The dimensioning of these elements is based on corresponding capacity drivers. 2G/3G-Connect

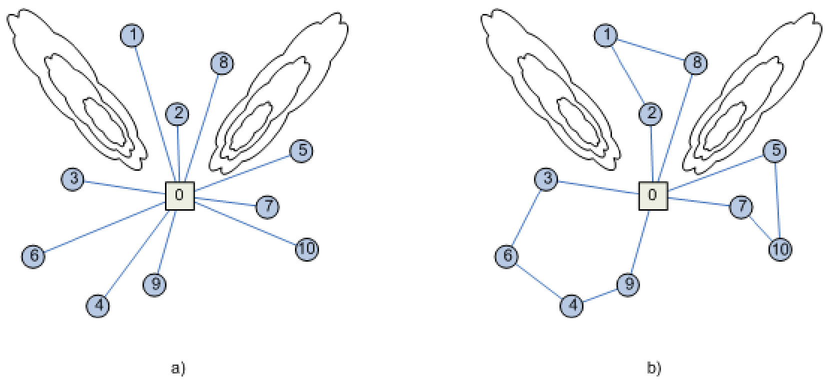

Fig. 6. Example of mapping a star structure into multiple ring topologies

considers that the capacities should not be fully used but an overhead is provided to anticipate a no estimated traffic increase. Table 5 shows the core network elements considered by 2G/3G-connect and an example for the corresponding input parameters considered in the dimensioning.

After the determination of the locations for the core network elements, 2G/3G-Connect distributes the traffic resulting from the different services to the corresponding elements. In case that this element is installed in a different core location 2G/3G-Connect routes the traffic to the corresponding one. For this purpose 2G/3G-Connect calculates for each service a traffic matrix between the core nodes and applies a distribution based on the core nodes weight related with the corresponding service e.g. the number of aggregated user. Figure 7 shows an example for this traffic distribution.

The traffic between different core node locations is routed over the logical structure of the core network which determines the required capacity for the physical layer. From practical studies results that the number of core node location in national mobile networks is small and hence the traffic concentration is high. Hence, 2G/3G-Connect considers for the logical structure a full meshed one and for the physical topology again a full meshed or optionally a ring topology. The last is mainly applied when the operator provides a proper transmission infrastructure while the first one is mainly appliedy under the application of leased lines.

3 Cost Model

2G/3G-Connect contains an economical evaluation based on a long run incremental cost (LRIC) model. In the LRIC model the cost evaluation contains two main cost types: Investment cost (CAPEX) and cost for the operations (OPEX). The first are calculated based on the network configuration resulting from the network planning and corresponding annual cost are deduced bt distributing the total investment cost over the life time of the network elements. In general,

Table 5. Core node location

Position	Driver for dimensioning and costing	Utilization ratio	N of SwRo locations
Media Gateway	N of E1/STM1 ports, BH traffic	70%	All SwRo nodes
MSC call server including VLR	BHCA	67%	Input
HLR	Number of subscribers, BHCA	80%	Input
EIR	Number of subscribers	60%	Input
SMSC	Number of SMS per s	80%	Input
SGSN	a. BHCA b. n of Attached Subscribers c. Throughput, in Mbps	78%	Input
GGSN	a. Throughput, in Mbps b. PDP context	77%	All SwRo with IP Interface
OAM	Considered in OPEX	n.a.	N.a.
Billing	Considered in indirect cost	n.a.	N.a.
IN	a. BHCA b. traffic over all services	80%	Input
Network management system (AAA, DNS functions)	BHCA over all services	80%	Input
MGW Interface card to the PSTN/ISDN/PLMN for circuit switched voice traffic	N of E1 ports	80%	At all SwRo with PSTN/ISDN interconnection
MGW Interface card to the PSTN/ISDN/PLMN for packet switched voice traffic	N of E1 ports	80%	At all SwRo with PSTN/ISDN interconnection

OPEX is considered by a mark up factor to the CAPEX. Figure 8 shows the different steps of the LRIC. Its application to 2G mobile network can be find in [6] and an overview about LRIC models is given in [11].

2G/3G-Connect applies a variant of LRIC referred to as total element long-run increment cost (TELRIC) which considers for the cost determination for the different services the routing path in the network. It calculates the cost for a unit of service as the weighted sum of the costs of all network elements used for the service, see [12]. The weights for the network elements are the so-called routing factors which reflect the way a particular service is routed over the various network elements and, in particular, how often a network element is used for the service.

The (cost) routing factors are determined from the network planning and hence are closely correlated with the traffic routing. In mobile networks, the traffic is always routed to the next core node location where a distribution is provided. From this follows that for a traffic unit for example for on-net voice traffic, there is always a routing factor of two used for all network elements from the cell site to the corresponding core network location. TELRIC provides a

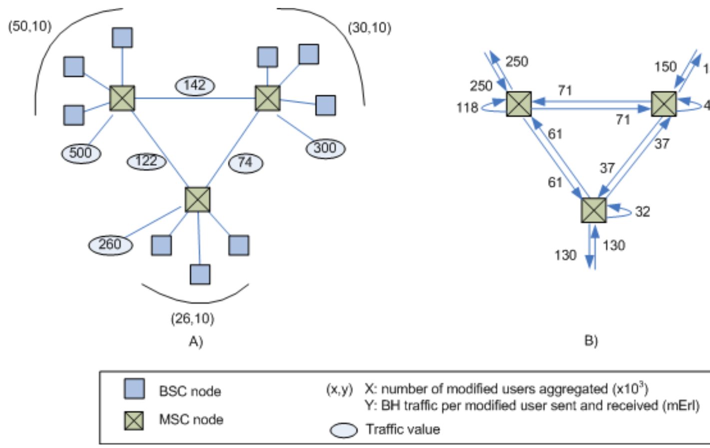

Fig. 7. Example for the traffic distribution of the aggregated traffic in the core nodes based on the weights resulting from the number of aggregated users

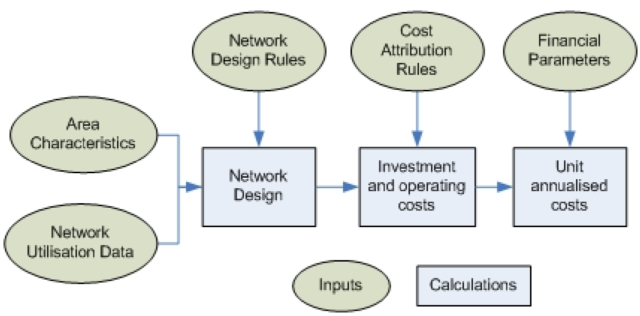

Fig. 8. Scheme for the LRIC model

distribution of network cost to the services that corresponds closely the services' use of the different network elements.

A special cost evaluation results from the so called marginal LRIC (also named pure LRIC) which considers only the cost increment provided by the traffic for an additional service. The next chapter provides an example.

4 Applications

The 2G/3G-Connect tool allows a strong set of applications which can be divided into three types:

- Practical techno-economical studies
- Applications for applied research studies
- Applications in higher level education.

2G/3G-Connect provides an instrument for practical techno-economical studies as strategic studies for mobile network operators who want to estimate the medium-long term tendency in its network evaluation and corresponding investment under different assumption of service and traffic evolution. These studies might be required also from equipment providers due to the fact that a number of mobile network providers require a complete solution "key in hand". But even financial institutions might require results for corresponding studies for risk estimation of credits given to network operators for the modernisation or a new implementation of a corresponding network. Last but not least 2G/3G will have a wide range of application in telecom regulation for national or international regulation entities to fix cost limits and parameters for different types of service e.g. for studying the influence of different parameters as QoS, service availability etc. to the corresponding service cost. For this purpose 2G/3G-Connect supports both TELRIC and pure LRIC as required from the current EU-regulation for mobile networks, see [4].

2G/3G-Connect can support applied research studies for network simulation under different technology scenarios for future qualitative and quantities equipment development or for the introduction of a new type of technology. An example is the study of the implication of changing the classical ATM layer equipment by new carrier Ethernet equipment and its evolution into the direction of equipment under MPLS-TP.

It is planned that 2G/3G-Connect will be applied in master courses for mobile network planning as currently provided by a consortium of five Spanish Universities; see [13].

5 Conclusions and Future Extensions

The contribution shows that the 2G/3G-Connect tool, based on a corresponding LRIC-cost model, allows a wide range of techno-economical studies for national wide mobile networks. Due to the incorporation of mobile broadband access using HSPA technology 2G/3G-Connect provides also a step in the direction of 4G networks based on LTE.

The team which developed the model and the corresponding tool is working on an extension for the future service and network evolution which considers in the fixed network part "fixed mobile integration (FMI)" under a common core network and an extension in the cell technology deployment by LTE based on OFDM as defined in release 8 of the 3GPP; see [5], [14].

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