A fair cost allocation scheme for CapEx and OpEx for a network service provider

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***Abstract*— In converged networks, an important part of the network costs is shared among different services. A fair allocation of those costs is important when determining the cost per service. This paper introduces a fair cost allocation scheme based on a combination of resource usage and peak capacity. The model is described theoretically, using different traffic flow scenarios and applied to a real telecom environment, indicating how the different CapEx and OpEx cost parts for a service provider can be allocated to the services. Finally, a case study for a realistic German network scenario is described.**

***Index Terms*— Converged Network, Cost-allocation, Shared costs**

I. Introduction

The telecommunication industry is one of the most evolving sectors in the economy. Network operators are offering more and more bandwidth, they introduce new or expand existing services. Moreover, competition is fierce in the telecom market. Incumbents must follow the standards new entrants are setting.

Networks will be more and more converged in the future. The number of technologies used today, will be reduced, allowing network operators to work more efficiently at lower costs. When offering services over a converged network, the operating costs of the network will decrease as a result of the declining maintenance and repair costs, and the standardization of the equipment. Offering triple play services (voice, data and video) and introducing new services and features will become easier when they are fully supported over one network infrastructure [1]. This will also allow operators to anticipate more rapidly to customer demand. Additionally, providing all services over one converged network will allow important cost reductions due to economies of scale and scope [2]. Economies of scale are defined as a reduction in the cost per unit resulting from increased production, realized through operational efficiencies. The average cost per unit will decline when more service units are offered. The cost of providing bandwidth for all services over one network will be less than the sum of the costs of providing bandwidth for each service over a separate network. This can be seen in Fig. 1.

Economies of scope arise when the cost of performing multiple business functions simultaneously proves more efficient than performing each business function independently. They have a positive effect on service costs as a result of usage of same technology. Due to the reduced number of network-technologies used in the converged network, costs of installation, reparation and maintenance will be smaller than in a not-converged network. This effect, however, is more difficult to measure.

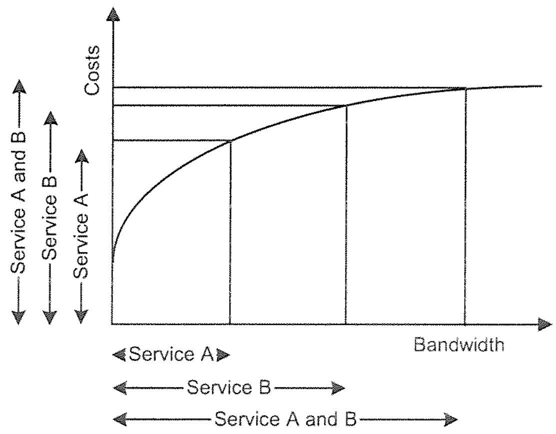

Fig. 1: Economies of scale

Cost modeling provides input information for several kinds of decisions. Knowing the cost per service is very important for pricing decisions, benchmarking, profitability analyses, simulations for possible introductions of new technology or services, etc. It is necessary that the cost modeling and allocation process is performed as correct and as fair as possible.

II. COST MODELING

A. *Methodology*

When operators are introducing new services, expanding their network infrastructure and/or optimizing their topology, the cost of these actions must be taken into account, as well as the time window they refer to. Depending on the different cost bases, different costs per service can be revealed. Two approaches can be followed for allocating costs to the different services, dependent on the considered starting point of the network modeling process, top-down versus bottom-up cost modeling. Both are illustrated in Fig. 2.

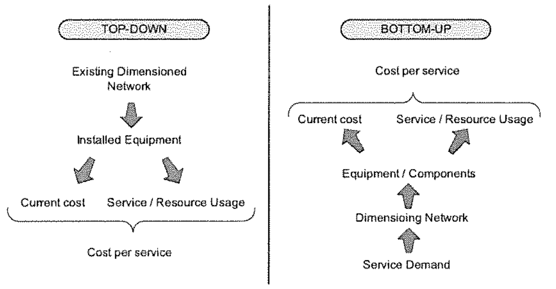

Fig. 2: Top-down versus bottom-up cost modeling

The first approach, the top-down method, starts from the existing network infrastructure. In this case, the actual network dimensioning is a result from fluctuations in historic and current demand, e.g. a growing number of customers and increasing traffic volume for several services, but also a declining service demand for other services (e.g. fixed telephone lines). The network is therefore less efficient than a new network (specifically designed for the current traffic demand). The cost of existing equipment is then allocated to the elements needed to deliver the service, through the use of cost drivers [3]. Therefore, an accurate identification of real cost drivers is required. In practice, it might be difficult to select the correct driver, leading to less efficient and less fair allocations. Two important cost bases can be distinguished for the top-down valuation of equipment. Historical Cost Accounting (HCA) uses the asset purchase costs as book value, taking depreciation into account. Since this method counts all historical costs, it can not be used for network optimization. Current Cost Accounting (CCA) values assets at the current market price. This cost base represents the replacement cost of an asset, i.e. how much it would cost today to purchase that asset. However, as a result of the continuous evolution of technology, it is not always possible to find the same equipment on the market as what has been installed in the network previously. A possible solution to this problem is given by the Modern Equivalent Asset (MEA) cost base, where the costs of equipment is valuated using the cost of a new technology offering the same (or more) functionality as the one that is currently installed.

The second approach, the bottom-up method, requires as starting point the demand for the services. The network is dimensioned in such way that it is optimal for the current situation: it can serve all customers with the requested services at the proposed quality of service. Service costs are allocated according to their required network equipment and usage. The bottom-up method can be used for different studies. It can be used for calculating the costs when designing a completely new network-architecture. It can also be used for making the comparison of the costs in an existing network considering an optimized (bottom-up calculated) network-architecture providing the same services. In the bottom-up method, the company's properties and goods will be evaluated following the forward looking cost (FLC). When considering a new network this means that only new and efficient technology will be used. When modeling an existing network, on the other hand, it might mean that less expensive technology is used in the study. This implies that the current network must be reconsidered and remodeled. There are two approaches for doing so, the scorched earth (green field) and scorched node (path dependent) approach. In the former approach, the network is redesigned with as few constraints as possible: a different number of nodes, a changed topology and other technological solutions can be taken into account. On the other hand, the latter approach makes a more fair compromise between efficiency of new technologies and networks and the existing network structure. The nodes stay at their original positions, whereas all equipment can be changed [4].

B. *Service cost categorization*

The allocation of the cost of the resources to the different resource consumers (services) is necessary to evaluate the profitability of these services. Capital Expenditures (CapEx) as well as Operating Expenditures (OpEx) need to be considered.

There are different service cost categories that need to be taken into account, as illustrated in Fig. 3. The direct costs are expenses which would not have been made if the product/service was not produced. Shared costs are defined as costs of the usage of resources which are shared amongst several processes/services. They can be divided in a fair way, e.g. according to bandwidth usage. Joint costs refer to costs of resources which are inherent to each other whereby providing the first resource will also provide the second resource and vice versa. They attribute to a substantial part of the revenues of the production-plant or service-provider. Increasing the provision of one of the resources also increases the other resource (possibly proportionally)1. Common costs are defined as joint costs for which the resources are not directly associated to the product or services sold. They are mainly seen as overhead.

[1] Note that there is no consensus in literature concerning the precise definition of shared and joint costs [3], [4]. We adopt the definitions given above.

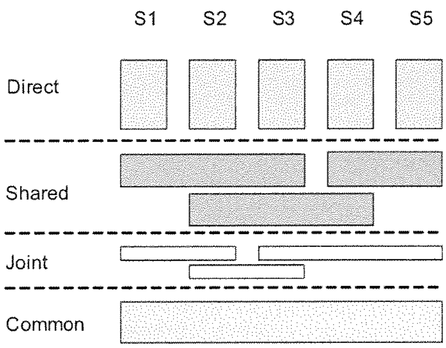

Fig. 3: Service cost categorization

Once all the processes have been described and costs have been categorized and assigned, different types of costs per service can be calculated through different methodologies, see Fig. 4. The first method is the *Stand Alone Cost (SAC)*. It considers the cost per service as if there was only one service offered. All shared/joint costs and common costs are added to the direct costs of the considered service and are allocated to that service. The SAC is the highest cost level the service can reach. This method is only used in a top-down approach to determine an upper bound for the cost of a service. The *Fully Allocated Cost (FAC)* method allocates all costs to all services. Direct costs are directly attributed to each cost consuming service, shared/joint and common costs through cost drivers. This method can be used for top-down as well as bottom-up approach. The hardest part when using this cost-base is to find the right driver for all costs. The *Incremental Cost (IC)* method only measures the change in total costs when a substantial and discrete increment or decrement in output is generated. This increment can be a newly offered service, but also an increase in output of one service. A well known methodology to measure incremental costs is through *Long Run Incremental Costing (LRIC)*. Long run implies that when a large increment occurs, capacity can be expanded. Economies of scale will be playing an important role in the allocation of shared/joint cost, resulting in a smaller part of attributed costs than in FAC. The LRIC method is mainly used in the bottom-up approach[2].

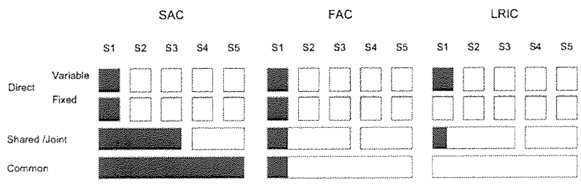

Fig. 4: Different methodologies for calculating cost per service

C. Motivation

The motivation for searching the fairest possible allocation of the shared costs lies in the necessity of this allocation in the FAC cost base method. In this paper, we mainly considered the use of the FAC method in a bottom-up approach, although the proposed cost-allocation method will also hold when using FAC in a top-down approach.

A well known method to allocate costs is through Activity Based Costing [5]. In this method, the starting point is that all business-processes can be seen as activities, which consume resources. In a first step, all processes should be captured into activities and their relation with the resources should be based on the usage of the resources by the appropriate cost driver. In a second step, the cost is calculated by adding up the amounts of resources used when the cost-drivers are known. The hardest part of the ABC-method is the implementation in complex environments. Time Driven Activity Based Costing [6] can be an answer for better solving the cost allocation problem for complex processes. The cost per time unit of capacity is estimated, followed by the unit times of activities. The total cost per activity is calculated by multiplying the unit time with the number of occurrences per activity.

In the telecom sector, however, it is not always possible to allocate costs through activities when modeling a network. This results from the fact that an important part of the network cost is a continuous infrastructure cost that can not directly be attributed to a certain activity. Our intention is to allocate these shared costs in a fair, reasonable way, through the identification of the correct cost drivers. This will result in a split of the shared costs into directly allocated parts for the different services.

III. ALLOCATION OF SHARED COSTS

A. Converged network as shared cost

In a fully converged network environment in which all services are running over a single network-architecture, the bandwidth provisioned in the network is available to all services. Providing different services over a converged network has several advantages. First, lower bandwidth is required. The bandwidth necessary to provide all services over one network will be less than the sum of the bandwidths necessary when providing all services over a different network. This is due to the joint effect of the granularity and the statistical multiplexing. Second, higher bandwidth will lead to lower costs per unit as a result of the positive effects of economy of scale and scope.

Since the equipment in a converged network is used by all services, the cost of installation and maintenance of the converged network is a shared cost among the different services. In order to make well-informed business decisions, one has to be able to calculate the economical drivers for each service correctly. This implies that a fair proportion of the shared network cost should be allocated to each service.

B. Allocation of the shared network cost

The most naïve allocation scheme would allocate an equal part of the shared network cost to each of the services running over this network. It is obvious that this scheme should not be used since smaller services would appear less profitable and the larger services more profitable than in reality.

[2] Although some applications of LRIC in a top-down approach exist.

1) According to the provisioned bandwidth

A better solution would be to allocate the costs of the usage of the network to the different services according to the part of network-bandwidth that the service was provisioned for during the design phase.

This, however, does not take into account possible future growth or shrinkage of the different services. A growing service would be allocated a too little part of the cost, while a declining service would be allocated a too large part of the cost. Since in the converged network, the bandwidth is limited, the growth of one service could also result in the (forced) decrease of another service, which will also render this service less profitable.

2) According to the bandwidth usage

Allocating the network costs according to the actual usage of the bandwidth available in the network would provide better results, since it would take into account all possible (short-term or long-term) fluctuations of the network usage of the different services. A mathematical formula for the proportion of the cost Cx allocated to one service x using this method is given in (1).

$$C_x = \frac{\int_{Time} Usage_x(t)}{\int_{Time} Usage_{tot}(t)} \quad (1)$$

This approach will lead to a fair cost in case of long-term fluctuations (eg. yearly) in bandwidth-usage and smaller short-term fluctuations, see Fig. 5. It would, however, not give a fair cost in case of larger short-term fluctuations as is the case in Fig. 6. In this case the second service would pay a cost which is much smaller than the first service, while the bandwidth required for running service 2 over the network (peak-bandwidth) is actually larger than the bandwidth required for running service 1 over the network.

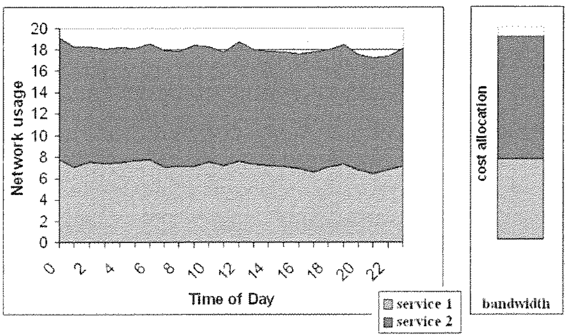

Fig. 5: small short-term fluctuations in network usage, allocation based on bandwidth-usage

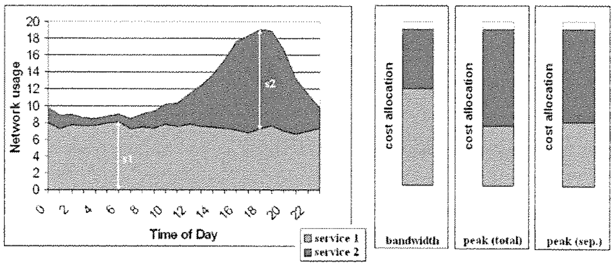

Fig. 6: short-term fluctuations in network usage, allocation based on bandwidth and peak usage

3) According to the peak usage

In order to allocate more fairly the network usage considering the peak-usage of one or more services, a cost-allocation scheme could be used in which the cost allocated to each service is equal to the proportion of either

- the usage of the different services at the time of the largest peak over all services (somewhere around 18h-19h on the example in Fig. 7). (peak (total) in the figures)

$$C_x = \frac{Usage_x(t_{peak})}{Usage_{tot}(t_{peak})} \; where \; t_{peak} = f^{-1}(Max(Usage_{tot}(t)) \quad (2)$$

- the peak-usage of each of the services individually. (peak (sep.) in the figures)

$$C_x = \frac{Max(Usage_x(t))}{\sum_{i \in Services} Max(Usage_i(t))} \quad (3)$$

Mathematical formulae for the proportion of the cost Cx allocated to one service x using one of these two methods are respectively given in (2) and (3).

When using the first alternative on the example given in Fig. 7, the cost allocated to service 1 (service 2) is the proportion of the network-usage of service 1 (service 2) at 19h to the total network-usage at 19h. When using the second alternative on the example given in Fig. 7, in which the peak for service 1 is located at 8h (peak s1) while the peak for service 2 is located at 19h (peak s2), the cost allocated to service 1 is the proportion of s1 to the sum of s1 and s2. The cost allocated to service 2 is s2 / (s1 + s2). It is very obvious that using the first alternative, the allocated cost for service 1 will be too small while the allocated cost for service 2 will be too large. The second alternative gives us a more fair cost for service 1 and 2 in this example.

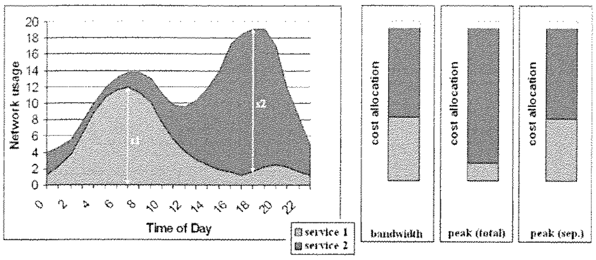

Fig. 7: two distant peak-hours in network usage, allocation based on bandwidth and peak usage

4) *Shortcomings of previous cost-allocation methods*

Fig. 8 shows a network-usage in which service 2 has a very narrow peak, consuming only a small part of the bandwidth available in the network, while having a large peak-usage. Service 1 on the contrary has a very large bandwidth-usage without having a much higher peak-usage. When allocating the cost in this case using the latest cost-allocation scheme proposed, the cost allocated to service 2 will be larger than the cost allocated to service 1, which is not fair considering the fact that service 1 uses much more of the available bandwidth than service 2 does.

Considering the bandwidth-usage of both services, the cost allocated to service 2 would be much smaller than the cost allocated to service 1. Since this allocates a too large part of the costs to service 1, this is not a valid alternative.

C. *Two-phased cost allocation*

A more fair solution for allocating costs of network-usage in a converged network takes both the peak-usage and the bandwidth-usage of each service into account. A first part of the cost for using the converged network for each service is allocated through its bandwidth-usage, using the formula given in (1). The remaining bandwidth, necessary for running all services (peaks) over the network is allocated by the proportion of the peak-usages of each of the different services, using the formula given in (3). The proportion of the cost to be allocated to the bandwidth-usage and to the peak-usage is defined by (4). In Fig. 9 the lower part (filled) shows the cost allocated to service 1 and service 2 according to the bandwidth-usage, while the upper part (striped) shows the remaining part of the cost to be allocated according to the proportion of the peak-usage for the example shown in Fig. 8. As mentioned before the peak-usages of each service separately should be considered (at 8h for service 1 and at 19h for service 2).

$$C_{bandwidth} = \frac{\int_{Time} Usage_{tot}(t)}{Max(Usage_{tot}(t)) \cdot Time} \qquad C_{peak} = 1 - C_{bandwidth} \quad (4)$$

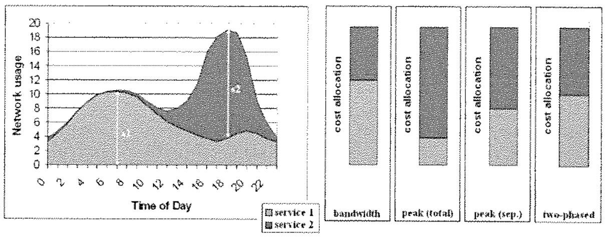

Fig. 8 - two distant peak-hours in network usage (one very small peak), allocation based on bandwidth and peak usage and using the two-phased approach

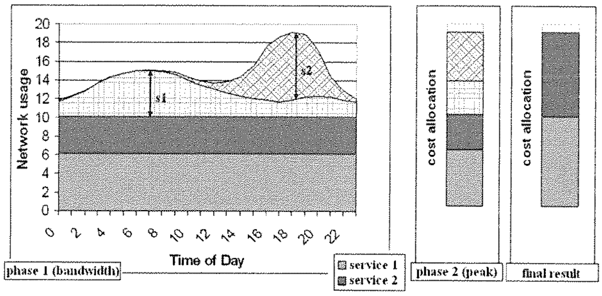

Fig. 9 - two-phased cost-allocation (example calculations)

IV. Mapping costs to services

A. *Definition of network costs*

A network service provider faces several types of expenses when offering services to his customers. They can basically be split in capital expenditures and operational expenditures. Capital expenditures (CapEx) contribute to the fixed infrastructure of the company and they are depreciated over time. They are needed to expand the services to the customers. Operational expenditures (OpEx) do not contribute to the infrastructure itself and consequently are not subject to depreciation. They represent the cost to keep the company operational and include costs for technical and commercial operations, administration, etc.

Capital and operational expenditures are interconnected issues. A network technology allowing to perform a lot of maintenance and provisioning tasks automatically, will probably have higher acquisition cost (CapEx), but will be cheaper to operate (OpEx). It is clear that, for a given amount of equipment, the more operation is automated, the more labour costs can be saved. Also the type of network (backbone versus access) can have an impact. Backbone networks may be more easy to set up (not many boxes, homogeneous technology). Finally, the fact whether we consider an incumbent operator or a new entrant will have an important impact on the ratio CapEx/OpEx as well. We can assume that most incumbents have bought their fiber infrastructure so that it is attributed to CapEx, whereas new entrants might lease their fibers.

B. *Capital expenditures*

For a network operator or network service provider, capital expenditures are constituted of 3 categories, as illustrated in Fig. 10.

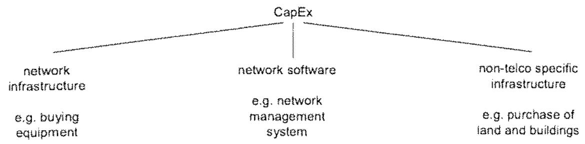

Fig. 10: Classification of CapEx costs for telco

First, there is the purchase of network infrastructure, starting from the outside plant infrastructure[3] (when it is bought and not leased), over the big network equipment parts like IP routers, Optical Cross-Connects etc. Remark that buying equipment always contributes to CapEx, independent from the fact whether the payment is made in one time or spread over time when paying back debt systematically (for financing reasons). Also interests to be paid for a loan are included here. Infrastructure (building, network equipment, etc.) being leased does not constitute to CapEx in our model, it is counted as OpEx[4]. Another part is the software that needs to be bought. This includes all assets needed to build the network, such as the network management system. This also includes the software to implement a distributed control plane in case of GMPLS deployment. The third part is the non-telco specific infrastructure, which means general assets, not specific for a telecom operator. This includes purchase of land and buildings, e.g. to house the personnel.

C. *Operational expenditures*

The operational expenditures for a telco can be split in three main categories: the OpEx for a network which is up and running, the OpEx concerning equipment installation and the non-telco specific OpEx parts. The OpEx classification is given in Fig.11 and discussed in the following paragraphs.

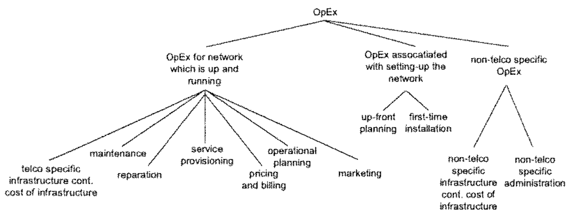

Fig.11: Classification of OpEx costs for telco

1) OpEx for network which is up and running

The first big category of OpEx costs combines all expenditures to operate a network which is already up and running.

The cost to keep the network operational in a failure free situation is the first important cost in this category. We call this the *telco specific continuous cost of infrastructure*. It includes the costs for paying (floor) space, power and cooling energy and leasing network equipment (e.g. fiber rental). Also right-of-ways, i.e. the privilege to put fiber on the property of someone else (e.g. along railways) is part of this cost.

Secondly, the traditional maintenance cost can then be seen as the cost to maintain the network or to operate the network in case a failure can occur. The main actions performed here aim at monitoring the network and its services. Therefore, the actions involved include direct as well as indirect (requested by an alarm) polling of a component, logging status information, etc. Also stock management (keeping track of the available resources and order equipment if needed), software management (keeping track of software versions, and install updates), security management (keeping track of people trying to violate the system and block resources if needed), change management (keeping track of changes in the network, e.g. a certain component goes down) and preventive replacement are included. Furthermore, cleaning of equipment can be taken into account as well.

Third, reparation means actually repairing the failure in the network, if this cannot happen in routine operation. Reparation may lead to actual service interrupts, dependent on the used protection scheme. The actions involved in the reparation process are diagnosis and analysis, the technicians traveling to the place of the failure, the actual fixing of the failure and performing the needed tests to verify that the failure is actually repaired.

The fourth important part of the OpEx cost for an existing network is given by the process of provisioning and service management. This means providing a (previously defined and negotiated) service to a customer. It follows the service request by the potential customer and includes the entire process from order entrance by the administration till performing the needed tests. Also the actions in case a service is ceased are counted here. This includes accepting the cessation request, deactivating the circuit, switching off and physically recovering the equipment.

The cost to operate the network includes the cost of pricing and billing as a fifth part. This means sending bills to the customers and making sure they pay. It includes actions like collecting information on service usage per customer, calculate tariff per customer as well as sending bills and checking payments. Calculating penalties to be paid by the operator for not fulfilling the Service Level Agreement (SLA) is another task here.

As the sixth OpEx cost part, we distinguish the ongoing network planning activity which we call operational network planning. It includes all planning performed in an existing network which is up and running, including day-to-day planning, re-optimization, planning upgrades.

Finally, there is the cost for marketing. With marketing we mean acquiring new customers to a specific service of the telco. The actions involved are promoting a new service, provide information concerning pricing etc. Possibly, new technologies enable new services.

[3] All network equipment not located in network nodes: cable infrastructure, optical fiber, amplifiers, etc.

[4] This is the approach followed by most companies and it is also consistent with the Eurescom project P901 (2000) [3]. However, other sources, like CIENA corp. (1999) [7] and Wavium (2003) [8] believe all infrastructure (no matter whether it is bought or leased) is to be counted as CapEx. The wide range of CapEx and OpEx definitions available indicates the difficulty to compare the cost structure of several companies.

2) OpEx associated with setting up a network

The second category of operational expenditures we distinguish is the OpEx associated with setting up a network. This represents all the costs to be made before connecting the first customer.

It includes the costs for *up-front planning*, which denotes all planning done before the decision "let's go for this approach" is taken. Planning studies to evaluate the building of a new network, changing the network topology, introducing a new technology or a new service platform, etc. are tasks to be performed here. Also the choice of an appropriate equipment vendor is counted here, e.g. including travel cost for discussions with different vendors.

The second part of the OpEx category on *equipment installation* is constituted by the operational aspects of first-time installation of new network equipment. All costs related to installing the equipment (after buying it, which is counted as CapEx) is counted here. This includes the actual connecting and installation of the new component into the network, as well as the necessary testing of the component and its installation. This first-time installation is usually carried out by the equipment vendor. In this case, the costs for the operator are included in the contract with the vendor. The OpEx costs concerning setting up the network are closely related to the CapEx cost of buying equipment. Therefore, in some cost models this OpEx category is taken together with CapEx as 'first installed costs'.

3) Non-telco specific OpEx

Finally, there are some general OpEx parts. The non-telco specific OpEx parts contain OpEx subparts that are present in every company; they are not specific for a telecom operator.

Non-telco specific continuous cost of infrastructure denotes the continuous infrastructure cost, like rental and leasing, power consumption etc. In this category we only include OpEx cost of infrastructure that is not related to the network itself. This includes buildings to house the personnel, energy for desktop PCs, heating, cleaning of buildings, etc. Note that, as indicated above, buildings to house network equipment, energy to operate network components, cleaning of network equipment,... are included in the subpart 'telco specific continuous cost of infrastructure'.

Non-telco specific administration includes the administration every company has, like the payment administration for employees, the secretary, the human resources department etc. Pricing and billing, network planning (both operational and up-front planning) and marketing can be seen as telco specific administrative tasks, therefore they were included in the previous categories. The general OpEx costs for infrastructure and administration can jointly be seen as 'overhead' costs.

In Fig.11, labour cost (personnel wages) is not indicated as a subpart of the OpEx cost. However, it is obvious that personnel cost is an important type of expenses for every company, and definitely also for a telecom company. We believe that personnel costs are present in several subparts of the OpEx costs, e.g. wages of the technicians performing reparation in the field as well as wages of the sales people performing marketing tasks or the network engineers performing network planning. Therefore, in [9] we have suggested a matrix representation for the OpEx for a telco, where the OpEx subparts of Fig.11 are combined with the actual expenses (like personnel wages, floor space, energy and rental).

V. Mapping of CapEx and OpEx parts on shared costs

In section 2, a new methodology was given to allocate shared network costs to network services. In the previous section, all network costs, both CapEx and OpEx, have been described and classified. This has made clear that there is not only the network equipment cost to allocate to the services. A network services provider aims at allocating all his costs to the services he is offering, in a fair way. This is the topic of the current section.

A. Direct, shared, joint and common network costs

A mapping of the CapEx and OpEx parts defined in the previous section on direct, shared, joint and common costs is given in Fig. 12.

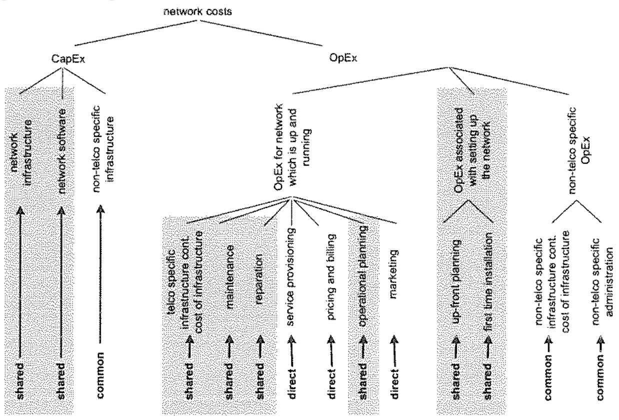

Fig. 12: mapping of CapEx and OpEx parts on shared costs

Some costs can directly be linked to a certain network service. It concerns the costs for service provisioning, pricing and billing and marketing. Those costs can therefore be seen as direct costs. For service provisioning, the entire process from ordering entrance by the administration till performing the needed tests is specific for a certain service. It includes planning, installing and configuring the equipment in order to be able to provide the considered service. If the considered service would not be offered, this cost would not exist. For pricing and billing, the cost of pricing (defining the price for a certain service) can definitely be seen as a direct cost as well. This activity is specific per service. Also, the cost of charging (calculating the price to be paid by a certain customer over e.g. one month) can be considered a direct cost. In case of billing, it is possible that a common bill is made for a certain customer, who uses different services. In that case the cost for billing is to be seen as a shared cost. If none of the services would be offered, this cost would completely disappear. In case the bill only concerns one service, the cost of billing can be considered a direct cost. If marketing is performed for individual services, then it is to be considered as a direct cost as well.

Further, there are some general costs, the non-telco specific CapEx (e.g. the buildings to house the Human Resources department, the PCs for the administration etc.), together with the non-telco specific OpEx costs (e.g. heating of the buildings to house the personnel, wages of the HR personnel, etc.) which are not specific to a certain network service. Those costs can therefore be considered as common costs. For the telecom operator or service provider, they can be seen as overhead costs.

Finally, the costs for the network infrastructure should be considered as shared costs, as the same network infrastructure is used to offer all network services in case of a converged network. Note that the network infrastructure cost does not only include the cost for the capacity required by the dimensioning process[5], but also the additional capacity in the network induced by a granularity of the equipment, equipment bottlenecks and backup capacity to provide protection and restoration.

Some other cost parts are very closely related to the infrastructure cost and are therefore also considered as shared costs. They are to be allocated in the same way as the infrastructure cost. First there is the cost of the network software (CapEx part), e.g. the NMS is used for several services as well. As explained in section 3, the telco-specific cost of infrastructure (e.g. floor space, energy) is the cost to operate the network equipment in a failure-free situation. Finally, also OpEx associated with setting up a network is close to the CapEx cost (together they form the first installed cost). All of those costs can be allocated together with the CapEx cost for equipment installation. The operational activities concerning network maintenance, reparation and planning are probably generally coordinated and performed without any reference to individual services. For this reason, they can also be seen as shared costs.

We recall from the introduction that joint costs refer to costs of resources which are inherent to each other whereby providing the first resource will also provide the second resource and vice versa. It is uncommon in telecom. Therefore, joint costs are not indicated in Fig. 12.

B. Fair allocation of all network costs

The non-telco specific costs (infrastructure acquisition, continuous cost of infrastructure and administration) were indicated as common costs. They cannot be allocated to the offered services in a straightforward way.

The network resources and the related costs to build and operate the network (network infrastructure, network software, telco specific continuous cost of infrastructure and OpEx associated with setting up the network) are indicated as shared costs in the previous section. They are all closely related to the infrastructure itself and can therefore be divided in a fair way according to the cost allocation scheme described in section 2 of this paper, partially on capacity usage and partially peak-based.

The costs associated to the operational processes of the network (maintenance, reparation, service provisioning, pricing and billing, operational planning and marketing) should be evaluated individually, in order to allocate them fairly to the different network services. The costs to maintain, repair and (operationally, i.e. day-to-day) plan the network are shared amongst several network services. They could follow the allocation scheme for the network infrastructure proposed in section 2 (usage and peak based) or they could be treated otherwise, e.g. if one believes the cost driver in this case is the dimension of the network rather then the services resource usage, one could distribute the costs equi-proportional over all services. Note that, some part of the maintenance cost can also directly be allocated to the considered service, e.g. to cost for the helpdesk center for a certain service. By employing helpdesk operators on a flexible basis, the cost will follow the volume of the considered service.

The direct costs are directly to be allocated to the considered services. This is the case for service provisioning, pricing and billing and marketing costs. If billing or marketing activities are performed jointly for multiple services, the considered costs are to be seen as shared instead of direct costs. In the latter case, however, it doesn't make sense to allocate them according to capacity usage or peak traffic. A more fair cost allocation scheme in this case would be an equi-proportional distribution among all services. E.g. if one bill is sent for several services, this cost for the distribution of the bill (paper, stamp, processing) should be equally divided among all services.

VI. CASE STUDY

A. Obtaining realistic figures

In order to quantify the impact of this two-phased cost-allocation scheme, we applied the different cost-allocation schemes on a more realistic case and compared the resulting costs for the different considered services. Realistic figures combining both traffic over an existing network and all CapEx- and OpEx-costs associated to this same existing network are, considering the confidentiality of such data, hard to find. However there are existing some illustrative figures for each of them separately in the public domain.

We used the CapEx- and OpEx-figures described in [10] for calculating a realistic network cost, considering a backbone network. The resulting costs for this network are given in Table . As described in section 4.1, the considered costs are CapEx-costs for the network (yearly) and OpEx-costs for maintenance, reparation, operational network-planning, telco. specific continuous cost of infrastructure and first-time installation and up-front planning. The total yearly cost for this network amounts to € 58,429,609, resulting in a daily cost of € 160,081.

[5] In case of a bottom-up approach.

TABLE I
REALISTIC (YEARLY) NETWORK-COSTS AS OBTAINED FROM [10]

CapEx		€ 34,500,000
OpEx	telco spec. cont. cost of infrastructure	€ 11,200,000
	Maintenance	€ 838,000
	Reparation	€ 1,290,000
	operational network planning	€ 225,000
	first time installation + up-front planning	€ 10,400,000
	Marketing	€ 652,560
	service provisioning	€ 610,493
	pricing and billing	€ 135,012
	non-telco specific cost of infrastructure	not considered
	non-telco specific administration	not considered

We also constructed the traffic-patterns for 5 different services comparable to realistic traffic-patterns as described in [11] and [12]. Fig. 13 and Fig. 14 show the considered traffic-patterns. Since no direct figures are available for the bandwidth available in the network considered above and all network costs will be allocated to the different services, traffic is expressed in function of the cost.

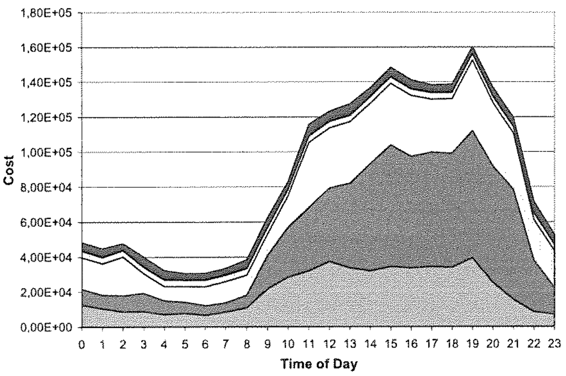

Fig. 13: Cumulative traffic patterns considered in the realistic case

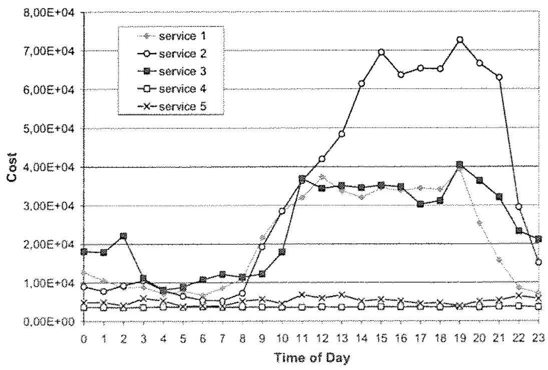

Fig. 14: Traffic patterns considered in the realistic case

B. Cost-allocation

Both the proportion of the allocated costs, as well as the actual allocated costs to the different services calculated using the formulae in 2.2, are shown in Table . It is obvious that none of the four proposed cost-allocation methods gives the same results as the suggested two-phased approach and big differences between the different methods can be observed.

TABLE II: ABSOLUTE COSTS ALLOCATED TO THE SERVICES USING THE CONSIDERED ALLOCATION SCHEMES

	serv. 1	serv. 2	serv. 3	serv. 4	serv. 5
Bandwidth	€ 38,02	€ 62,07	€ 43,86	€ 6,68	€ 9,45
peak (tot)	€ 39,33	€ 72,68	€ 40,44	€ 3,72	€ 3,92
peak (sep)	€ 38,60	€ 71,32	€ 39,69	€ 3,72	€ 6,76
two-phased	€ 38,28	€ 66,26	€ 41,97	€ 5,34	€ 8,23

Fig. 15 shows the relative difference (averaged over all 5 services) [6] between our two-phased cost allocation approach and the classical approaches described in section 2 (bandwidth, peak (tot) and peak (sep)). The difference in costs allocated to the services between the two-phased approach and the bandwidth-based allocation scheme is on average 10.27%. It is 19.78% for the scheme using the proportion of the usage at the largest total peak (peak(tot)) and 12.42% for the scheme using the separate peak usages (peak (sep)).

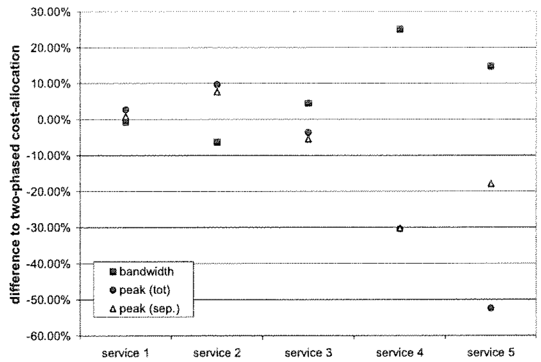

Fig. 15: relative difference of the costs allocated to each service to the case in which the two-phased cost-allocation method is used.

The following observations can be made concerning the performance of the different cost allocation schemes:

- We observe the largest impact for services 4 and 5, which might be explained by the following two facts. First, both services are more or less time-independent as shown in Fig. 14. Especially service 4 seems to consume a constant amount of bandwidth with only small fluctuations in time. Service 5 contains larger fluctuations. Second, both services are very small considering both peak-usage and bandwidth-usage in comparison to the other services.
- The cost allocation method using the proportion of the usage at the largest (total) peak, gives the worst results. It amounts to an average difference in allocated costs of nearly 20%, when compared to the two-phased cost-allocation method. In particular for services 4 and 5, this cost-allocation scheme gives a cost which is up to 50% lower than in case of the two-phased cost-allocation scheme.

[6] Calculated using absolute values, to take into account both positive and negative differences with the results obtained using the two-phased approach.

- Overall, the impact of the two-phased approach is still considerable. Both the cost-allocation schemes considering the bandwidth-usage or the (separate) peak-usages, give an average difference of 10% compared to the two-phased approach. Apart from the effect for small services described above, also larger services like service 2 and service 3 show large differences between the different allocation schemes. Only service 1, for which the traffic pattern seems to fit most closely to the cumulative traffic-pattern over the network, shows only small differences between each cost-allocation method (within 3% and even within 1% when discarding the results of the total peak-usage method).

The observed differences between the classical and the two-phased approach might prove very important as several strategic decisions are partly based on these figures. Return on Investment (ROI) or Net Present Value (NPV) based investment decisions, price calculation, etc. all use the costs calculated in this allocation process. It is very obvious that for instance a cost which is 30% larger (which is the case for service 4) will lead to a higher tariff for the service, which will in its turn lead to a competitive disadvantage for this service. A much lower cost (up to 50%) might lead to the misconception that the considered service (through the calculation of ROI) is very profitable, while it is actually a non-profitable service.

VII. Lowering costs by reducing the peak-usage in the network

Previous paragraphs have indicated how service providers can fairly allocate network costs to the different services they provide. The proposed cost allocation scheme (usage and peak based) is driven by the traffic flows over the network. If the provider could influence those flows, he would be able to reduce the overall network costs and therefore increase his profits. One possibility could be to introduce a new service, skimming away customers from the peak hours in the original service. Another method could use the effects of price elasticity[7] by differentiating between the pricing for peak and non-peak hour traffic. The results from this change in the traffic demand pattern are described in Fig. 16:

A. Revenues will be lost as a result of skimming high paying customers in peak hours to the non-peak hours.

B. New revenues will be generated by the skimmed customers. These newly generated revenues will be lower than the lost revenues due to the lower price set to attract these customers to a time-restricted bandwidth service.

C. When the total maximum capacity is decreased, the resulting network dimensioning will be smaller and thus cheaper. In case of a bottom-up approach (building a new network), the costs for the service provider are decreased.

D. In case of a top-down approach, reducing the required capacity for the current customers, frees some (C in the figure) of the available capacity in the network. This will not directly reduce equipment cost here (equipment has already been installed), but it might allow the provider to attract new business customers (instead of A in the figure) or delay network expansion investments in case of a growing traffic demand.

When all factors are cumulated and a positive effect is accomplished, this will result in a better competitive market position. Those effects, together with the impact of price elasticity [13] will be studied in future work.

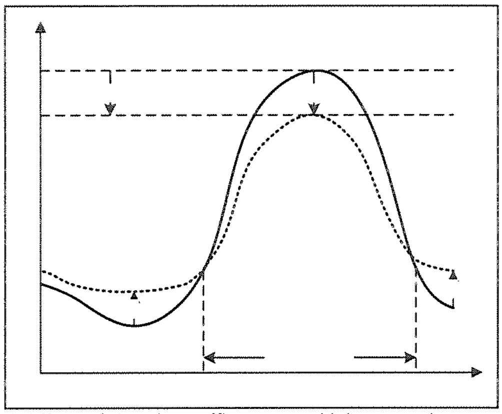

Fig. 16: Effects of changing traffic pattern, with lower maximum capacity

VIII. Conclusions

In the light of the recent evolution towards converged networks, a fair cost allocation of network costs to the different services offered over this network has become an important topic. Some cost items can be seen as direct costs and can therefore be directly allocated to a certain service. However, in a converged network, an important part of the costs is shared among different services. This paper introduces a method to allocate those shared costs to the different services in a fair way. We describe the method theoretically, using different scenarios concerning the traffic flows over the network. We suggest a cost allocation scheme based on a combination of resource usage and peak capacity. We apply the model to a real telecom environment, indicating how the different CapEx and OpEx cost parts for a service provider can be allocated to the services. Finally, we discuss a case study were the cost allocation is performed for a realistic German network scenario. In this study we find that the costs allocated to the different services can differ up to 50% according to the cost allocation method used. Also an average difference of 10% in the cost allocated to different services was found, when comparing our two-phased approach to more traditional methods. It is obvious that, since the costs calculated to services can be used in the calculation of profit, price-setting, ROI, etc. that this difference might have an important influence on the strategic decisions and competitive strength of a network operator.

Our analysis shows that a fair allocation of shared costs is especially important in telecom environments, because of the importance of the costs related to network equipment infrastructure compared to the overall network cost. Network infrastructure costs are shared in nature, especially in

[7] Price elasticity of demand is the percentage change in quantity as a result of a one percent change in price [13]. Cross elasticity [14] can be defined as the percentage change in quantity of service B as a result of a one percent chance in price of service A.

converged networks. We have shown that a bottom-up approach allows clearly separating all costs amongst the services. We also indicated that, to some extent, the traffic flows can be impacted by an intelligent pricing scheme.

ACKNOWLEDGEMENTS

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His research deals with design and planning of communication networks. This work is focussing on optical transport networks, to support the next-generation Internet. Up till now, he has actively been involved in several IST projects (LION, OPTIMIST, DAVID, STOLAS, NOBEL and LASAGNE), in the COST-action 266 and 291 and in the ITEA/IWT TBONES project. His work has been published in more than 100 scientific publications in international conferences and journals.

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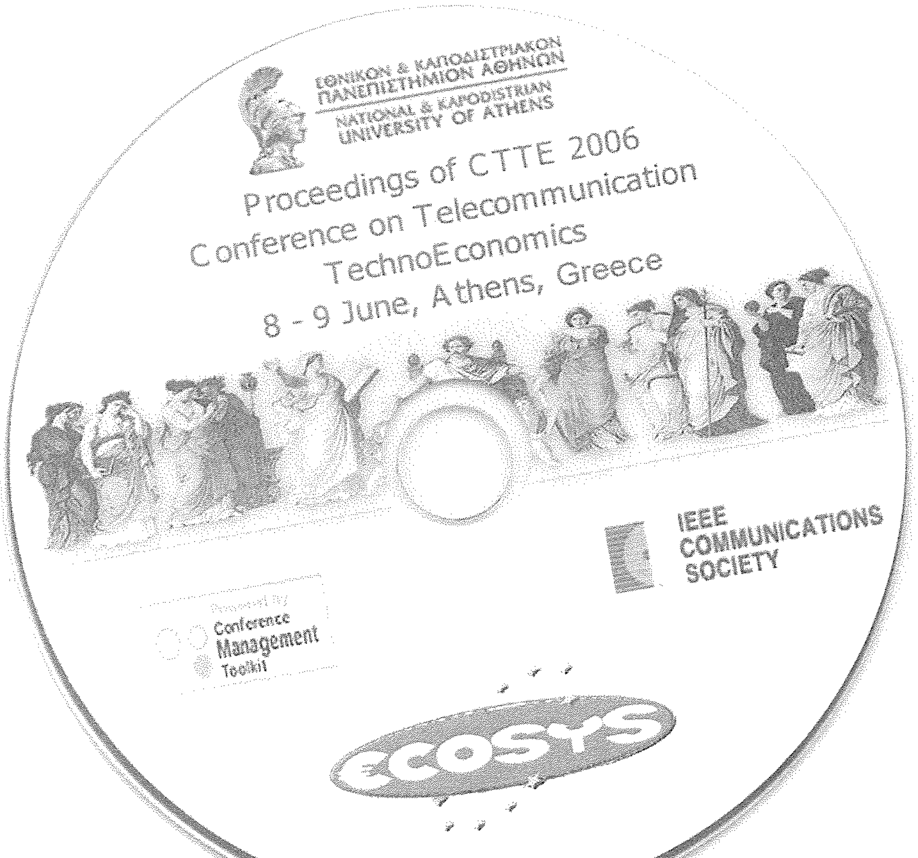
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