Techno-economic analysis of software defined networking as architecture for the virtualization of a mobile network

Bram Naudts*, Mario Kind†, Fritz-Joachim Westphal†, Sofie Verbrugge*, Didier Colle* Mario Pickavet*
*Dept. of Information Technology (INTEC)
Ghent University - IBBT, Ghent, Belgium
Email: {bram.naudts, sofie.verbrugge, didier.colle, mario.pickavet}@intec.ugent.be
†Deutsche Telekom, Germany
Email: {mario.kind, fritz-joachim.westphal}@telekom.de

***Abstract*—Worldwide mobile network operators have to spend billions to upgrade their own network to the latest standards for wireless communication of high-speed data for mobile phones (e.g. Long Term Evolution, LTE). This is in contrast with the decline in average revenue per user and threatens: (1) their profitability and (2) the fast adaptation of new standards. Investigating new mechanisms that can decrease the capital expenditures (capex) and operational expenditures (opex) of a mobile network is therefore essential. Enabling multiple mobile network operators on a common infrastructure is one such mechanism. Software defined networks can overcome this problem and a solution based on exploring OpenFlow (OF) as architecture for mobile network virtualization has been proposed. We investigate two network scenarios based on this OF solution in a techno-economic analysis: (scenario 1) software-defined, non-shared networks and (scenario 2) virtualized, shared networks and compare it against the current situation. By doing so, this paper provides insights on the relative cost savings that a mobile network operator can reach through Software Defined Networking (SDN) and network sharing.**

The techno-economic analysis indicates that SDN and virtualization of the first aggregation stage and second aggregation stage network infrastructure leads to substantial capex cost reductions for the mobile network operator. As a consequence, mobile network infrastructure virtualization through the use of OpenFlow could be one of the problem solvers to tackle the issue of rising costs and decreasing profitability. Still, we did not take into account the direct effect on operational expenditures and the indirect effect that network sharing can adversely affect the ability of the operators to differentiate themselves.

I. THE NEED FOR A NEW NETWORK ARCHITECTURE AND NETWORK SHARING FOR MOBILE NETWORK OPERATORS.

Global mobile data traffic more than doubled in 2011 [1] while average revenue per user is flat or decreasing. At the same time equipment prices are declining by only 10 to 20 percent ultimately shrinking profitability. Declining profits leave the mobile network operator with lesser amount of re-investable funds for expansion of services. At the same time operators must invest in their infrastructure to provide the bandwidth to meet demand and to provide faster mobile network connection speeds. It is therefore important to reduce the total cost structure of a network operator.

One of the main contributors to the cost structure of network operators are the network devices. Much of today's network equipment is highly specialized and monolithic (there is no separation between the control and the forwarding capabilities). In today's dynamic environment network operators need to be able to rapidly deploy new capabilities and services in response to changing user demands in order to stay competetive. However, because of the lack of an open interface between the control logic and forwarding logic the ability to innovate is hindered. The operator must wait for the vendor of network infrastructure equipment to implement it which can take several years.

This mismatch between market requirements and network capabilities has lead to a rethinking of network architecture. By separating the control and forwarding logic it is possible for the operator to reduce vendor dependence, increase the speed of innovation and reduce the total cost of ownership. This will result in operators using standard networking hardware and custom control and management software in standard network controllers.

Another main contributor to the cost infrastructure of a network operator is the cost of physical infrastructure. By sharing one physical grid among several mobile operators it is possible to reach greater efficiency of existing resources, fewer site builds and broader coverage. Mobile network operators have already adopted a form of passive sharing by sharing of site locations and masts. Active sharing of resources is however uncommon as this can be prohibited by the telecom regulator to make sure there is enough competition between the network operators. The degree of differentiation between network operators is also reduced when they actively share resources.

This mismatch between regulatory requirements and demand from mobile operators to actively share resources has (again) lead to a rethinking of network architecture. By separating the control and forwarding logic it is possible to impose independent management control per operator over the infrastructure shared by different operators. This enables each operator to offer differentiated services and stimulates the degree of competition because new entrants can enter the market without huge investments in physical infrastructure.

The goal of this paper is to perform a techno-economic analysis of the network architecture that has been proposed to overcome both mismatches mentioned in this section. In Section II we discuss how the first mismatch can be tackled by Software Defined Networking (SDN) and how the second mismatch can be tackled by network virtualization. In Section III we will qualitatively discuss the impact of SDN and full network sharing on the capital expenditures and operational expenditures of a mobile network operator. In section IV, we quantify the capital expenditures for a German reference network scenario. Finally, section V will summarize the results.

II. THE PROPOSED TECHNICAL SOLUTION FOR REDUCED VENDOR DEPENDANCE AND NETWORK SHARING

Software Defined Networking (SDN) is a network architecture where (1) forwarding is decoupled from network control and (2) there is more freedom of choice in programming the forwarding logic. Network intelligence is (logically) centralized in software-based SDN controllers, which maintain a global view of the network [2]. The SDN controller typically has knowledge about the physical topology of the network either by discovery mechanisms or appropriate databases and can based upon this topology create paths that are programmed into the forwarding engines of network devices. In essence, SDN abstracts the network like an operating system abstracts the applications from the hardware.

OpenFlow [3] is considered as the enabler of SDN. It is a standard communications interface defined between the control and forwarding layers of an SDN architecture. OpenFlow allows direct access to and manipulation of the forwarding plane of network devices such as switches and routers, both physical and virtual (hypervisor-based) [2]. The path of packets through the network of OpenFlow enabled switches is determined by software running on a separate OpenFlow controller.

OpenFlow is, as an enabler of SDN, a solution to the mismatch between market requirements and network capabilities as it provides an open communication interface between the control and forwarding layer allowing network operators to be less vendor dependent.

Network virtualization is a method to use the physical resources in a network by splitting resources into slices. Each slice is isolated from the other channels and can be assigned to a particular network device in real time. The monitoring and managing of the network is possible from a single computer. Network virtualization allows multiple isolated logical networks each with potentially independent addressing and forwarding mechanisms to share the same physical infrastructure.

Realizing network virtualization in a mobile network architecture means to split the resources into slices while network operators maintain independent management control over their slice. This includes radio base stations (RBSs), routers and even Ethernet links. In [4] the virtualization between the air interface of the user equipment and the e-UTRAN Node B has been discussed. In [5] the virtualization of the physical nodes from the E-UTRAN Node B extending to the backhaul has been discussed. The proposed solution in [5] has a dedicated OpenFlow network which implements FlowVisor [6] based isolation. FlowVisor is a OpenFlow controller that uses the OpenFlow protocol to slice the underlying physical network.

OpenFlow is as the supporting protocol for FlowVisor the enabler of network virtualization. Network virtualization allows several network operators to share their existing physical infrastructure while allowing for service differentiation and increased competition at the same time. It is as such an answer to the mismatch between regulatory requirements and the demand from operators to share their existing networks.

OpenFlow can be an enabler for both SDN and network virtualization. In the next section we will conduct a techno-economic study that takes into account the benefits of OpenFlow as enabler for SDN and FlowVisor (using the OpenFlow protocol) as enabler for network sharing. Our goal is to research the impact of SDN and network sharing on the capital expenditures and operational expenditures of a mobile network operator. The impact on capital expenditures is qunatified in this study.

III. QUALITATIVE COST EVALUATION OF SOFTWARE DEFINED NETWORKING AND NETWORK SHARING.

We qualitatively compare three generic scenarios in this section:

- Classical scenario: A distributed network architecture with network control tightly bound in individual network devices.
- SDN scenario: A centralized network architecture with network control decoupled from forwarding using OpenFlow as communication interface.
- Sharing scenario: One step beyond the SDN scenario, network virtualization and network sharing between several network operators with a FlowVisor controller.

We follow the definition of cost categories as described in [7] to evaluate the costs of a network for a telecom operator. This study defines capex as contributing to the fixed infrastructure of the company, and they are depreciated over time. For a network operator, they include the purchase of land and buildings (e.g. to house the personnel), network infrastructure (e.g. optical fiber and IP routers), and software (e.g. network management system). Opex do not contribute to the infrastructure. They represent the cost of keeping the company operational and include cost of technical and commercial operations, administration, etc. For a network operator, opex are mainly constituted of rented and leased infrastructure (land, building, network equipment, fiber, etc.) and personnel wages. [7] further identifies and defines categories of operational expenditures, an approach we follow.

An overview of the cost reductions for the scenarios we consider is given in figure 1. The relevant cost reductions are discussed in the next subsections.

	capex	opex										
		telco specific opex for network which is up and running							opex equipment installation		general opex	
		telco specific cost of infra-structure	mainte-nance	repair	service provi-sioning	pricing and billing	opera-tional network planning	marke-ting	first time installa-tion	up-front planning	non telco specific cost of infra-structure	non telco specific admini-stration
Classical Scenario	0	0	0	0	0	■	■	■	0	■	■	■
SDN Scenario	-1	-1	-1	-1	-1	■	■	■	-1	■	■	■
Shared Scenario	-2	-2	-2	-2	-1	■	■	■	-1	■	■	■

0	no effects on costs	-1	reduction in cost
■	not considerd	-2	extra reduction in cost

Fig. 1. Overview of capital expenditures and operational expenditures and potential savings with the classical scenario as reference point.

A. Capital Expenditures

In the SDN scenario, complicated features are not needed in each device thus devices are simpler and cheaper. Complex control logic is moved to an external device that can control multiple network devices. The extra cost for OpenFlow controllers, line cards and tranceivers required to connect the network devices to the OpenFlow controller will however increase the capital expenditures. Further, SDN provides a global view of network utilization, allowing for traffic-steering. This can reduce the current practice of overprovisioning network capacity and reduce capital expenditures.

The main sharing gains in a mobile network can be achieved in the access network through radio base station sharing. This study is however focused on the pre-aggregation, aggregation and core sites. Because of the sharing of network equipment and the aggregation of traffic, some equipment will become redundant and in general utilization rates will increase. Sharing gains will be lower closer to the core network because traffic is already aggregated and each operater can already use its equipment to a full extend.

Main parameters that will influence the potential for capital cost reductions by applying SDN are: (1) cost savings that can be reached by using simpler network devices, (2) cost of extra components such as OpenFlow controllers, line cards and tranceivers, (3) the ratio of the number of switches that an OpenFlow controller can manage, (4) the possibility to better align network capacity with actual demand.

B. Operational Expenditures

The *continuous cost of infrastructure* for the SDN scenario will be lower because the cost for power and cooling energy is reduced as there is no more energy consumption by the control plane in the network switches. Further, SDN allows for better traffic-steering reducing the number of network devices and their power consumption. Energy costs will be even lower for the sharing scenario as a result of higher utilization of network equipment. The additional OpenFlow controller(s) will, if not embedded, consume more energy compared to a classical scenario without OpenFlow controllers.

Maintenance cost will be lower in the SDN scenario. SDN creates a single cohesive system where in old architectures it was required to manage and maintain a bunch of independent autonomous devices. An example is the maintenance cost of software. Software management will be easier because the number of running software versions is reduced to a minimum of one. Similar effects come into play for security management and stock management. In the sharing scenario maintenance costs such as preventive replacement of equipment are shared among multiple operators.

Costs for repair can be reduced in the SDN scenario because of the better testing possibilities ahead of rollout which will reduce the number of bugs that can reach actual production traffic. Sharing the equipment will reduce the costs for repair further as each operator can take responisbility for a part of the network (e.g. each half of the network). A large drawback of SDN is the creation of a single point of failure: the OpenFlow controller. Failures in these network elements can destabilize the entire network.

Cost of service provisioning can be lowered because SDN enables automated configuration of the network. Today experienced networking personnel are required to set up, administrator, change and maintain the network. These personnel can be hard to find, expensive and difficult to retain. SDN reduces the amount of manual configuration required in the network which will also result in fewer errors and less network downtime.

The cost for first time installation of network equipment will alter siginifcantly. SDN creates a higher level of innovation which will lead to faster iteration times and a higher frequency of testing. SDN however has robust testing abilities ahead of rollout and reduces the number of devices that need to be updated. The network environment can be simulated to create a test environment before transition to the new system and production flows can be mirrored into this test environment allowing for early identification and fixing of bugs. The created test environment also offers the opportunity to train staff working at the network operating center on a real-world simulated network before they need to operate the network while they are in production.

IV. CASE STUDY FOR A GERMAN REFERENCE NETWORK

In this section we present a quantitative study on the capital expenditures for a network operator in a German reference network scenario. The scenarios under considerations are the same as in section III. We assume that both mobile network operators have the same network design but that the number of customers is different. The forecasted number of customers for each network operator and the evolution is shown in figure 2. This is based on expert opinion and knowledge in the SPARC project [8].

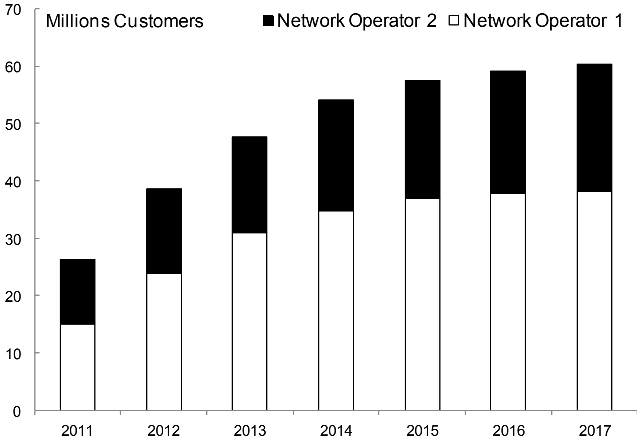

Fig. 2. The amount of mobile data subscribers is forecasted to grow quickly between 2012 and 2015. Growth will slow down from 2015. Network operator 1 has on average 1.7 times more customers than network operator 2.

A. Capital Expenditures

1) Network Dimensioning: Figure 3 gives a schematic overview of the traffic flows for 2017 and the network design we consider. An overview of the core network design is given in Figure 4.

We consider a logical (IP) network with 25000 access nodes (Radio Base Stations, RBS), two aggregation stages (1000 pre-aggregation sites and 80 aggregation sites) and 12 core locations. 6 of the 12 core locations form the inner core, each of the 6 inner core locations is as such also a 12 location in parallel. Each of the 6 inner core locations is interconnected to the internet.

The RBSs are connected with the pre-aggregation stage with a ring network (5 RBSs per ring and 5 rings per pre-aggregation site). The same is true for the connections between the pre-aggregation sites and the aggregation sites (4 pre-aggreagtion sites per ring and 4 rings per aggregation site). A ring network provides shared protection with extra traffic (1:N protection). We chose ITU-T G.8032 [9] as a solution to provide ring protection. 7 aggregation sites are concentrated at 1 of the 12 core locations with a redundant path to another 1 of the 12 locations. A combination of mesh and direct connections links the core locations directly. Each of the 12 core locations is attached redundant to 1 of the 6 inner core locations. By doubling the available capacity at disjunctive locations and appropriate connections a complete redundant network is provided. The inner core (6 locations) is connected to the internet. Mobile core network elements such as the Serving Gateway (SGW), PDN Gateway (PGW), Evolved Packet Data Gateway (ePDG) are provided at each 12 location.

2) Traffic Dimensioning: The analysis of traffic profiles of customers, analysis of distribution of customers to RBS, and the analysis of distribution of radio base station to pre-aggregation sites is based upon industrial input. Figure 5 gives an overview of the real traffic for 2011 and forecasted traffic for 2012-2017. Traffic estimations are based upon busy hour traffic (7% of daily traffic) and take into account a large variation in traffic during busy hour by adding a heavy-tailing factor (3 times the average traffic during busy hour). The large difference in traffic load in between radio base stations is accounted for by using a distribution of base station clusters.

3) Dimensioning of Devices: The most inexpensive device configuration for each network location was chosen and the number of modular port adapters and interfaces is increased at the start of each year to support the increase in traffic.

For the classical- and SDN scenario the Cisco ASR 9001 router is deployed in both the pre-aggregation and aggregation locations. Each location has two routers for redundancy reasons in case of a single node failure. For the sharing scenario the Cisco ASR 9001 router is deployed in the pre-aggretion locations. The Cisco ASR 9006 router is deployed in the aggregation locations. Node protection is provided.

The mobile core network is the logical data center area where the operator positions all the central packet- and voice gateways, auxiliary control plane systems and consumer and business application servers. For the mobile core components the Cisco ASR 5000 multimedia core platform is used. The Cisco ASR 5000 platform combines the network functions such as the voice and packet gateway function for 3G and Long Term Evolution (LTE) in a single specialized hardware platform. We assume that one ASR 5000 device can support up to one million of subscribers and that it is capable of 20Gbit/s of biderectional throughput. This assumptions are based on a independent public performance test for the CISCO ASR 5000 platform [10], [11]. The following set of design rules were applied for dimensioning the core:

- Each 6 inner core location is a 12 core location
- Each 6 inner core location requires the Cisco ASR 5000 platform as mobile core element
- Each 6 inner core location provides redundant Cisco ASR 5000 capacity for mobile core elements for one other 6 inner core location
- Each 6 inner core location provides capacity to all 5 other 6 inner core locations for $\frac{5}{6}$ of total traffic
- Each 6 inner core location must be able to carry all traffic to the internet

For the classical- and SDN scenario the Cisco ASR 9010 router is deployed in each of the 12 core locations that is not one of the 6 inner core locations. For each of the 6 inner core locations a dual device approach is used and 2 Cisco ASR 9010 routers are deployed. For the shared scenario the Cisco ASR 9010 router is deployed in each of the 12 core locations and 3 Cisco ASR 9010 routers are deployed at each of the 6 inner core locations.

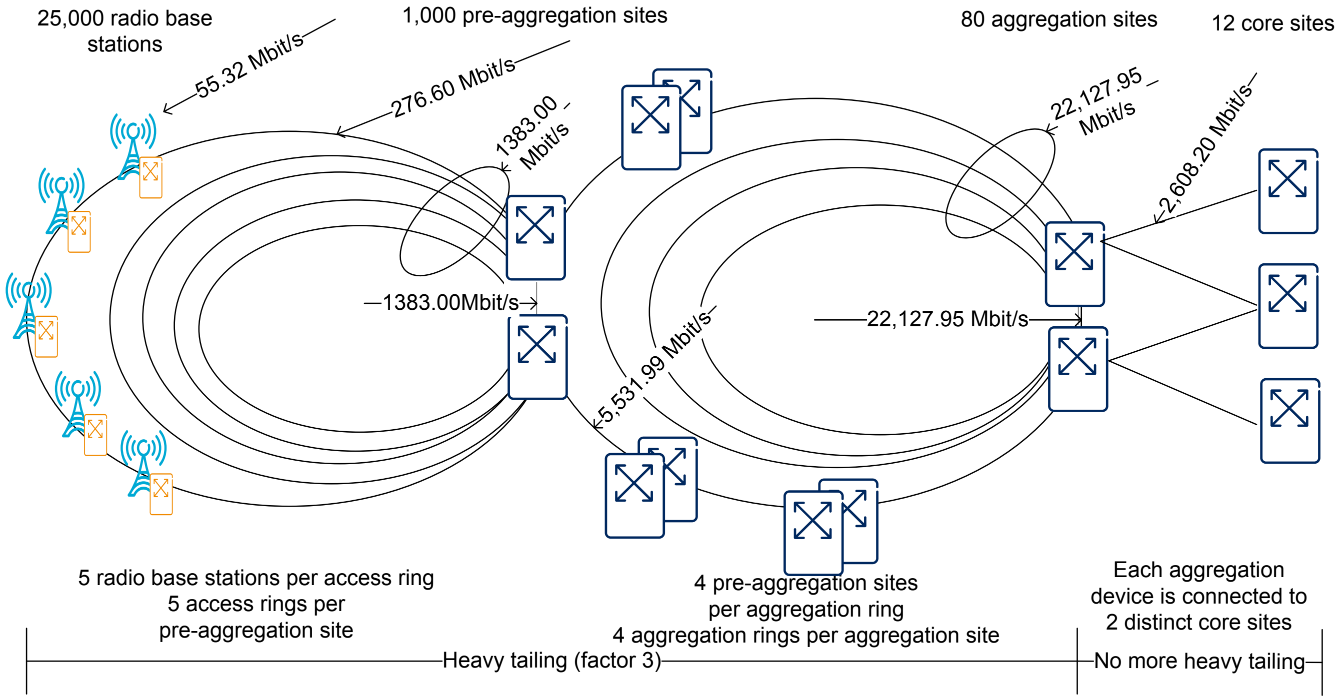

Fig. 3. Schematic overview of the network under consideration and the traffic estimations for mobile network operator 1 in 2017. Heavy tailing or distribution of RBS clusters are only supposed up to the aggregation locations. These two effects are no longer considerd for the outgoing connections from the aggregation sites to the mobile core locations and any further. Each core site is connected to 7 aggregation sites and an extra 7 aggregation sites to provide redundancy. This figure lacks the links between the core locations and the links to the internet. These links are detailed in Figure 4.

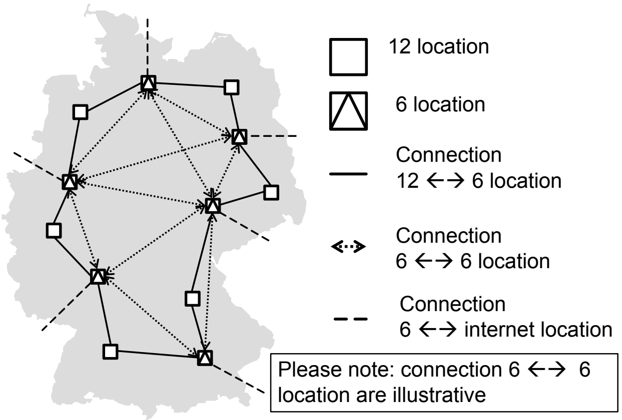

Fig. 4. Schematic overview of the 12 core locations.

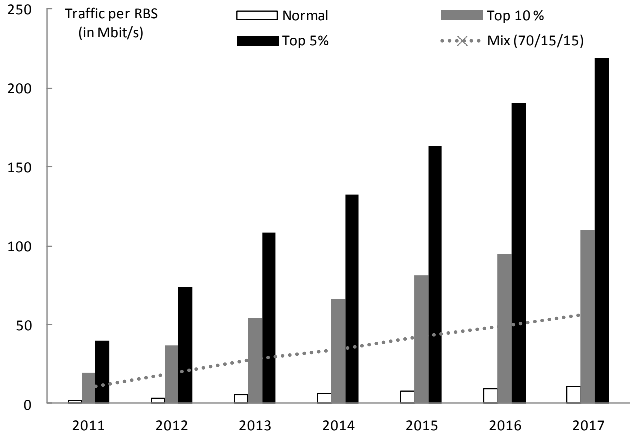

Fig. 5. Mobile traffic per RBS is forecasted to grow at an average rate of 25% per year over the period 2012-2017. There is however a large difference in traffic load between radio base stations. The top 5% and top 10% of RBSs with most traffic have respectively around 20 times and 10 times more traffic than a ‘normal’ RBS. There is also a large difference between the distribution of RBSs to pre-aggregation sites. To take this into account into our traffic estimations, we work with the following distribution between types of RBSs: 15% top 5 + 15% top 10 + 70% normal. (data for mobile operator 1)

4) SDN Additional Equipment: The ratio of OpenFlow controllers to OpenFlow switches was estimated at 1 to 100. This estimate is based on the rather simple and static network design under consideration. This will limit the networking dynamics and decreases performance requirements for an OpenFlow controller. For the SDN- and shared scenarios two OpenFlow controllers are added to each of the 12 mobile core locations. These can serve a total of 2400 switches (2160 for the network design under consideration). The price for an OpenFlow controller is estimated to be in line with the price of the NEC Univerge PF 6800 ProgrammableFlow controller. Each OpenFlow controller is duplicated to eliminate a single point of failure.

The routers in the SDN- and shared scenario function as OpenFlow enabled switches. Even though the support from vendors for OpenFlow is increasing we could not find any OpenFlow enabled switches with complete specifications that could meet the requirements for the network under considera-

	2012-2017	
	Classical Scenario	SDN scenario
pre-aggregation sites network operator 1	43.89%	36.46%
pre-aggregation sites network operator 2	43.02%	35.58%
aggregation sites network operator 1	4.97%	4.38%
aggregation sites network operator 2	4.22%	3.62%
core 12 sites network operator 1	0.39%	0.39%
core 12 sites network operator 2	0.28%	0.27%
core 6 sites network operator 1	1.82%	1.82%
core 6 sites network operator 2	1.41%	1.33%
SDN components network operator 1		1.17%
SDN components network operator 2		1.17%
TOTAL CAPEX	**100.00%**	**86.19%**

	2012-2017	
	Shared Scenario	Shared SDN scenario
pre-aggregation sites network operator 1	28.46%	23.80%
pre-aggregation sites network operator 2	16.89%	14.12%
aggregation sites network operator 1	4.37%	4.37%
aggregation sites network operator 2	2.56%	2.07%
core 12 sites network operator 1	0.27%	0.42%
core 12 sites network operator 2	0.16%	0.25%
core 6 sites network operator 1	1.74%	1.64%
core 6 sites network operator 2	1.02%	0.96%
SDN components network operator 1		2.16%
SDN components network operator 2		2.16%
TOTAL CAPEX	**55.47%**	**51.96%**

Fig. 6. The extra cost of OpenFlow controllers is marginal in comparison with the capex reductions for network devices in the pre-aggregation and aggregation locations.

tion. Therefore we had to model the Cisco ASR-9000 platform as if they were OpenFlow enabled (which we assumed can be done by the vendor via a firmware upgrade, but is open for further analysis). Once the network devices are OpenFlow enabled the OpenFlow controller will take over the control plane functionality like maintaining routing databases from the routers. By removing the control functionality from the routers they turn into no more than a switch that handles forwarding decisions. This is modeled by removing the cost for software licenses responsible for the functioning of the control logic from the shopping list for network devices. The networking devices require three types of software: an Operating System (OS) for the router (Cisco IOS XR IP/MPLS Core Software), a license for synchronisation support (Cisco Advanced Mobile License) and a license for enhanced VPN (Cisco AIP or VRF LC license). The license for synchronisation is a hardware feature and is required. VPN licenses can be replaced by custom written software. The software development cost is modeled, assuming good open source software exists, as a fixed fee per year for 10 full time software designers. We expect the OS to be simpler as it requires less capabilities, fewer updates and modifications. This was modeled by reducing the cost of the OS with 25 percent.

5) Results: An overview of the capex savings is given in figure 6. We've used the Cisco global price list without any discounts to complete the shopping list. Each cost category is compared to the total cost of the classical scenario. For the shared scenarios, costs are distributed according to the average amount of customers the mobile network operators serve. Both the SDN- and the shared scenario have a substantial lower cost than the classical scenario.

V. CONCLUSION

The capital expenditures savings that Software Defined Networking and its protocol of choice OpenFlow can provide for a mobile network operator that owns and operates its own network are dependent on:

- cost savings that can be reached by using simpler network devices,
- cost of extra components such as OpenFlow controllers, line cards and tranceivers,
- the ratio of the number of switches that an OpenFlow controller can manage,
- the possibility to better align network capacity with actual demand.

The quantitative analysis reveals that the benefits of software defined networking outweigh the extra costs. We therefore conclude that software defined networking can provide substantial cost reductions in capital expenditures.

For the reference case in particular:

- The considered capex and could be reduced by 13.81% for the SDN scenario in comparison with the classical scenario.
- The considered capex could be reduced by 58.04% for the SDN based sharing scenario in comparison with the classical scenario.

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