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SDN-enabled Infrastructure Sharing in Emerging Markets: CapEx/OpEx Savings Overview and Quantification

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Abstract: The paper quantifies the importance of network resource sharing in leveraging Software Defined Networking (SDN) in mobile network infrastructure and reducing operation costs between multiple operators, especially critical to extend broadband access in less populated and thus less profitable rural areas. The paper starts with an overview of the concept of infrastructure sharing and different levels of sharing, such as RAN, backhaul and core sharing, and then attempts to quantify the economic impact of sharing. The impact is estimated in terms of how long it takes to recover CapEx investments and make a network profitable. This is illustrated utilizing the use case example of the South African environment that full sharing may allow an order of magnitude reduction in time needed to reach profitability, which may allow for profitable operation in rural areas and easier entry of smaller operators into market.

Keywords: Infrastructure Sharing; Software Defined Networking; SDN; Network Slicing; Economics; capital expenditure; CapEx; operational expenses; OpEx; Tenant; Network Owner.

1. Introduction

Broadband penetration in emerging markets is still considerably poor with an alarming “digital divide” between rural and urban areas. Rural areas are typically sparsely populated with low population density. Therefore the cost associated with rolling out infrastructure to rural areas typically surpasses the return on the investment (RoI) in the costs of installations and setting up (capital expenditure or CapEx) and network operation expenses (OpEx)[1]. For instance, a consensus was reached that 50% of the radio access sites carry traffic that yields less than 10% of the revenue [2]. For rural installations, the profit margin declines significantly. As a result, operators are reluctant to expand coverage to rural areas. However, operators in most emerging markets are often subjected to geographic coverage obligations that mandate them to extend coverage to areas with low or no network footprint and to still charge fair subscription fees. This has left operators in a quest for cost effective means to meet these coverage obligations. To this end, infrastructure sharing has emerged as a mechanism to reduce network rollout and operation cost.

Infrastructure sharing entails the sharing of mobile network components such as radio sites, antennas, base stations, masts, etc. between multiple tenants (vertical markets, over-the top (OTT) providers and mobile virtual network operators (MVNO)). To date there are different kinds of sharing agreements entered into by mobile network operators. Such agreements may be unilateral (incumbent operator leases its mobile infrastructure to another operator), bilateral (operators mutually lease their infrastructure to each other), or multilateral (involving several operators) [3].

This paradigm has been explored in the past and partially deployed in most matured and emerging markets. However, in most emerging markets the deployment of infrastructure sharing is limited to densely populated urban areas because of their attractive profit margins. Site acquisition in urban areas is extremely expensive making it virtually impossible for new entrants to rollout their own competing infrastructure. This fosters vertical integrated business models by incumbent operators which ultimately results in unfair lease fees and capacity allocation to new entrants [4]. This model promotes anticompetitive behavior and increased subscriber service costs [5]. To address this challenge, many countries regulate the sharing of the infrastructure to promote non-discriminatory lease fees and capacity allocation.

Another challenge with the current sharing model is the lack of flexibility in capacity leasing. Currently, the network owner and tenant enter into long term contractual agreements that bind the tenant to pay for capacity even when they are not utilizing it. This directly increases the OpEx for the tenant and gives the network owner an unfair advantage to reap returns on unused capacity. A potential solution to this challenge is dynamic allocation of capacity as per service level agreements (SLAs) between tenants and network owner. A promising technology to achieve allocation dynamism is the current technological trend called software defined networking (SDN) coupled with its complementary technologies namely Network Function Virtualization (NFV) and Mobile Edge Computing (MEC).

Unlike the conventional model where the network data plane and control plane are tightly coupled, SDN decouples control plane from the data plane and logically centralizes it in an entity called controller [6]. In the context of infrastructure sharing, the controller has a global view of the network resource utilization by all active tenants. The controller acts as a broker between tenants and the network owner and securely (through authentication/authorization) exposes network service capabilities (e.g. network utilization status) via APIs to each tenant. This allows potential tenants to dynamically request network resources from the network owner and negotiate SLAs via signaling means [7]. NFV enables hardware commoditization through the implementation of network functions as software running on generic hardware, instead of the conventional method which uses proprietary network appliances [8]. In the context of infrastructure sharing, NFV enables the slicing of the network infrastructure into end-to-end logical slices through service function chaining, and enables lifecycle service orchestration through its ETSI NFV MANO engine [9]. Last but certainly not least, MEC brings cloud computing resources closer to the mobile edge to satisfy the requirements of delay sensitive applications [10]. In a shared mobile infrastructure, MEC minimizes traffic congestion on the mobile backhaul and core since delay sensitive applications are routed to the edge cloud located near the radio access network.

This paper investigates the economic implications of infrastructure sharing enabled by SDN in emerging markets (specifically, modelling the South African market). To do this the impact of infrastructure sharing on the CapEx/OpEx is quantified for the operator's business case. At present, the publication coverage of this topic is still limited. To the best of our knowledge, the work done on the economic impacts of infrastructure sharing did not consider SDN. For example, authors of [11] investigate regulatory and economic implications of infrastructure sharing and propose various technical solutions to network sharing for both 2G and 3G networks. The authors quantitatively estimate savings on CapEx (for a no-turnkey and full-turnkey equipment supply scenario) and OpEx (for a scenario where the network operations are outsourced to a 3rd party). The result obtained in [11], suggest that deploying a full sharing approach with total outsourcing of network operations and full-turnkey equipment supply significantly reduces CapEx and OpEx. However, the authors' model is tailored for a developed market and the emerging market case is not considered. Authors of [12] investigate the regulatory as well as the technical and economic aspects of mobile infrastructure sharing to quantitatively measure the feasibility of sharing. To achieve this, the authors present and analyze the estimated CapEx/OpEx savings of different sharing solutions (RAN sharing (with and without spectrum sharing), backhaul sharing, and RAN + backhaul) for different areas (including metropolis, rural, and suburban scenarios). The authors work was specifically for the emerging market context. Our paper is an extension of the work presented in [11] and [12] in that it investigates the economic impacts of infrastructure sharing leveraging the SDN paradigm. Our financial model is tailored towards the sparsely and low populated rural part of emerging markets whereby there is a pressing need to rapidly rollout infrastructure in an effort to prepare emerging markets for the upcoming 5G technology and to combat ICT inequality.

This paper is organized as follows: Section 2 describes the taxonomy of infrastructure sharing; Section 3 defines the SDN paradigm in the context of infrastructure sharing; Section 4 describes our financial model; Section 5 presents the results from our model as well discussion; and finally Section 6 concludes the paper.

2. Infrastructure Sharing Taxonomy

Currently there are three technical approaches to infrastructure sharing namely: passive sharing, active sharing and roaming-based sharing [13]. According to 3GPP Rel.99 passive sharing entails the sharing of passive elements such as the site or physical compound, masts, antenna frames or rooftops, power supply and microwave links or leased lines. Active sharing involves sharing elements of the active network layer such as the radio access network (RAN), backhaul and the core network. The roaming technical solution is a form of sharing that allows subscribers of a mobile operator to utilize the infrastructure belonging to another mobile operator when they are in a geographic area not covered by their mobile operator.

The rest of this section overviews the different levels of infrastructure sharing currently available.

2.1 Passive RAN Sharing

Passive infrastructure sharing allows mobile network operators to enter into an agreement to share passive RAN elements such as the site, mast, cabinets power supply (e.g. air conditioning and backup batteries), with the intention to reduce capital (CapEx) and operating (OpEx) expenditures [3GPP Rel.99]. As shown in Figure 1(a), site acquisition and power which form part of passive elements account for at least 34% (i.e. 4%+30%) of the initial roll-out investment. For OpEx (shown in Figure 1b), site-related costs such as land renting and maintenance account for about 20%. With passive infrastructure sharing, this investment is recovered over a short timeframe by the network owner and in long term the network owner enjoys good profits. On the other hand, the network tenant avoids investing on passive elements which significantly reduces rollout costs. Therefore, site sharing facilitates mobile infrastructure rollout thereby encouraging

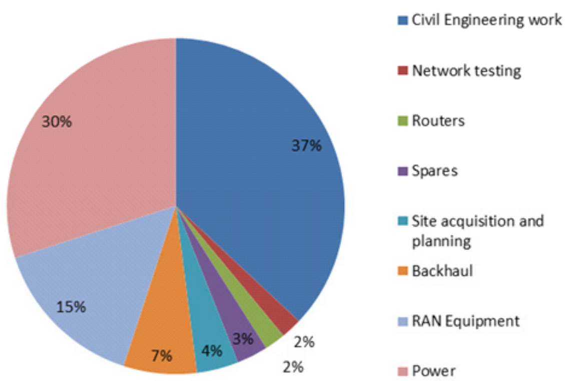

Figure 1 (a) CapEx breakdown [Source: Analysys Mason]

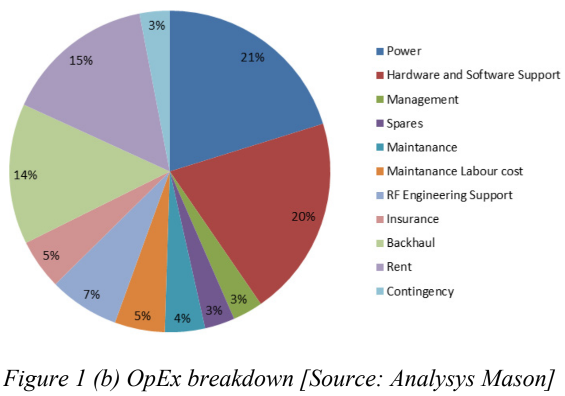

Figure 1 (b) OpEx breakdown [Source: Analysys Mason] mobile operators to provision broadband services to rural and remote areas. Moreover because of the potential cost savings, passive sharing may also contribute to affordable broadband which is pivotal to bridge the digital divide present in emerging markets.

2.2 Active Fronthaul Sharing

Fronthaul sharing involves sharing the access transmission technology between the base station and the radio access network controller [14]. The access transmission technology used on fronthaul can be microwave links or dedicated lines. Microwave links dominate in emerging markets [15] and typically account for roughly 4% of the roll-out investment. Therefore, sharing the fronthaul would result in some CapEx and OpEx savings.

2.3 Active RAN Sharing-No Frequency Pooling

In Active RAN sharing, multiple core networks are sharing common RAN elements [16]. In this sharing model, each tenant is exclusively allocated their own virtual RAN instance. These virtual instances are connected to the corresponding operator's core network. In this sharing scenario, operators can either use the frequency licenses allocated to them by the spectrum regulatory authorities or only use the frequency spectrum of one of the participating operators. The former ensures that each sharing party maintains a maximum level of autonomous control in terms of capacity and quality of service. However, if only one spectrum is used, capacity and quality of service are considerably reduced [17]. This sharing mechanism substantially reduces CapEx and OpEx costs since the number of RAN elements used by each individual operator is reduced dramatically, resulting in reduced power consumption (accounting for roughly 20% of total CapEx as shown in Figure 1a), maintenance (accounting for ~2% of OpEx as shown in Figure 1b) and civil engineering work accounting for ~20% of CapEx). This reduction is more dramatic in networks featuring many operators.

2.4 Active Backhaul Sharing

Backhaul sharing means the sharing of the transport technology (microwave links, optical fibre, and copper) between the RAN and core network [18]. The backhaul carries critical business data that must be kept strictly confidential. To guarantee service differentiation and confidentiality, it is indispensable to isolate the backhaul into several non-overlapping secure virtual backhaul instances. In this sharing model each tenant in the network is guaranteed autonomous control of their allocated virtual backhaul instance. Backhaul accounts for approximately 2% of CapEx and 14% of OpEx. Therefore, sharing backhaul would result in significant CapEx and OpEx savings. Moreover, this sharing mechanism can be combined with RAN and/or passive sharing for a further reduction in CapEx/OpEx investments.

2.5 Core Sharing

Core sharing entails the sharing of the mobile core functions such as mobile switching center (MSC) and Serving GPRS Support Node (SGSN) in 3G and Mobility Management Entity (MME) and Serving/Packet Gateways (S/P–GW) in 4G, by multiple RANs belonging to different mobile operators [19]. The core carries out several functions that are critical to optimize operator's quality of service. As a result, most operators (e.g. MVNOs) are not willing to give up independent control of their core and are thus not strongly attracted to core network sharing. Nonetheless the advent of next-generation core networks in which the control and data planes are decoupled, core sharing while ensuring service differentiation and confidentiality is feasible. Core elements typically account for approximately 7% of the total CapEx investment, and about 14% of the total OpEx. Therefore, sharing the core will result in a notable reduction in CapEx and OpEx.

Table 1: Mobile infrastructure sharing solutions brief overview.

Sharing Approach	Type	Details	Features	Regulatory Complexity
Site	Passive	Operators share the construction site/land used for building cell towers.	Entails sharing of costs related to leasing, acquisition of property items, contracts ,etc.	Medium
Mast	Passive	In addition to site sharing, operators share the same mast and rooftops.	Each operator has own antenna. Significant CapEx/OpEx savings.	Medium
Antenna	Active	The antenna and associated connectors (e.g. coupler, cables) are share by operators.	Passive elements such as power supply, alarms and air conditioners, fire extinguishers are share too.	Medium
Base station (BS)	Active	Operators are allocated logical "slices" of the base station.	Spectrum is either pooled or independent control is maintained.	High
Radio Network Controller (RNC)	Active	The baseband processing unit is shared by operators.	Each operator maintains independent control of the RNC virtual instance.	Low
Fronthaul	Active	Operators share the access transmission technology between the base station and RNC	This is applicable to 3G and less since 4G has RNC and BS tightly coupled.	Low
RAN	Active	Multiple core networks share RAN resources (antennas, site, BS, RNC, and transmission equipment)	Each operator is allocated a virtual RAN instance, frequency can optionally be pooled.	High (for shared spectrum)
Backhaul	Active	Multiple RANs share the transport network (e.g. optical fibre).	Backhaul sharing is most preferred in areas with limited demand.	Low
Core	Active	Core network functions such as MME and S/P–GW are share by multiple operators.	Includes sharing of MME and S/P-GW, MSC and SGSN for 4G and 3G respectively.	High
MVNO	Active	Virtual network operators lease wireless capacity from incumbent operator at wholesale prices.	MVNO resells minutes to customers.	Medium
Roaming	Active	Wireless service extension to area not covered by service provider.	Grant new entrant nationwide coverage.	High

3. SDN-enabled Infrastructure Sharing

Service differentiation and confidentiality are critical requirements in a shared mobile network. In order to achieve a high level of differentiation and confidentially, sharing parties must maintain autonomous control of the quality of service delivered to their customers. The conventional sharing paradigm presents an inevitable trade-off between cost savings and the level of control maintained by each sharing parties as shown in Figure 1 [11]. This means that the level of control by each sharing party diminishes as the sharing level increases. Another challenge posed by sharing within the conventional network domain is the rigidity in network resource allocation to sharing parties. For instance, in a scenario where active sharing is desired, the incumbent operator and network tenant (MVNO, OTT, ISP) enter into long contractual agreements which bind the tenant to pay for allocated resources even during periods of underutilization. Not only is this unfair to the tenant, but it also starves new tenants that may be craving a slice of resources during periods of un/under-utilization. This gives the incumbents an unfair advantage to enjoy profits at all times (i.e. regardless of network utilization status). Moreover, this creates an entry barrier to the telco industry, stimulates monopolization, impairs quality of service, and promotes unaffordable broadband.

An inevitable requirement to address aforementioned issues is dynamism in resource allocation. This means that network resources are allocated on-demand and released immediately after utilization. To date SDN has appeared as the most attractive enabler of dynamic resource allocation [20], [21]. By decoupling the data plane from the control plane, SDN ensures network programmability, unlike the conventional approach whereby the data and control planes are tightly coupled requiring manual configuration and management of the network. In an SDN environment, the controller has a global view of the current network utilization. Therefore, in the case of infrastructure sharing, new tenants can dynamically request network resources and negotiate SLAs with incumbent operator on-demand. The SDN controller also enforces strong isolation of traffic belonging to different tenants [22] to guarantee confidentiality.

Infrastructure sharing in an SDN-enabled network is commonly known as network slicing [20] as illustrated in Figure 3 [23] for a 4G network. Figure 3 illustrate a “sliced” mobile infrastructure leveraging SDN. In this scenario the SDN controller facilitates end-to-end dynamic provisioning of network slices to tenants and enforces confidentiality in the network. The communication between the control plane and data plane is via a southbound interface such as openFlow.

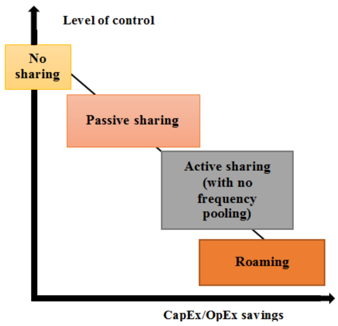

Figure 2: Cost savings versus level of control in a shared network.

In the context of emerging markets, operators are seeking a cost effective option for coverage and capacity growth. Therefore, service differentiation becomes the most important factor. This is potentially achievable with the adoption of SDN, since it guarantees tenants independent control of their network slices and thus the quality of their service [24]. Moreover, SDN capitalizes on hardware commoditization where generic hardware is used instead of proprietary hardware. Therefore, rolling out a shared SDN-enabled network would potentially result in significant CapEx/OpEx savings in comparison with the traditional counterpart. The economic benefits of SDN in a shared network are more prominent when the active sharing solution (RAN and/or Backhaul and/or Core) is adopted. The deployment of a shared SDN-enabled mobile infrastructure will alleviate the entry barrier and thus stimulate service level competition which is likely to result in improved broadband services at affordable prices.

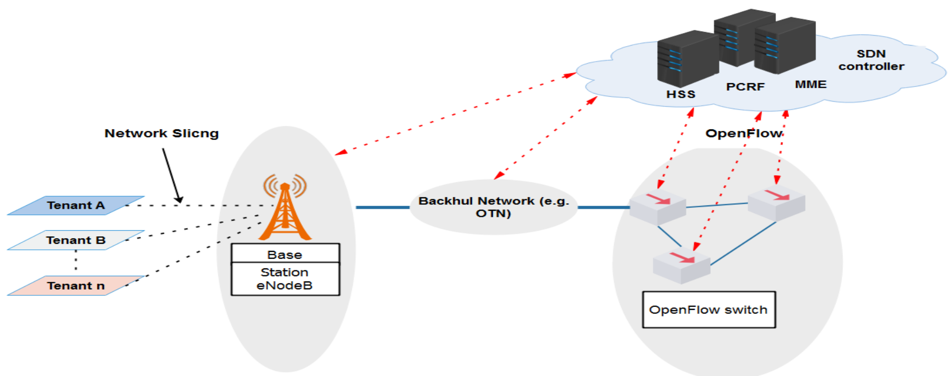

Figure 3: Infrastructure sharing in an SDN-enabled 4G mobile network.

4. Methodology

4.1 Financial Simulation Model

In order to investigate and quantify the economic benefits of infrastructure sharing through leveraging SDN in emerging markets, two scenarios are considered. The first scenario quantifies the CapEx recovery time in a non-shared environment, before infrastructure sharing, as the owner of the infrastructure exclusively utilizes the capacity of the network. The second scenario quantifies the CapEx recovery period under sharing agreements, where the infrastructure is actively shared between different operators. This scenario assumes that the infrastructure is SDN-enabled. The simulation is tailored for South African rural areas. However, this model can easily be adopted to evaluate other emerging markets. The main aim of this simulation is to quantify the CapEx recovery time. To do this, we devised a spreadsheet-based financial model for the legacy network model and SDN model. Our spreadsheet includes a multi-step calculated estimate of capital and operating expenditures for the legacy and SDN scenarios. Because of paper length restrictions, this spreadsheet has not been included in the paper.

4.2 Assumptions

We model a case where the infrastructure rollout is at a rural area and assume that the rollout is for a new installation. This assumption was driven by the fact that to the best of our knowledge, there is no general consensus, at this juncture, on the implementation and feasibility of hybrid SDN (which addresses the enablement of SDN in existing legacy mobile networks).

We assume a case where an incumbent operator shares their mobile network with a new entrant. The incumbent operator in our case is the statutory monopoly (government) which is in accordance with the South African regulatory framework known as the Electronic Communication Amendment (ECA) bill [25]. The ECA bill is a progressive policy that aims to transfer ownership of the mobile infrastructure to the government. The government will thus deal with the regulatory aspect of infrastructure sharing. Therefore, the regulatory dimension has been left out in this work.

Our assumption is that the number of subscribers for each sharing operator remains constant for both the “sharing” and the “no sharing” scenarios. This is to simulate the worst case scenario where the profit margins for the “sharing” and the “no sharing” case is the same. Last but not least, we assume that OpEx is recurring every month.

4.3 Scenarios

4.3.1 Scenario A: Unshared Infrastructure

In this scenario, the incumbent operator independently acquires sites, equipment and man power needed for building the network, and operates and maintains the network infrastructure. This scenario assumes that the network does not have SDN intelligence. To calculate the CapEx recovery period, the following cost parameters were considered: i) CapEx (civil engineering work + network testing + site acquisition + RAN equipment + etc.), ii) OpEx (salaries + maintenance + power + hardware and software support + etc.), and iii) Income (data usage per month + calls made per month).

Research on the typical costs associated with each parameter was done to ensure that our cost estimates are as realistic as possible. To calculate the CapEx recovery time without sharing the following equation is used:

$T_{bs}=C_{bs}/P_{bs}$………. (1)

where:

- *"bs"* denotes "before sharing";
- T_{bs} is the time taken to recover CapEx before sharing,
- C_{bs} denotes CapEx;
- $P_{bs} = I_{bs} - O_{bs}$ is the profit, with I_{bs} denoting total income and O_{bs} denoting total OpEx, calculated from the start of building of the network.

4.3.2 Scenario B: The network infrastructure is shared between tenants

This is illustrated with Figure 4, and includes MVNOs, vertical markets and OTT providers. This scenario leverages SDN for dynamic resource allocation. To calculate the CapEx recovery time with sharing, the following equation is used:

$T_{as}=C_{as}/P_{as}$………. (2)

where:

- *"as"* denotes "after sharing";
- T_{as} is the time taken to recover CapEx after sharing,
- C_{as} denotes CapEx;
- $P_{as} = I_{as} - O_{as}$ is the profit, with I_{as} denoting income and O_{as} denoting OpEx, calculated from the start of building of the network.

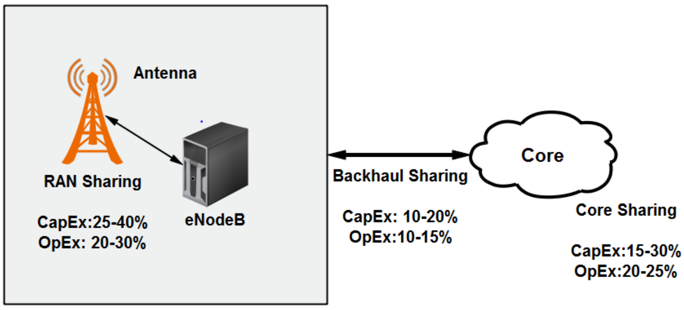

Figure 4: Shared infrastructure with possible CapEx/OpEx savings

5. Results for CapEx/OpEx savings

The analysis done in [26] (see Figure 4) shows that sharing the radio access network including passive elements (such as land and masts) can reduce on an average 25-40% of CapEx and 20-30% of OpEx costs. An additional 10-20% CapEx and 10-15% OpEx is saved by sharing the mobile backhaul. Finally, sharing the core network would decrease CapEx and OpEx by an additional 15-30% and 20-25% respectively. We use this data alongside our CapEx/OpEx calculations for an SDN-enabled mobile network deployment in a typical rural area. However, we only consider the minimum possible savings in our analysis. The number of people served by each base station is assumed to be 500.

Table 2 shows the output from our financial model, presenting the number of months to cover CapEx and OpEx costs and become profitable. From the results it is clear that the conventional model of single ownership and operation of infrastructure in rural areas is likely to considerably delay payback periods. This has been one of primary reasons of delivery of both expensive and poor quality of service in rural areas. Moreover, this has resulted in a tough entry barrier for new entrants who do not have the CapEx required for network rollout. As a result, established operators end up monopolizing the telecom industry and charging harsh subscription costs in an attempt to quickly recover their CapEx investments. The impact of this contributes to the slow economic development of emerging markets.

As shown in Table 2 infrastructure sharing enables quicker recovery of CapEx investment. For instance, we witness a huge drop in payback period when the number of base stations deployed is 2 at a rural area with about 500 users connected, per base station. When the number of base stations is increased, the payback period is drastically decreased for the "no sharing" scenario. However, the CapEx investment required for this is too high. This explains operators' reluctance to extend coverage and capacity to rural areas. Under the sharing model, increasing the number of base stations reduces the payback period by more than 50% of its "no sharing" counterpart.

Table 2: Financial Model Output: Number of Months to become profitable for the no infrastructure sharing (T_{bs}) and for the shared infrastructure (T_{as}) scenarios. Parameters: CapEx Savings=50% and OpEx Savings=40%.

Number of base stations	***T_{bs}* (Months)**	***T_{as}* (Months)**
2	5.4	1.3
4	3.3	1.1
6	2.4	0.9
8	2.1	0.8
10	1.9	0.8
12	1.8	0.8

Table 3 shows the effect of the sharing approach on CapEx recovery time. Our results show that only sharing the backhaul or the core does not yield a significant drop on the payback period. The partial sharing approach that yields the best results is the RAN sharing. When combined with other approaches the results are improved by an additional 24% minimum. Full sharing of network elements outperforms other combinations. Full sharing decreases entry barrier and stimulates competition on service level instead of infrastructure level, thereby forcing network tenants to seek innovative ways to improve the quality of their service, so as to distinguish themselves from their rivals. This model is likely to dramatically reduce broadband subscription costs in emerging markets. Ultimately this is likely to pave a way to bridging the digital divide in emerging market to foster economic growth.

Table 3: *CapEx and OpEx savings and investment recovery period (T_{as}) for different sharing approaches. This model assumes 2 base stations (Rural small enterprise type of scenario, which would require 5.4 months to start generating profits if it did not share the infrastructure at all)*

Sharing Approach	**CapEx Savings**	**OpEx Savings**	**Tas (Months)**
RAN sharing	25%	20%	2.5
Backhaul sharing	10%	10%	3.7
Core sharing	15%	10%	3.5
RAN and backhaul	35%	30%	1.9
RAN and core	40%	30%	1.7
Backhaul and core	25%	20%	2.5
Full sharing	50%	40%	1.3

6. Conclusion

In this paper, a brief quantitative review of the different infrastructure sharing paradigms is presented. The paper also highlights the importance of enabling SDN in shared mobile network rollouts to optimize capital and operational expenditures. A financial model has been devised, for a new rollout, and used to estimate the economic impact of infrastructure sharing in the rural part of emerging markets. The impact of sharing has been estimated in terms of the number of months required from starting a new infrastructure rollout to making it profitable.

For the South African environment, it is shown that full implementation of sharing can reduce the time to reach profitability from 5.4 months down to less than 1.3 months. This strong impact of sharing can be interpreted as resulting in a range of compelling possibilities, from lowering costs to the end users, to enabling smaller telecom operators to enter the market, to higher profits for incumbent telecom operators.

In future, we intend to expand our analysis to cover other emerging markets, also considering scenarios where there already exists some infrastructure. This will incorporate a hybrid SDN solution.

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