Analysis of CAPEX and OPEX Benefits of Wireless Access Virtualization

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Introduction

- The process of combining hardware and software resources into a single software based entity is at the core of the notion of network virtualization
- Virtualization in the application layer is well investigated; visible in today's network architecture in the form of VLAN, VPN, overlay networks, etc.
- Wireless access network virtualization dictates a new direction in the research of cost effective and energy efficient network modelling
- Different research initiatives are dealing with virtualization of wireless resources (e.g. nodes, wireless access cards, wireless spectrum, etc.)

Wireless Virtualization Motivations

- Radio access accounts for about *40%* (core network *10%-30%*) of the total operational cost of cellular network
- From power consumption point of view, wireless access network is responsible for up to *60%-80%* of the telecom's total energy consumption
- Major cellular vendors and operators have notably advocated for wireless virtualization for cost effective and energy efficient service provisioning
- Leveraging *cloud computing* and *virtual networking* can be significant drivers of so-called *Green Communications* in the telecom domain

Wireless Virtualization Frameworks

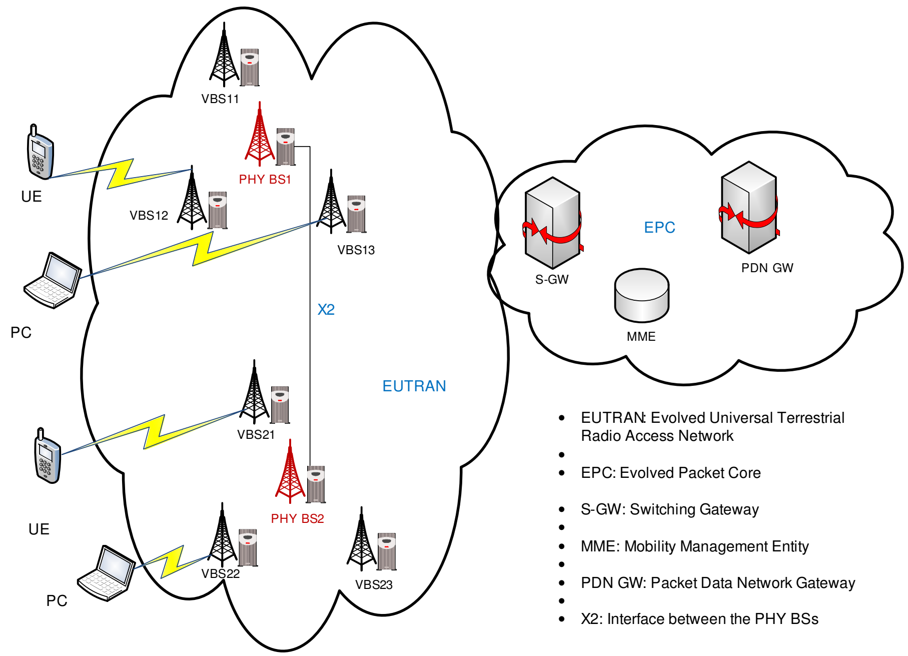
- Our vision of wireless virtualization is an intelligent amalgamation of:
  - Efficient spectrum sharing techniques (in time, frequency, space, code or any combination of them)
  - Shared use of hardware resources
  - wireless cloud computing, etc.
- The absence of conceptual definition of wireless access virtualization in the existing literature has prompted us to propose three different frameworks to implement this concept. The proposed frameworks are:

❑ *Local Virtualization (LV)*

❑ *Remote Virtualization (RV), and*

❑ *Hybrid Virtualization (HV)*

Local Virtualization (LV)

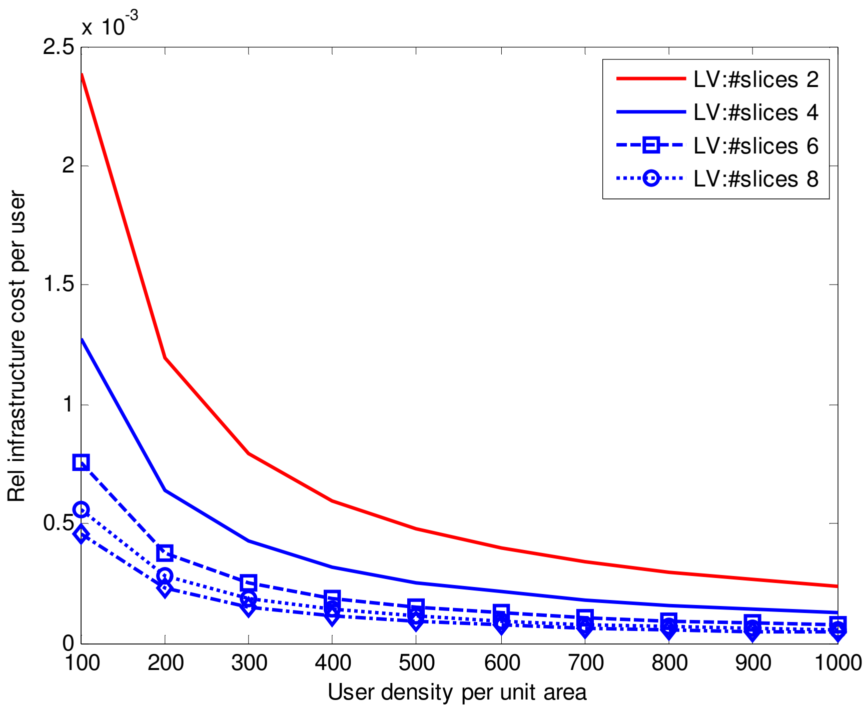


- PHYBSs are *sliced* to create multiple VBSs
- VBSs emulates the PHYBS with reduced capabilities
- Physical network managed by the infrastructure providers (InPs) and virtual operators (Vos) lease nodes from the InPs
- Slight modification of the existing Telco structure
- *Hypervisor* is in charge of synchronous allocation of resources among different virtual instances

CAPEX Analysis for LV

- Say, in an area *A*, n_{op} operators are serving their customers
- λ is the user density/BS (/slice in virtualized network case)
- cell radius is, R
- Base station cost , c_{bs}
- Cell cite construction cost, c_{cs}
- Number of slices per SBS, n_{sl}
- Cellular infrastructure cost/user, $c_{\text{infra}-u} = \frac{c_{cs}+c_{bs}}{\pi\lambda R^2}$
- For a virtualized network infr. cost/user, $c_{\text{infra}-sbs-u} = \frac{c_{cs-sbs}+c_{sbs}}{\pi n_{sl}\lambda R^2}$

Rel. Infrastructure cost (for *R=2* unit)



- Relative infrastructure cost decreases with denser user distribution
- For a local virtualized network, the infr. cost gain increases with the number of slices per SBS
- Cost gain is not linear with the increase of #slices. As we can see cost gain is *21.66%* when #slices is increased from *2 to 4* but it is *8.34%* when #slices increases from *4 to 6*

OPEX Analysis for LV

- Power consumption of a BS

$$P_{BS} = n_a \times (P_{trans} + P_{rect} + P_{PA} + P_{DSP}) + P_{air} + P_{mw}$$

- Power consumption for a super BS (SBS)

$$P_{SBS} = n_{sl} n_a \times (P_{trans} + P_{rect} + P_{PA} + P_{DSP}) + P_{airSBS} + P_{mwSBS}$$

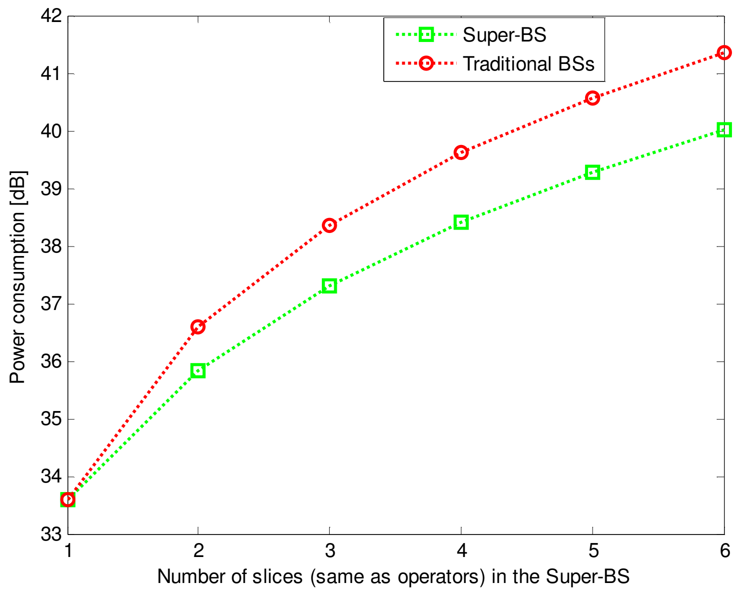
We assume that for a SBS the air conditioning and microwave power increases by *20%* for each additional slice

- Air conditioning power of a SBS, $P_{airSBS} = P_{air} \times [1 + 0.2(n_{sl} - 1)]$
- Backhaul MW link power consumption of a SBS, $P_{mwSBS} = P_{mw} \times [1 + 0.2(n_{sl} - 1)]$

Power consumption of different parts of a typical BS

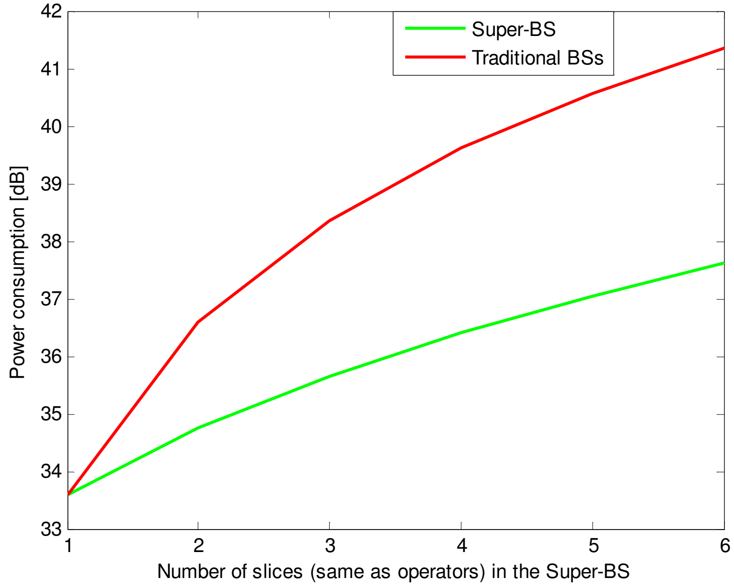
BS Parts	Power consumption (Watts)
Digital signal processor, P_{DSP}	100
Power amplifier (SISO), P_{PA}	156
Power amplifier (MIO), P_{PA}	10.4
Transceiver, P_{trans}	100
Rectifier, P_{rect}	100
Air conditioning, P_{air}	225
Microwave link, P_{mw}	80

Total power consumption vs. #slices(SNR *10.5 dB*)



- Total power consumption increases with the number of operators (slices in a SBS)
- Gain in power consumption tend to stabilize with the increase in #slices
- for *2 slices* the power gain is *0.76 dB* while for *4 slices* it is *1.32 dB* and for *6 slices* it is *1.36 dB*

Power consumption vs. #slices (antenna sharing case)



- When the antenna is shared by the VBSs, the power consumption gain is quite significant

- For *2 slices* per SBS the gain is *1.85 dB* while it is *3.76 dB* for *6 slices*

Power consumption per bit

- Channel capacity with modified Shannon's formula $R = w \times w_{eff} \times \log_2(1 + \frac{SNR}{SNR_{eff}})$

- Power consumed per bit for a traditional network $P_{bit-BS} = \frac{P_{BS}}{\lambda\pi R^2 \times w w_{eff} \times \log_2(1+SNR)}$

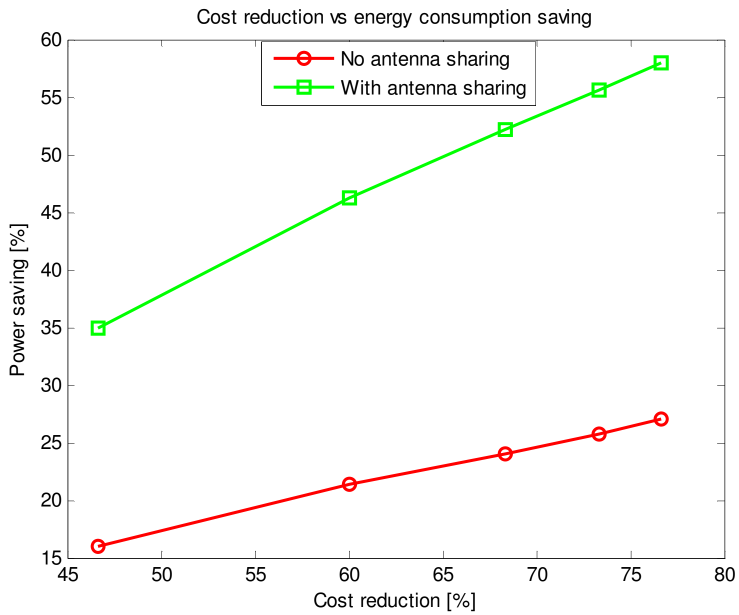
- Power consumed per bit for a virtualized network $P_{bit-SBS} = \frac{P_{SBS}}{n_{sl} \times \lambda\pi R^2 \times w w_{eff} \times \log_2(1+SNR)}$

- For a SBS, power per bit *decreases linearly* with the number of slices it contains

Rel. Infr. Cost gain and power saving per bit

#slices in the SBS	Relative cost reduction (%)	P_{sav} %(no antenna sharing)	P_{sav} %(antenna sharing)
2	46.67	16	35
3	60	21.4	46.3
4	68.33	24	52.12
5	73.33	25.7	55.6
6	76.67	27	58

Cost Reduction vs. Power Saving



- The figure shows the cost reduction and saving in power consumption trends for a SBS
- For no antenna sharing case, while a cost saving of *30%* is achievable by increasing the #slices from *2 to 6*, power saving is about *11%*
- When antenna is shared by VBSs, power saving of *23% (for* #slices from *2 to 6)* is noticed
- Cost of antenna is considered to be integrated in the SBS cost

Challenges

- Each additional slice will add to the complexity level of the required hardware implementation
- Existing hardware technologies can set a hard limit on the achievable cost gain of using SBS
- SBS need extensive processing capabilities, requires highly efficient multi-core and multi-threaded processors
- Adept design of hypervisor is a critical challenge

Conclusion

- Infrastructural cost gain by virtualizing base stations is very significant. The analysis shows that the possible cost reduction varies from *46.67%* (for *2 slices/SBS*) to *76.67%* (for 6 slices/SBS) in a LV network
- Power consumption is a major contributor of OPEX in a cellular network. Hence, a power saving of *27%* (*6 slices*) to *58%* (*6 slices*, *antenna sharing*) is very compelling in this regard
- In practice, gains will be reduced by hardware limitation and hypervisor complexity
- An edge in mitigating inter-cell interference and better hand-off management is possible in a virtualized network
- By centralizing baseband processing in wireless data centers (remote and hybrid virtualization) can stimulate the use of *green energy* by powering the sites with air, water or solar sources
- Detailed analysis of remote and hybrid virtualization will be carried out in future work

Thank you!