A Novel LTE Wireless Virtualization Framework

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Abstract. Network virtualization is one of the topics that recently have been receiving attention in the research community. It is becoming evidently clear that network virtualization will be a major player in the shaping of the Future Internet. Many research projects around the world are studying different aspects of network virtualization: some are focusing on resource virtualization like Node, Server and Router virtualization; while others are focusing on building a framework to setup virtual networks on the fly based on the different virtual resources. In spite of all that work, we still think that one very important piece of the puzzle is still missing that is "Wireless Virtualization". According to the best of our knowledge, the virtualization of the wireless medium has not yet received the appropriate attention it is entitled to, and there has been very small work done in that field. This is why this paper is proposing a framework for the virtualization of the wireless medium. This framework is proposed to virtualize mobile communication systems so that multiple operators can share the same physical resources. We mainly focus on the Long Term Evolution (LTE) but the framework can also be generalized to fit any other wireless system.

Keywords: network virtualization, wireless virtualization, LTE simulations, Future Internet.

1 Introduction

Virtualization is a well known technique that has been used for years, especially in computer science like the use of virtual memory and virtual operating systems. What is new though is the idea of using virtualization to create complete virtual networks. One option in the Future Internet is the possibility of having instead of only one multiple co-existing architectures, in which each of the architectures is designed and customized to fit one specific type of network and satisfies its requirements. That is why Network Virtualization will play a vital role since it helps diversifying the Future Internet into separate virtual networks that are isolated from each other and can run different architectures within.

This paper is organized as follows: section 2 gives a short introduction to network virtualization as well as wireless virtualization and the motivation behind it. Section 3 introduces the Long Term Evolution, and our proposal for mobile system

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virtualization is discussed. A network simulator that is developed in OPNET for the mobile system virtualization is described in section 4. At the end, section 5 and 6 shows the simulation scenarios and results, as well as the conclusions and the outlook.

2 Network Virtualization

Due to the congenital flaws, e.g. inadequate supporting of security, mobility and multi-homing, the current Internet architecture is being criticized and it seems that many people believe that the current Internet will soon break and will not be able to cope with all the requirements coming in the future, although many patching-up works have been done for years. In order to satisfy the boom of new services running on the networks, many research activities on the Future Internet architecture have been launched throughout the world, for example 4WARD [4] in Europe, VINI [2] and GENI [1] in the U.S. and AKARI [5] and AsiaFI [6] in Asia. VINI is a virtual network infrastructure based on PlanetLab on which researchers can deploy, run and test their own protocols and services in a large scale. GENI (Global Environment for Network Innovations) is a novel suite of architectures which support a range of experimental protocols, and virtualization is one of the most important features of it. The AKARI Architecture Design Project aims to implement the basic technology of a new generation network from a clean slate, and network virtualization has been seen as one of the principles. Asia Future Internet Forum (AsiaFI) was founded to coordinate research and development on Future Internet where network virtualization is also one of the research topics. By observing these projects, one tendency can be perceived that network virtualization is an attractive technique which receives more and more research attention, and it will be a key area in the future network development.

In principle, network virtualization enables multiple virtual networks to coexist on a common infrastructure. Each virtual network is running similar to a normal network and does not necessarily have the awareness of the underlying virtualization process. Individual virtual networks can contain operator-specific protocols and architectures which could be totally different from other co-existing virtual networks.

2.1 Motivation of Wireless Network Virtualization

Mobile system virtualization can obtain several advantages and also have impacts on different aspects:

- For the infrastructure providers: deploying and operating a mobile system such as GSM or UMTS needs enormous investments. The maintenance and upgrade of the hardware need high operational expenditure. The big companies have to play both roles: system operators as well as infrastructure providers. With virtualization, they can only concentrate on the maintenance of the physical equipments and save the manpower for running the networks.
- For the virtual mobile system operators: infrastructure sharing is very attractive, where the huge investment on the hardware and fundamental construction could be saved. It also enables the small companies to get into the

market without huge investments. The deployment, maintenance, migration and upgrade of the virtual mobile systems will be flexible and with short time frame, even on-the-fly.

- For the end users: the increased number of operators will bring a diversity of services to end users. Which mean more options to satisfy the user's personal demand and subsequently enjoy the services with reasonable pricing.

2.2 State-of-the-Art of Mobile System Sharing/Virtualization

One of the interesting commercial products of soft radio is VANU [3], that is a wireless infrastructure solution that enables individual base stations to simultaneously operate GSM, CDMA, iDEN and beyond. It is also announced that the virtualized base station and RAN are also supported by their products. Spectrum sharing is one crucial part of our proposal on the mobile system virtualization, through which multiple operators can be introduced into one band. Other than the traditional DSA (dynamic spectrum allocation) model, [14] proposed a centralized spectrum broker that has the responsibility to coordinate the frequency allocation among different wireless networks. Two optimization problems, maximized requirements and minimized interference, are formulated and algorithms are designed to solve the efficiency problem.

One thing has to be mentioned here that MVNO (Mobile Virtual Network Operator) has been available for long time in the current mobile systems. However, from the definition of MVNO we know that they don't own any physical resources and have no impact on the network configuration or algorithms. Actually, MVNOs act more like a service provider. Our proposal introduced in the next section is trying to decouple the physical system from the network, and the Virtual Operator has the overall control of its own virtual network.

The mobile system infrastructure sharing also exists along with the deployment of the network, especially at the beginning. The reason is to reduce the cost and to roll out the infrastructure quickly. As referred to in [15], the infrastructure sharing has mainly three areas: *Passive component sharing, Active element sharing* and *Geographical sharing*. To reduce the operating cost, different operators will share the fundamental establishments like roof locations, tower frame, equipment houses and power supply. This kind of sharing doesn't involve network virtualization at all and is already accepted by most of the operators because of the economical benefits. Geographical sharing is simply dividing the whole area into several regions and each operator will be in charge of one of them. In this way the full coverage can be achieved in short time by the federation of operators on different regions.

3 LTE Virtualization Framework

Long Term Evolution (LTE) has been seen as one of the major solutions of next generation mobile systems. According the specifications from 3GPP, LTE will provide much higher data rates than UMTS, low latency and enhanced QoS especially for the users at the cell edge. Due those promising system performances, we choose the LTE system as a case study to show the advantages of (wireless) network virtualization. The idea is to virtualize the LTE base station or what is also known as the enhanced Node-B (eNodeB). This is the physical hardware that is responsible to send and receive the date to and from the LTE users. Virtualizing the eNodeB is similar to any other node virtualization, where an entity called "Hypervisor" is added on top of physical resources, and is responsible for scheduling these resources between the different virtual instances running on top of it. Figure 1 shows the LTE eNodeB virtualization architecture.

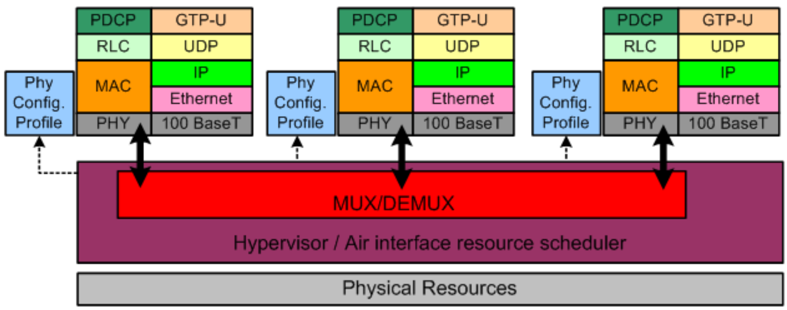

Fig. 1. Virtualized LTE eNodeB protocol stack

The hypervisor is also responsible for scheduling the air interface resources or the LTE spectrum between the different virtual eNodeBs (different virtual operators). The virtual operators share the spectrum based on different criteria. The Hypervisor collects information from the individual virtual eNodeB stacks, like user channel conditions, loads, priorities, QoS requirements and information related to the contract of each of the virtual operators. This information is used to schedule the air interface resources between the different virtual operators. LTE uses OFDMA in the downlink, which means that the frequency band is divided into a number of sub-bands each with a carrier frequency. The air interface resources that the hypervisor schedules are actually the Physical Radio Resource Blocks (PRB); this is the smallest unit that the LTE MAC scheduler can allocate to a user.

Scheduling the PRBs between the different virtual eNodeBs actually means splitting the frequency spectrum between the different eNodeBs of the different operators. The hypervisor can make use of apriori knowledge (e.g. users channel conditions, virtual operator contract, load ... etc.) to schedule the PRBs. OFDMA scheduling has been studied extensively in the literature [10] [11] [12] [13], but what is new here is that the frequency spectrum among the different operators has to be scheduled. This is even more challenging because of the additional degree of freedom that has been added. A number of possibilities and degrees of freedom exist here, where the scheduling could be based upon different criteria's: bandwidth, data rates, power, interference, pre-defined contracts, channel conditions, traffic load or a combination of them. At the end the hypervisor has to convert these criteria into a number of PRBs to be scheduled to each operator, but the challenge is to make sure that the allocated PRBs would be fair and enable the operators to satisfy their requirements. This means that some mechanisms/contracts guidelines has to be defined to guarantee the resources to the operators which could be done by different options for example setting a guaranteed amount for each operator and leaving the rest of the resources to be shared. What is also important here is the time frame that the hypervisor operates with in order to guarantees the pre-defined requirements.

In our paper, we only concentrate on two different types of the scheduler algorithms, a static and a dynamic one. In the static algorithm the spectrum is divided between the virtual operators beforehand, and each operator gets his operating spectrum and keeps it for the whole time. This is similar to today's network, where each operator has his own frequency spectrum and no other operator is allowed to use it. In the dynamic algorithm, the resources are allocated to the different operators during runtime, and the amount and allocation can be changed over time depending on the operators traffic load. The latter algorithm is an example of what can be gained by applying network virtualization into wireless mobile communication systems, where not only the operator will share the physical infrastructure but will also share the frequency spectrum and this in turn will lead to better resource utilization.

4 Simulation Model

The LTE simulation model used in this paper was developed using the OPNET simulation tool [7]. The model is designed and implemented following the 3GPP specifications.

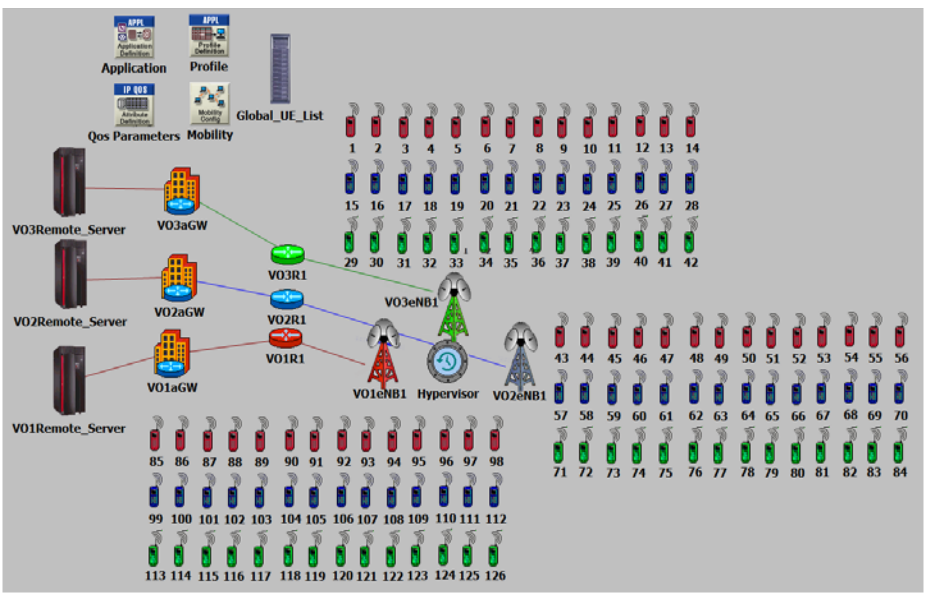

Fig. 2. Three Virtual Operators example of a virtualized LTE network

The focus of this work was not on the node or link virtualization, but rather on the air interface virtualization and how to schedule the air interface resources among the different virtual operators, no node/link virtualization was simulated, instead the assumption was that we have a perfect node/link virtualization. Figure 2 shows an example scenario, it can be seen that an additional entity between the virtual eNodeBs that is the “Hypervisor”. This entity is responsible for scheduling the air interface resources (frequency spectrum or PRBs) among the different virtual eNodeBs. The Hypervisor also has direct access to the MAC layers of each of the LTE virtual eNodeBs to collect the required relevant information to be used to base the scheduling on, like each operator’s users channel conditions, and operator traffic load.

In our implementation, two versions of the hypervisor exist based on the previously discussed hypervisor types. One is the static version, where the hypervisor allocates the PRBs among the different virtual operators just once at the beginning of the simulations, the number of the allocated PRBs for each operator will be equal, where each virtual eNodeB will get the exact same amount of PRBs and keeps it regardless if it is being actually used or not. The second version of the hypervisor is a dynamic one, where the PRBs are allocated to the different virtual operators in a dynamic manner at equal time intervals. The amount of the allocated PRBs will depend on the load that each operator is experiencing during the last time instance. In this way, each operator will only get his required share of the PRBs and no waste of resources will occur.

5 Simulation Configurations and Results

In this paper, we mainly aim to show the effects and advantages of using network virtualization in mobile communication systems. Specifically we investigate on additional benefits that could be gained if the mobile operators actually share the air interface resources (i.e. frequency band), which would be possible through virtualizing the mobile system infrastructure. From that, the simulations scenarios investigated in this paper are divided into two different setups:

- Static hypervisor configuration: which could be viewed similar to today’s mobile network setup apart from sharing the infrastructure which is an additional benefit
- Dynamic hypervisor (load based) configuration: which aims to show how the mobile network operators can share the spectrum and what are the benefits of the LTE virtualization

5.1 Simulation Configurations

As discussed earlier, two different scenarios are investigated within this paper; besides of the hypervisor scheduler algorithm the rest of the configuration is exactly the same for both scenarios and is shown in subsequent Table 1.

Table 1. Simulation Parameters

<table>
<tr><td>Parameter</td><td>Assumption</td></tr>
<tr><td>Number of virtual operators</td><td>3 virtual operators</td></tr>
<tr><td>Number of virtual eNodeBs</td><td>3 eNodeBs (one per virtual operator)</td></tr>
<tr><td>eNodeB coverage area</td><td>Circular with Radius = 375 meters, number of cells = 3 with 120°</td></tr>
<tr><td>Total Number of PRBs</td><td>99 (which corresponds to about ~ 20 MHz), Reuse factor = 3</td></tr>
<tr><td>Mobility model</td><td>Random Way Point, users are initially distributed uniformly</td></tr>
<tr><td>Users speed</td><td>5 km/h</td></tr>
<tr><td>Number of active users</td><td>
<table>
<tr><td></td><td>Cell1</td><td>Cell2</td><td>Cell3</td></tr>
<tr><td rowspan="2">VO 1</td><td>10 VOIP</td><td>10 VOIP</td><td>10 VOIP</td></tr>
<tr><td>4 Video</td><td>2 Video</td><td>1 Video</td></tr>
<tr><td rowspan="2">VO 2</td><td>10 VOIP</td><td>10 VOIP</td><td>10 VOIP</td></tr>
<tr><td>4 Video</td><td>2 Video</td><td>1 Video</td></tr>
<tr><td rowspan="2">VO 3</td><td>10 VOIP</td><td>10 VOIP</td><td>10 VOIP</td></tr>
<tr><td>4 Video</td><td>2 Video</td><td>1 Video</td></tr>
</table>
</td></tr>
<tr><td>Path loss model</td><td>128.1 + 37.6 log10(R) dB, R in km [8]</td></tr>
<tr><td>Slow Fading model</td><td>Lognormal distributed with Mean value = zero
Standard deviation = 8 dB and Correlation distance = 50 meters</td></tr>
<tr><td>Fast Fading model</td><td>Jake’s model</td></tr>
<tr><td>CQI reporting</td><td>Ideal</td></tr>
<tr><td>Downlink Low traffic model</td><td>Voice Over Internet Protocol (VOIP)
Silence/Talk Spurt length = neg. exponential with 3 sec mean
Call duration = 10 sec
Inter-repetition time = uniformly distributed between 5 and 10 sec throughout the whole simulation</td></tr>
<tr><td>Downlink Peak traffic model</td><td>Video conferencing application
Incoming/Outgoing stream inter arrival time = Const (0.01 sec)
Incoming/Outgoing stream frame size = Const (80 Bytes)
Duration = Const (300 sec) (see Table 2)</td></tr>
<tr><td>Hypervisor resolution</td><td>1 sec (this is only for the dynamic scenario)</td></tr>
<tr><td>Simulation run time</td><td>1000 sec</td></tr>
</table>

In order to show the effect and benefits of the wireless virtualization and the air interface resource sharing, a peak traffic model has been introduced to the simulation scenarios, where, as it can be seen from the table above, this peak traffic model is used for only 300 seconds to emulate a sudden peak in the load of the operator. The place where this peak traffic model is used for each operator’s users within the simulation time is configured as follows:

Table 2. Peak traffic setup for each virtual operator

	Cell 1	Cell 2	Cell 3
Virtual operator 1	0 – 300 sec	600 – 900 sec	300 – 600 sec
Virtual operator 2	300 – 600 sec	0 – 300 sec	600 – 900 sec
Virtual operator 3	600 – 900 sec	300 – 600 sec	0 – 300 sec

5.2 Simulation Results

As discussed earlier the main focus of this paper is the LTE air interface virtualization, and in order to show the performance gains from virtualizing the air interface and thus sharing the resources i.e. frequency band between the different virtual network operators two different scenarios are compared against each other.

The scenarios are configured as stated in the earlier section, one scenario which is similar to today mobile network operator setup apart from sharing the infrastructure, where three different operators are operating in the same region, each operator uses his own frequency band; these bands are being pre-allocated in the beginning of the simulations. Since we have 99 PRBs in total, each operator will get one third of the PRBs that is 33 PRBs. the second scenario can be looked at as the futuristic approach where the three operators are actually sharing the frequency band dynamically depending on their traffic load and requirements, each second the hypervisor tries to calculate from the previous time instance what the traffic load of each operator is and how the channel conditions experienced by the operator's users look like, and then assigns the PRBs among the different operators based on these calculations. The first scenario is called "Static" and the second one "Dynamic".

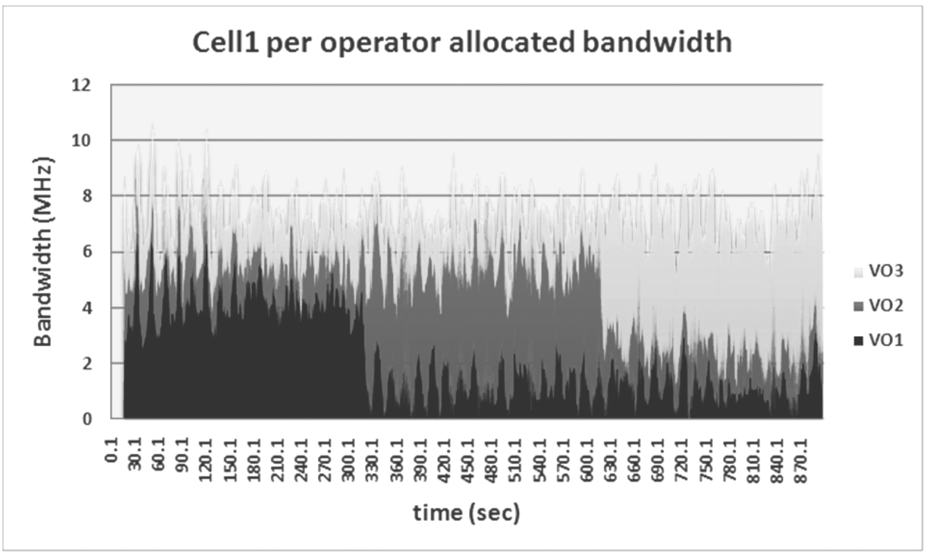

Fig. 3. Cell1 per virtual operator (VO) allocated bandwidth (MHz)

Figure 3 shows the bandwidth of each of the virtual operators that the hypervisor has allocated. It can be noticed that the allocated bandwidth changes with time depending on the traffic load and the users channel condition of each operator. In the first 300 seconds of the simulation run time it can be seen that operator 1 has been allocated a much higher bandwidth compared to the other two operators. This is due to the scenario configuration, where as it was previously configured in Table 2, operator 1 will have four additional users with video applications causing an increase in that operator's traffic. Similarly there are additional users in the second 300 seconds in the virtual network 2 (VO2) and the last 300 seconds in the virtual network 3 (VO3).

The average per user air interface throughput for operator 1 users in cell number 1 can be seen in Figure 4. The left side figure shows the air interface throughput for the

VOIP users whereas the right side figure shows the video users throughputs. What can be noticed from these figures is that the dynamic scenario achieves an expected better throughput than the static case. The reason for that is mainly the fact that additional resources have been used for the dynamic case, where in the static case these resources were allocated for the other operators but were not used.

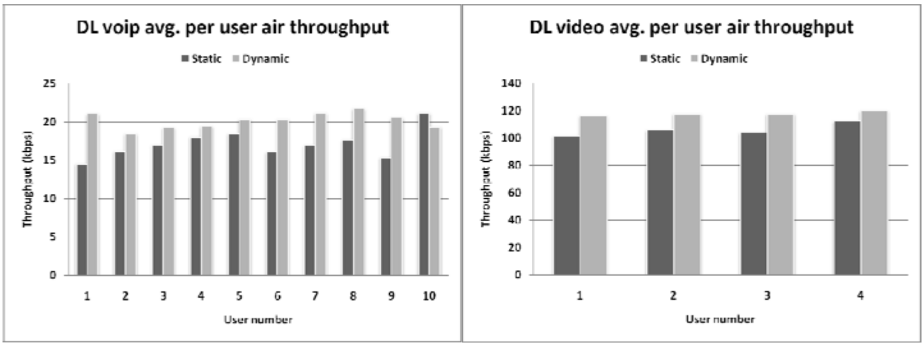

Fig. 4. Cell1 virtual operator 1 per user air interface throughput (kbps)

The average user application end-to-end delays can be seen in Figure 5. It can be noticed that the static scenario suffers from higher application delays as compared to the dynamic case especially for the video users. The reason is the limited air interface resources.

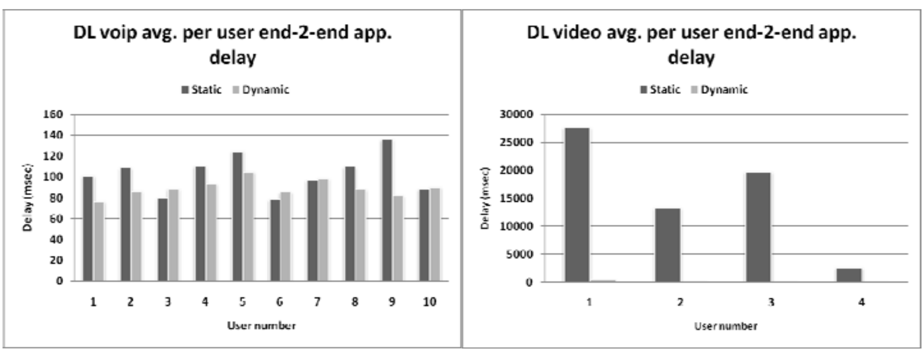

Fig. 5. Cell1 virtual operator 1 per user end to end application delay (m sec)

In order to check how the VOIP application performs, the average delay values shown in the previous figures are not sufficient. So in addition Figure 6 shows the probability when the end-to-end delays of the VOIP packets were greater than 300 msec (which is the QoS limit for the VOIP packets). It can be seen that the static case has a higher probability for not satisfying the QoS threshold.

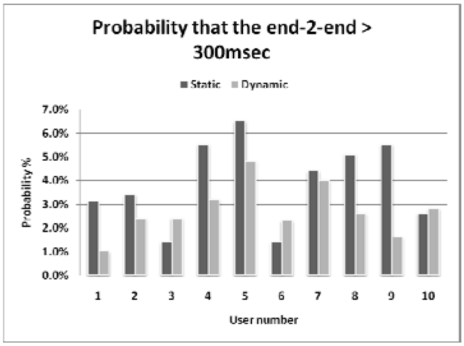

Fig. 6. Cell1 virtual operator 1 end to end delay probability > 300 m sec

Figure 7 to Figure 12 show results of cell 1 obtained for the other two operators. Similar observations can be made from these results, where mainly the dynamic case performs better than the static one especially when it comes to the video traffic. The video users are sending a continuous stream of data for a larger time span as compared to the VOIP bursty traffic.

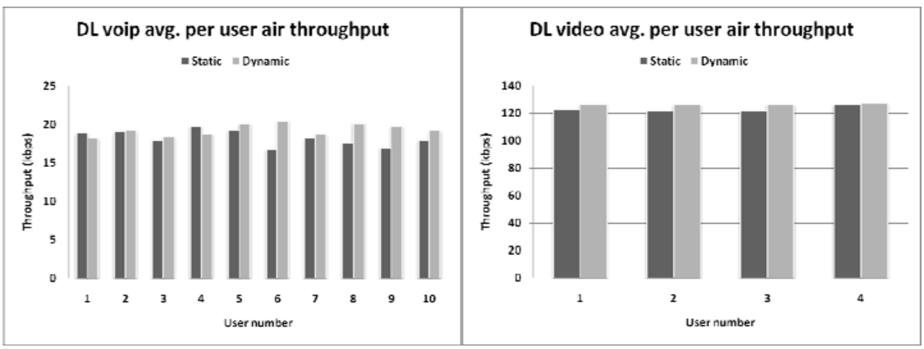

Fig. 7. Cell1 virtual operator 2 per user air interface throughput (kbps)

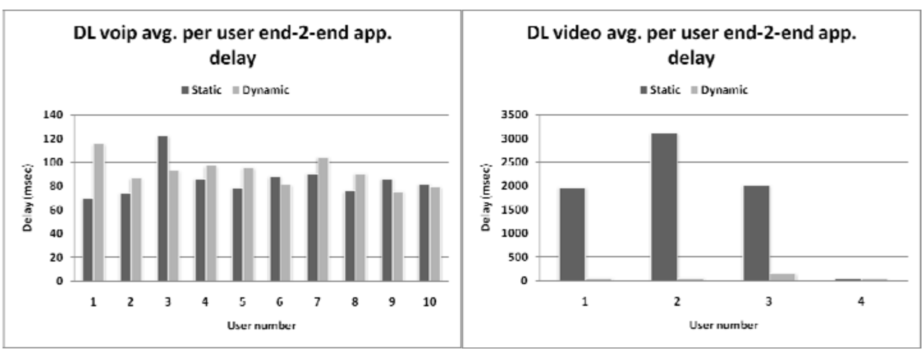

Fig. 8. Cell1 virtual operator 2 per user end to end application delay (m sec)

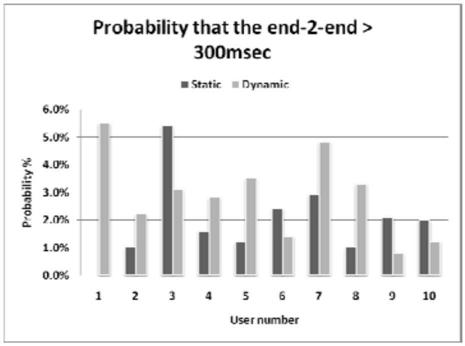

Fig. 9. Cell1 virtual operator 2 end to end delay probability > 300 m sec

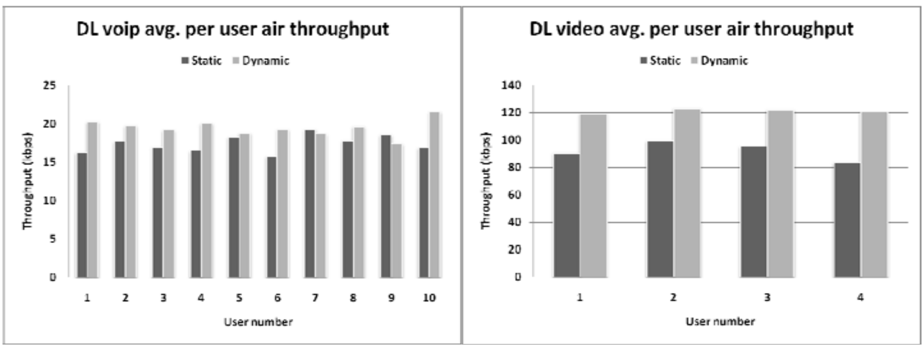

Fig. 10. Cell1 virtual operator 3 per user air interface throughput (kbps)

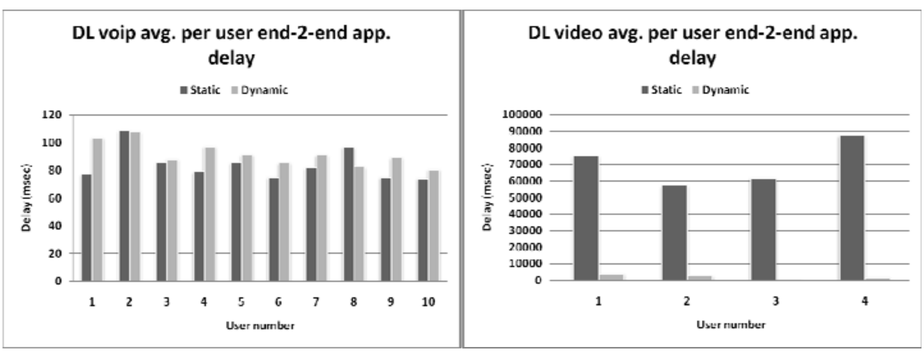

Fig. 11. Cell1 virtual operator 3 per user end to end application delay (m sec)

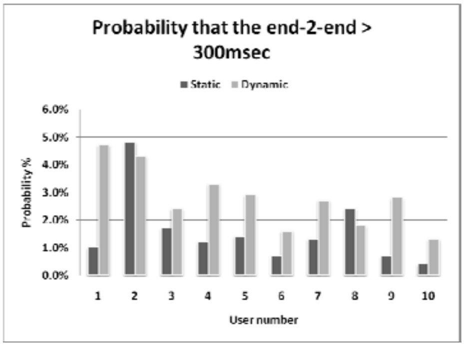

Fig. 12. Cell1 virtual operator 3 end to end delay probability > 300 m sec

As a summary, the simulation results show that using the dynamic spectrum sharing hypervisor compared to the static case is of advantage. This mainly shows in the better quality of service of the users and in particular video users receive. In the dynamic case the video users do not suffer from the huge end-to-end delay experienced in the static scenario. Keeping in mind that both scenarios used the same total amount of air interface resources and same configuration, the only difference is that in the dynamic case a better overall resource allocation has been achieved and no resources have been wasted as in the static one.

Some of the results (especially the ones related to the VOIP users) showed that the static scenario has a slightly better performance mainly when it came to the end-to-end delays. The reason this is that in the static case there are not sufficient overall resources to serve all of the video and VOIP users. Since the video traffic was put in a higher MAC priority class with higher data rates to be served first, and due to not having enough resources to fulfill all of the video user requirements in all of the TTIs, more free resources were left available to serve the VOIP users which explain the better performance. Whereas in the dynamic case, there are sufficient resources to serve all of the video users, this means fewer resources for the VOIP users.

6 Conclusion and Outlook

From the introduction of the LTE virtualization, it can be expected that better system performance can be achieved by dynamic spectrum sharing, and the simulation results confirmed this expectation. Based on the instantaneous traffic load each of the virtual operators can require more resources (PRBs) from the other virtual operator when they still have spare resources. In this way, the overall resource utilization is enhanced and in turn the performance of both network and end-user perspective is better. Although the simulation results are quite scenario-specific, the basic findings are representative and show the advantages that can be achieved by applying network virtualization to the LTE system. In addition for some cases especially in rural areas with low density of population and traffic using the dynamic spectrum sharing it is a much better choice than in today’s static spectrum allocation.

This work is a starting point of the LTE virtualization, as there are more issues to be addressed, e.g. interference coordination among multiple virtual operators, signaling overhead due to the hypervisor in charge of the resource allocation, defining guidelines and scheduling disciplines for the hypervisor based on different criteria/contracts and more diverse simulation scenarios. Nevertheless, with LTE wireless virtualization operators can expect not only lower investment for flexible network deployment but also lower costs for network management and maintenance, meanwhile the end-user can expect better services with lower prices in the future.

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