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The Case for Network Virtualization: Concurrent Multipath Transmission within Routing Overlays

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Abstract

In this paper we will investigate the deficiencies and the achievements of today's Internet. We outline why and how Network Virtualization (NV) can overcome the shortfalls of the current system and how it paves the way for the future Internet.

Furthermore, we investigate the performance of a concurrent multipath transmission mechanisms which is implemented using routing overlays and which is facilitated by Network Virtualization.

The major building blocks of NV are the a) use of application-specific routing overlays, b) the safe consolidation of resources by OS virtualization on a generic infrastructure, and c) the exploitation of the network diversity for performance enhancements and for new business models, such as the provisioning of intermediates nodes or path oracles.

The performance investigation the concurrent multipath transmission reveals that an appropriate engineering of the high capacity pipe is required. This means that the path selection and the dimensioning of its mechanisms has to be done carefully.

1 Introduction

While today's Internet and its protocols are apparently reaching their limits, a new technology is emerging which promises to overcome many of the deficiencies of current system. This technology is denoted as *Network Virtualization (NV)*.

NV is the technology that allows the simultaneous operation of multiple logical networks (also known as overlays) on a single physical platform. It permits distributed participants to create almost instantly their own network with application-specific naming, topology, routing, and resource management mechanisms such as server virtualization, and enables users to use even a whole computing center arbitrarily as their own personal computer. Recently, NV received tremendous attention since it is expected to be one of the major paradigms for the future Internet as proposed by numerous international initiatives on future networks, e.g. PlanetLab (USA, International) [1], GENI (USA) [2, 3], AKARI (JAPAN) [4], and G-Lab (Germany) [5].

In this paper we argue why and how NV can constitute a powerful technology for the future Internet. Therefore, we will outline major building blocks for NV and provide an example for a transport mechanism for high throughput data transmission in routing overlays. The transport mechanism is based on *concurrent multipath (CMP)* transmission, also known as stripping. In addition, we outline the parallels of CMP transmission to the successful multiple source download mechanisms of P2P content distribution applications.

The paper is organized as follows. First, we will discuss in Section 2 the deficiencies and achievements of today's Internet and its application. In Section 3, we discuss how recent results in overlay technology, network diversity, and operating system virtualization contribute to the capabilities of NV. Section 4 outlines the capability of Network Virtualization using the example of CMP transmission. In Section 5 we will discuss the performance engineering for CMP transport mechanisms with respect to packet reordering. Finally, the paper will be conclude with a short summary and a discussion of future Internet reference architecture models.

2 Some Deficiencies and Achievements of Today's Internet

When addressing the shortfalls of the current Internet, the discussion usually focuses quickly on architectural and operation issues such as the anticipated lack of IP addresses [6], the complexity of today's management [7], or the insufficient extensibility of today's IP protocol family (denoted as *protocol ossification*)[8]. However, this discussion leaves out often the requirements of the future applications and users. Since it is particularly hard to foresee the future, we restrict this discussion to accepted requirements of current applications and usages which are not solved, even until today. This discussion will provide us with a benchmark whether a future Internet architecture will solve today's problem. After that, we acknowledge that the current Internet is still a success story, despite its many deficiencies. We will outline selected achievements of the current system and its applications and investigate what one can learn from these successes for the future system.

2.1 Deficiencies

A major deficiency of today's Internet is still the *missing control of the end-to-end quality of service (QoS)* . Many solutions such as IntServ or DiffServ have been developed and certain QoS islands have been formed depending on the technology and the capabilities of the providers which apply these mechanisms. As result user may ask why they can't take advantage of these islands?

Although the protocols of the current Internet haven been designed for catastrophic failures, the *reliability* of the current system and its application is very poor. However, the sophisticated resilience concepts exists, e.g. for MPLS, and are available at experienced Internet Services Providers (ISPs). Again, this fact raises the question why the reliability islands can't be exploited for better system or service reliability.

Finally, a major deficiency is the lock-in of users to their ISPs which suppresses competition among ISPs. John Crowcroft expressed this shortfall precisely in a posting to the End2End-Interest Mailing on April 26^{th} 2008: " ... i can go on the web and get my gas, electricity, ... changed, why is it not possible to get a SPOT price for broadband internet?"'.

2.2 Achievements

Despite all its deficiencies, the current Internet has facilitated never expected ways of using and operation the networks.

2.2.1 P2P-based Content Distribution

One of the fastest revolution in Internet usage was the development of *Peer-to-Peer (P2P) content distribution applications*. P2P systems are a specific type of distributed systems, which consist of equal entities, denoted as *peers*, that share and exploit resources in a cooperative way by direct end-to-end exchanges on application layer.

Type	P2P	not identified	Web	eMail	FTP
Percent	67.3 %	23.3 %	7.9%	1.2%	0.3%

Table 1: Typical Traffic Distribution in Residential Access Systems, after [9]

P2P content distribution systems are used to distribute very large video and audio files like DVDs or CD. The first major P2P content distribution application was Gnutella [10], released in 1999. After only four years, P2P contribution applications have become the major source of Internet traffic. Table 1 shows the shares of the different traffic types at a residential access system [9] .

Traditional P2P content distribution applications consider a loose notion for quality, i.e. a file will eventually be downloaded after some time. P2P-based IP-TV applications are even capable to support strict quality constraints for video playback. The popularity of P2P-based IP-TV was revealed in recent studies, e.g. in [11]. Table 2 depicts observed and estimated traffic volumes of different IP-TV applications. Again, P2P-based IP-TV has gained a significant market share in very short time. It can even compete with conventional Content Distribution Networks (CDNs) as used by YouTube.

Traffic Type	Terrabytes per month
YouTube – worldwide (Cisco est., May 2008)	100.000
P2P Video Streaming in China (Jan. 2008)	33.000
YouTube – United States (May 2008)	30.500
US Internet backbone at year end 2000	25.000
US Internet backbone at year end 1998	6.000

Table 2: Amount of IP-TV Traffic, after [11]

In order to understand the success of P2P-based content distribution, we will investigate now briefly the highly popular eDonkey system [12, 13] which is a typical

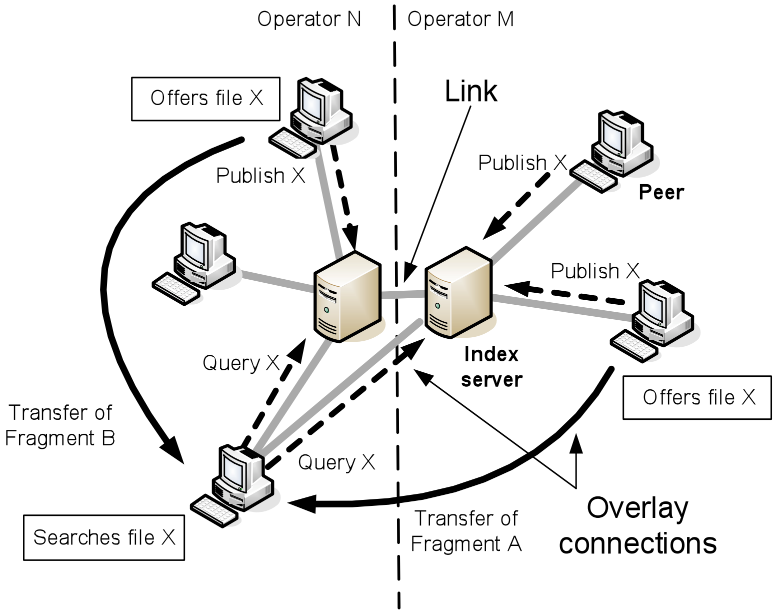


Figure 1: Hybrid P2P Content Distribution Application

representative for P2P content distribution applications. The eDonkey architecture is depicted in Figure 1. eDonkey is denoted as a hybrid-P2P system since it consists of two kinds end-user peers (for short denoted as peers), which provide and download files, and index server which provide the information on the locations of a file or parts of it. When a peer wants to download a file, it queries the index servers and then asks the providing peers for data transmission. The data transmission can be accelerated by using the *multiple source download principle*. Here, two or more different pieces of a file are downloaded in parallel from different providing peers. Due to the availability of order information, the pieces can be reassembled appropriately. Since peers can download or provide information, the boundaries between consumer and provider vanishes in P2P systems.

A closer look reveals, that P2P content distribution systems form two different overlays. One overlay is dedicated to distribute query information, while the other one is typically used for user data, i.e. video or audio information. It becomes also evident that the two overlays may have different topologies, even different addresses, and different routing principles. In addition, a downloading peer remains in command where to download the data from. If numerous peers provide the same information, the downloading peer can choose the best peers to download from. This characteristic facilitates also the feature of P2P overlays to be more reliability than conventional client/server systems since they don't rely on a single source. Another feature of P2P systems is that they can apply their own addressing scheme and thus they are able to circumvent the problems of Internet hosts being behind NAT (Network Address Translation). In this way, P2P overlay enables the integration of different networks and facilitates the notion

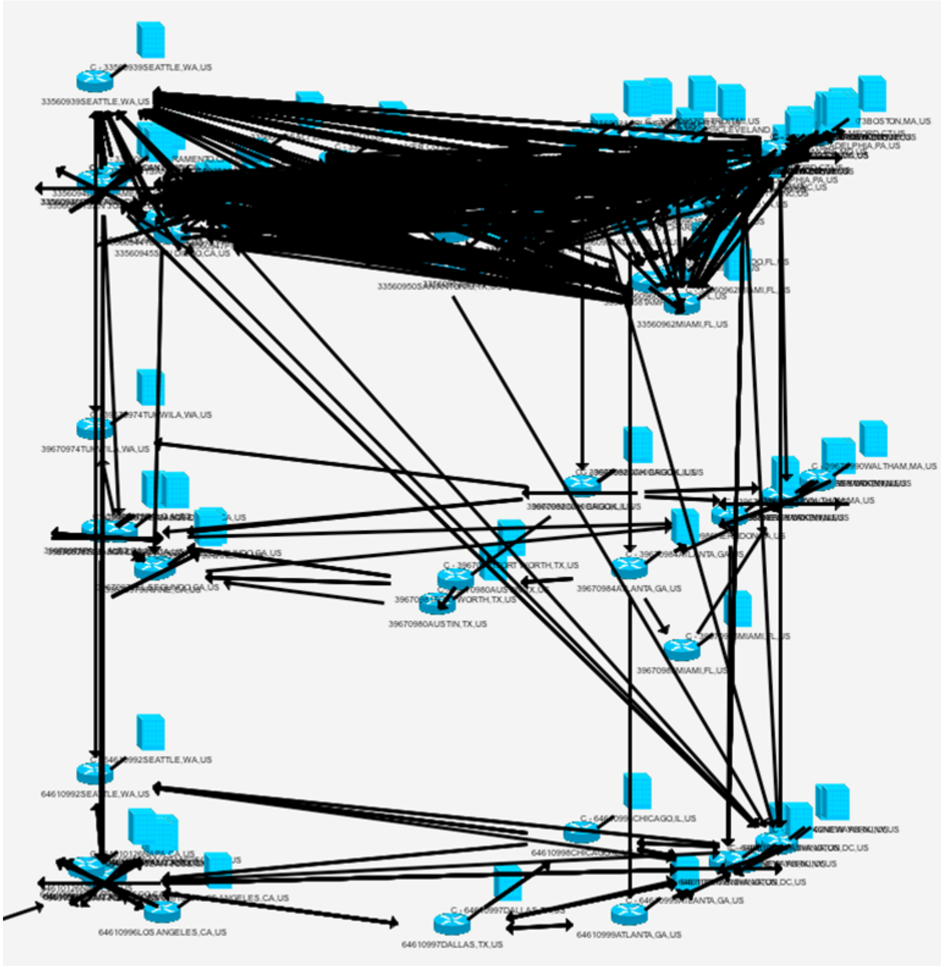


Figure 2: Selected North-american Tier 1 Provider Networks

of *multi-network services* [14].

2.2.2 Diversity in Connectivity and Quality

Another achievement of today's Internet is a diversity in connectivity and quality.

The Internet is not a homogenous network with a flat topology. Figure 2 depicts the topologies of three North-american Tier 1 network operators (AS3967, AS3356, AS6467) on Point-of-Presence (POP) level [15]. The figure reveals that a high ratio of locations has a high number of routes to arbitrary destinations. Additionally, the routes are spread among different operators. Hence, a user would have theoretically the possibility to chose among multiple providers and even among multiple routes. This characteristic would not only facilitate better performance but also increased competition among providers. Additionally, this picture shows that a significant redundancy is present in the networks. A better exploitation of this characteristic might enhance the reliability of the system.

The current Internet is not only diverse in its topology. Accompanying this feature

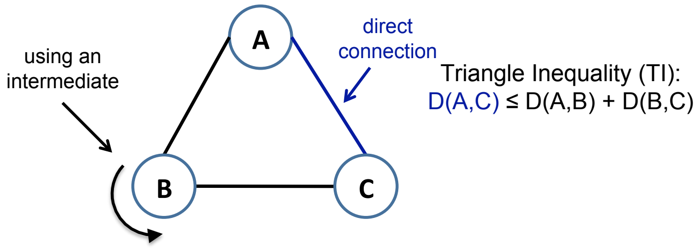


Figure 3: Triangle Inequality Violation

is its *diversity in quality*. Theoretically, the current Internet protocols should find the shortest routes and ideally the *triangle inequality (TI)* should hold, cf. Figure 3. However, recent measurements within PlanetLab have demonstrated that this inequality is violated more often than expected. The violation might be as high as 25% [16].

This results shows that a) the current Internet routing is far from being optimal, b) better route exists and sufficient capacity is often available in the networks and c) it can potentially be exploited and offered. Unfortunately, current IP transport protocols are not readily multi-homing capable.

2.2.3 Operating System (OS) Virtualization

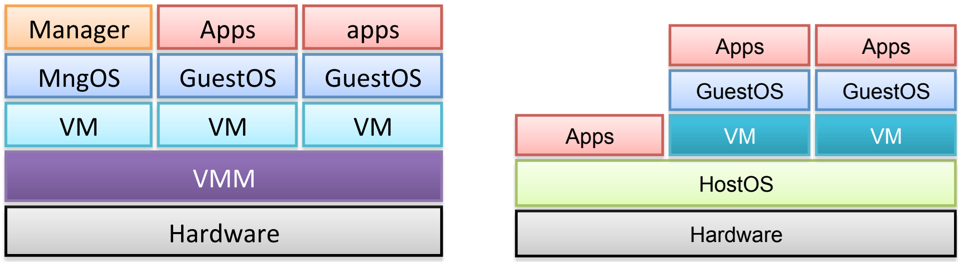
The virtualization of operating systems has become very popular recently due to its capability to consolidate multiple virtual servers into a single physical machine [17]. The application of OS virtualization reduces directly the operational costs of multiple servers. Elaborated virtualization techniques like "Hypervisor-based" or "Host-based" virtual machine control (cf. Figure 4) permit a fair and reliable *resource isolation* among virtual machines. In this way, virtualization allows a safe testing of server configuration without harming the other virtual machines or the specification of a personal configuration on a server. As a result a user can use a complete computer center as a PC which is located next to his desk.

Another advantage is that virtualization enables application to be moved arbitrarily within the memory. This *memory invariance* can be exploited. Applications and systems can easily be moved to arbitrary physical locations.

In oder to speed up the relocation of application, efficient compression technologies for complete server states such as SBMUL (Scrap-Book User Mode Linux) [18] have been developed. SBUML can safe up to 90% of the real memory size. Such a compression ration allows even a fast relocation of a router operating system image within a network.

3 Network Virtualization: Solving the Puzzle

The puzzle how Network Virtualization can overcome the shortfalls of today's Internet and paving the way for the future Internet resolves rapidly when the outlined achievements are considered.



(a) Hypervisor-based (b) Host-based

Figure 4: Virtualization Control Options

3.1 Building Blockings

The concept of *virtual network structures*, such as P2P overlays, form the first major building block for Network Virtualization, cf. Figure 5 . Due to their ability to form arbitrary application specific network structures, overlays can achieve higher performance and are more reliable than other network architectures. In addition, the specific ability of P2P overlays for symmetric roles prevent a look-in of users into a specific provider. The capability of overlays for bridging between various network architectures facilitates services across multiple technical and operational domains.

The second building block is *the diversity in connectivity and quality* in networks. The diversity of today's Internet will even be increased in the future Internet due to new physical transport systems for core networks, such as 100GB Ethernet, and more

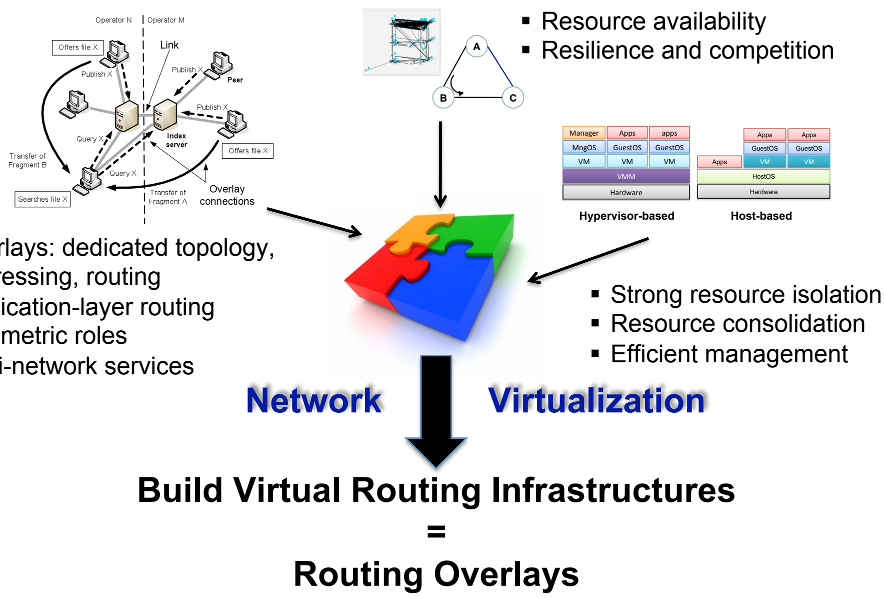


Figure 5: Components of Network Virtualization

network providers. As a result, it can be assumed that high amounts of data transmission capacity will be available in the future. If one is able to locate these resources, they can be utilized for achieving high performance and reliability of the system.

Finally, *OS virtualization* constitutes the third building block. It provides the opportunity to consolidate safely multiple networks in one physical platform. In addition, it may simplify the management of the system due to the reduction of physical entities.

3.2 Routing Overlay: The Basis for Evolving Today's and the Future Internet

The combination of these building block provides the basis for Network Virtualization. The deficiencies of today's system and the foundation for the future Internet can be laid by defining a virtual routing infrastructure, also known as *routing overlays* . This infrastructure should a) enable its re-use on small scale, b) provide services invariant from the location of the service provider, and c) permit the use of application-layer mechanisms safely in lower layers of the stack.

4 Implementing Advanced Routing Overlays

Recently, various architectures of routing overlays have been proposed [19, 20]. A highly promising approach is the concept of *one-hop source routing*. Hereby, the user data is forwarded to a specific intermediate node which then relays the traffic to its destination using ordinary IP routing. The dedicated forwarding can be easily achieved by establishing a tunnel to the intermediate node. The advantage of one-hop source routing is the easily control of performance by selecting an appropriate intermediate node while still being scalable.

4.1 An Efficient One-hop Source Routing Architecture

An efficient one-hop source architecture capable of NV was suggested in [21, 22]. This architecture is depicted in Figure 6. The architecture applies edge-based NV-boxes which can execute safely *virtual router software*. These software routers can accept incoming traffic from tunnel and forward this traffic to the destination using conventional IP routing protocols. When a source wants to send data with controlled performance, cf. Step 1 in Figure 6, then it sends a signal to an NV-box running the *One-hop Source Router (OSR)* software. When an OSR router receives such a signal it asks a *Path Oracle* to provide him with the address of an intermediate node which can forward this data in the required way, cf. Step 2 in Figure 6. Subsequently, the ingress OSR router establishes a tunnel to the selected intermediate OSR router, cf. Step 3 in Figure 6. Finally, the intermediate OSR router inserts the traffic into the conventional IP routing process.

This architecture shows a separation of the former monolithic IP system into two virtual overlays, one for signaling and one for data forwarding. This separation can be seen in parallel to the two overlays in P2P content distribution applications. The two

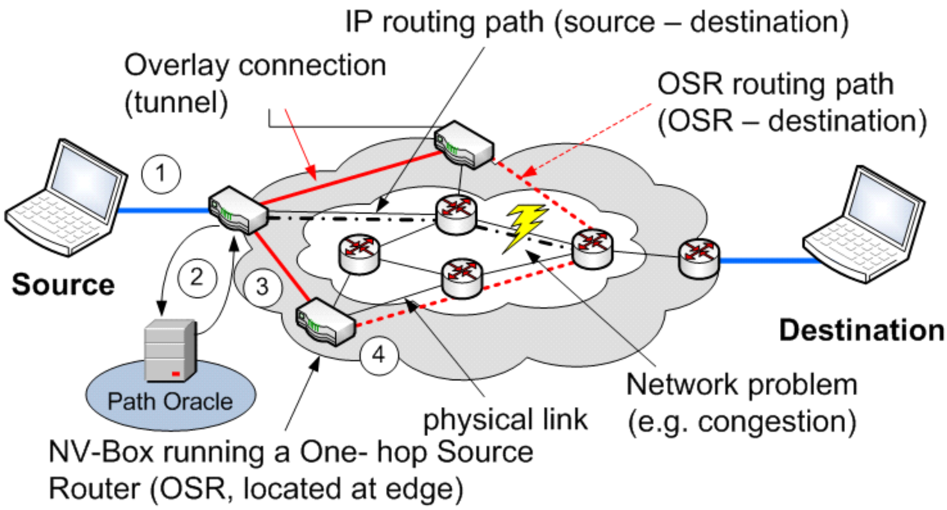


Figure 6: Routing Overlay using One-hop Source Routing

overlays can be structured and equipped with routing mechanisms according to their specific function.

However, it also has to be mentioned here that edge-based nature of this architecture reduces the efficiency of one-hop source routing. As a consequence SOR systems should also be deployed in core networks.

Due to the use of NV-boxes and their placement at arbitrary locations, virtual SORS systems be also instantiated at arbitrary locations. Thus, virtual routing overlays can re-use the generic infrastructure available in the network.

4.2 Concurrent Multipath Transfer

The capability of the above introduced one-hop source architecture can be demonstrated readily by the problem of achieving very high throughput data transmissions. The solution to this problem is the combination of the multiple overlay paths into one large overall transport pipe by using concurrent multipath transfer.

4.2.1 Overall Architecture

The considered CMP architecture sends data packets concurrently on different overlay paths from the source to the destination, cf. Figure 7. This principle is also know as *stripping*. The paths can be chosen from different overlays which can span across different physical networks.

The combination of different paths achieves a direct increase of throughput and a higher reliability since the system does not rely on a single path anymore. In addition, this architecture facilitates interdomain traffic management and edge-based performance control due to the selection of appropriate intermediate nodes. In addition, the application of the path oracle can lead to rapid discovery of available resources in the network.

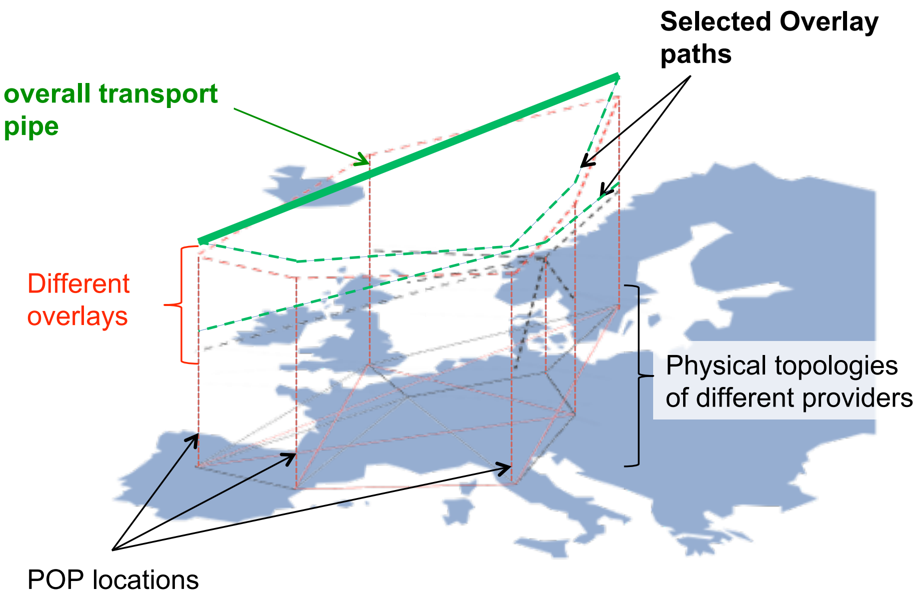


Figure 7: Providing a High-capacity Pipe by Combination of Multiple Overlay Paths

Such a path oracle can be provided by the network operator or by other institutions [23].

4.2.2 Transmission Mechanism

Figure 8 shows a detailed model of the stripping mechanism. The data stream is divided at the SOR router into segments which are splits into k smaller parts. These k parts are transmitted in parallel on k different overlay paths. The receiving SOR router reassembles these parts again into segments. The parts can arrive at the receiving router at different time instances since they are transmitted on paths with different delay distributions. Therefore, it is possible that they arrive "out of order". It should be mentioned here, that part re-ordering can only happen between different paths. The order of packets on a path is maintained since packets typically can not overtake each other on a path.

In order to avoid having this behavior impact on the application performance, the receiving SOR router maintains a finite re-sequencing buffer. However, when the re-sequencing buffer is filled and the receiving router is still waiting for parts, part loss can occur. This loss of parts is again harmful for the application and should be minimized. This can be achieved by an appropriate selection of the re-sequencing buffer size. This size is discussed in the following section.

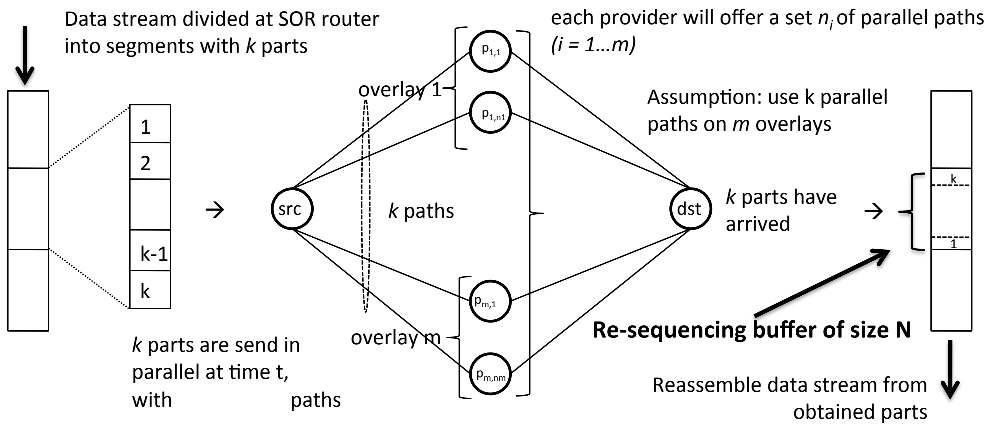


Figure 8: Transmission Mechanism

5 Re-sequencing Buffer occupancy in Concurrent Multipath Transport

In order to investigate the performance of the CMP mechanisms, we implemented a time discrete event based simulation. The simulation model assumes a continuously data stream at the SOR source route. This source router divides the data into parts and send them in parallel on either two or three paths. The delay on the different paths is modeled by different discrete delay distributions with a resolution of one time unit. Every time unit a packet is transmitted via each of the available concurrent paths.

The three different delays distributions can be considered for a path: a truncated gaussian, a uniform and a bimodal distribution. The probability density functions (PDFs) of the distributions are depicted in 9. The mean delay value for each the distributions is $E[d] = 25s$, the minimum delay is $d_{min} = 0s$ and the maximum delay $d_{max} = 50s$. The coefficient of variation c_v varies between $v_c = 0.4$ for the gaussian distribution to $v_c = 0.8$ for the bimodal distribution. We decided to investigate these distributions in order to achieve a sweeping view on the system behavior for a different number of simultaneous connections. It should be noted that this is a first, quantitive analysis of such a system.

The following notation is used to indicate the delay distributions leading to the illustrated buffer occupancy: *bi* denotes a bimodal distribution, *gaus* a gaussian distribution and *uni* a uniform distribution. We start with investigating the influence of these different delay distributions on the re-sequencing buffer for two concurrent multipaths, i.e. data is transfered over two different paths simultaneously. The buffer occupancies for the different delay combinations for two paths are depicted in Figure 10. The y-axis denotes the probability of the packets stored in the re-sequencing buffer, assigned on the x-axis. For the sake of clarity we plotted only the *bi,bi* buffer occupancy distribution with confidence intervals for a confidence level of $99-\%$. It should be noted that the size of the confidence intervals for the other curves is similar to the illustrated intervals.

It can be seen that the delay distributions have a big influence on the re-sequencing

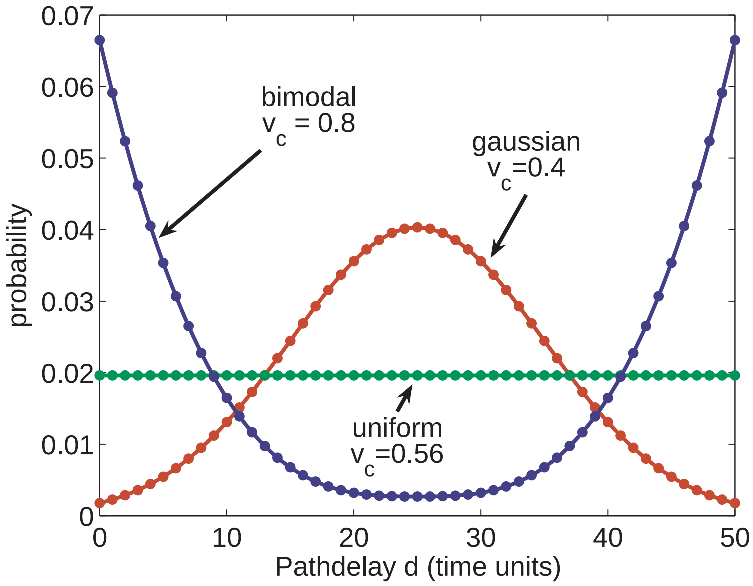


Figure 9: Used distributions

buffer occupancy. For the case of two gaussian delay distributions, the buffer occupancy is left leaning and higher buffer occupancies are not very likely. However, for two bimodal delay distributions a big part of the probability mass is covers a buffer occupancy bigger than 30 packets.

It should be noted that the maximum buffer occupancy in the investigated scenario $o_{max} = 50$. As we see, the type and the variation of the path delay have a major influence on the buffer occupancy of the receiver. We can conclude that the buffer occupancy is not invariant to the delay of the used paths. In Figure 11 the buffer occupancies for three concurrent paths and different delay distributions are shown as PDFs. It should be noticed, that the maximum buffer occupancy in this scenario $o_{max} = 100$. That denotes the worst case which can occur if a packet over one path has the maximum delay. In this case up to 100 packets might be transmitted over the other paths and have to be stored in the buffer until the next packet in sequence arrives.

Furthermore it can also be seen, that the buffer occupancy for three gaussian distributions is the smallest. For three times uniform and for one delay distribution of each type the occupancy is rather the same and higher than in the only-gaussian case. For three times bimodal the buffer occupation is the highest for the investigated scenarios, and a noticeable part of the of the probability mass covers an occupancy bigger than 60 packets.

The presented results in this paper are a first investigation on the influence of different delay distributions and numbers of paths on the re-sequencing buffer occupancy. We can conclude that there is a considerable influence of these parameters on the needed buffer size. But, in order to understand the relationship between those parameters properly, a larger set of parameters has to investigated. This will be done in future studies.

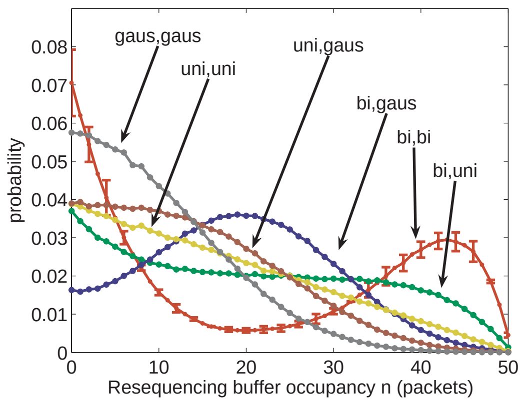


Figure 10: Buffer occupancy for two paths

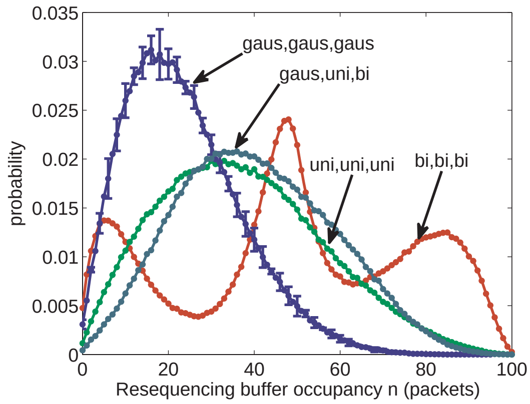


Figure 11: Buffer occupancy for three paths

6 Conclusion

In this paper we have investigated the deficiencies and the achievements of today's Internet. We outlined why and how Network Virtualization (NV) can overcome the shortfalls of the current system and it paves the way for the future Internet. NV is the technology that allows the simultaneous operation of multiple logical networks (also known as overlays) on a single physical platform.

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The performance investigation of the concurrent multipath transmission revealed that an appropriate engineering of the high capacity pipe is required. This means that the path selection and the dimensioning have to be done carefully.

The CMP-based transmission mechanism can be seen as being closely related to the powerful data transfer mechanism of P2P content distribution applications. Each path can be considered as a peer and the system has to chose the paths such that reordering, throughput and resilience is minimized or optimized.

Future investigations will be focused on two areas: a) the extension of the performance analysis which considers N paths with heterogenous capacity and b) on the discussion of a stronger separation of the future network architecture into a generic data transport and a generic control layer.

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