A study on Concurrent Multipath Transmission

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ABSTRACT
The future internet can achieve superiority over the present system by focusing on the requirements of the future applications and users besides dealing with the architectural and operational challenges. The technology of Network Virtualization, NV has many appealing features for its use in the future internet. An outline of shortcomings and selected achievements of the current internet system, together with the capabilities of the combination of NV and one-hop source routers have been discussed by a concurrent multipath transmission mechanism, CMT. The main idea of CMT addressed is to combine local transport resources to form a large and more powerful transport service for obtaining high throughput. Further, a brief discussion on the functions of CMT and stripping mechanism along with re-sequencing buffer occupancy and the path selection criteria are presented.

Categories and Subject Descriptors
C.2.2 **[Network Protocols]**: SCTP, Concurrent Multipath Transfer; C.2.3 **[Computer-Communication Networks]**: Network Architecture and Design; D.4.8 **[Operating Systems]**: Performance - *Simulation*; I.6.4 **[Simulation and Modeling]:** Model Validation and Analysis

General Terms
Algorithms, Performance, Simulation.

Keywords
Future Internet, Multihoming, Network Virtualization, Path selection, Re-sequencing buffer, Stripping mechanism, Transport Virtualization.

1. INTRODUCTION
A network that is built on top of another network is called an overlay network. Nodes in the overlay network are assumed to be connected by logical or virtual links. Each virtual link corresponds to a path which integrates multiple physical links in the underlying network. The ability of overlays to bridge among various networks promotes services across multiple domains [1]. This concept of overlays forms a major building block for Network Virtualization, NV.
NV facilitates sharing of resources and this can significantly reduce the operational costs of networks. Enabling users to create their own application specific network instantly is an appealing feature for NV use in the future internet [1].
The capabilities of future internet are enhanced by the concept of Transport Virtualization, TV. The TV involves aggregation of multiple physical or virtual resources from different virtual networks and selection of the best resources for unshared or concurrent use. The concept of TV can be assumed as an alternative mode of NV [2].

Multihoming strengthens fault tolerance of a host. In present internet, multihoming functionality is supported by only few protocols and unfortunately there exists many shortcomings. The presence of multiple active interfaces advocates the simultaneous existence of multiple paths between the multihomed hosts [3].
These multiple paths can be consolidated and utilized effectively by TV techniques. TV is implemented using Concurrent Multipath Transfer, CMT. CMT is the simultaneous or concurrent transfer of data from a source host to a destination host via two or more overlay paths. CMT mechanism is beneficial in achieving high throughput and resilience [2]. Besides many advantages, CMT introduces additional complexity which will be discussed in the subsequent sections.
This paper focuses on outlining the significance of CMT technique in future internet. The following sections of this paper include Importance of multihoming, some of the shortcomings of the present internet protocols, a brief discussion on Network and Transport virtualization techniques, the mechanism of CMT, challenges of CMT, various mechanisms and their performance.

2. SIGNIFICANCE OF MULTIHOMING
One of the challenges for the future internet can be characterized by multihoming between different access networks with the goal of providing wide range of services to the users. A host system which is equipped with multiple interfaces can be connected effectively to multiple networks simultaneously through different providers to improve resilience to path failures and this functionality is termed as Multihoming[3] [4]. It is a feature wherein a single network has multiple connections to the Internet. The hosts can be accessed in spite of unreachability to one of their IP addresses Thus, the concept of multihoming enhances fault tolerance of a host. A noteworthy point here is about the presence of multiple active interfaces, which suggest simultaneous existence of multiple paths between multihomed hosts.

3. PRESENT INTERNET-SHORTCOMINGS
The current internet protocols discover the shortest route to a destination. This theoretically means that the triangle inequality holds for the packet delay. But, recent measurements demonstrated that this inequality is violated in 25 percent of the cases. This concludes that the present internet routing is far from being optimal and also state that better routes exist which can be exploited and utilized [1].
The Transmission Control Protocol, TCP is a transport layer protocol whose connection involves single source and single destination IP address. It allows binding to only one IP address at each end of a connection and does not support multihoming between two endpoints. When an endpoint's IP address is unreachable the existing TCP connections will timeout thus forcing the application to recover. This recovery overhead and the delay associated with it is undesirable during critical communications [4].

The Stream Control Transmission Protocol, SCTP is another transport layer protocol which provides reliability, congestion and flow controlled data transfer to applications, similar to TCP. Additionally, SCTP supports fault tolerance through transport layer multihoming. SCTP allows multistream service in each connection, which is called an association in SCTP terminology. If one of the stream is blocked, the other streams can still deliver their data. An SCTP association binds multiple interfaces at each end of the association. The sending and receiving host can define multiple IP addresses in each end for an association. Using current SCTP only a pair of IP addresses can be chosen for normal communication. Alternative addresses can be used if the primary address fails. In other words, existing SCTP doesn't allow load sharing between different paths and doesn't support concurrent transfer of new data to multiple destinations [4].
In spite of many other shortcomings, the current internet has facilitated efficient operation of networks and an example for it can be portrayed by the peer-to-peer systems.

4. PEER-TO-PEER ARCHITECTURE

The peer-to-peer architecture forms first building block of NV. Peer-to-peer systems are distributed systems that consists of peers which are equal entities that share resources on application layer through direct exchanges between hosts [1].They are used in the distribution of large files. Applications like eDonkey and Bit Torrent adapt peer-to-peer architecture and the concept of multi-source download. These peer-to-peer systems can be viewed as infinite storage for the data. Multiple parts of a file are downloaded in parallel through different peers. Hence, the downloading peer no longer depends on single peer for data and this in turn increases the reliability. When there are number of peers providing same information then downloading peer selects the best peers in such a way that the throughput is optimized [5]. In peer-to-peer architecture the former IP system is segregated into two virtual overlays. One virtual overlay is for signalling and the other is for forwarding data.

5. NETWORK VIRTUALIZATION

Future internet demands many resources like interconnected subnets and nodes but the availability of resources is constrained. Therefore temporal leasing of resources is required. The technology which enables sharing of these resources is called as NV [2]. Overlays facilitates achievement of higher performance and reliability compared to other network architectures due to their capacity to form arbitrary application specific network structures [1]. This concept of overlays forms a major building block for NV.NV facilitates the simultaneous operations of multiple overlays and involves efficient combination of multiple virtual structures into a single topology.

5.1 One-hop source routing

various architectures have been proposed for routing overlays and a promising approach among them is the concept of one-hop source routing, OSR. In OSR, data is forwarded to the destination through a single intermediate node which relays traffic.Similar to the peer-to-peer architecture, OSR architecture shows segregation of the former IP system into two virtual overlays. The main advantages of OSR are performance control by selecting intermediate node and scalability. OSR is very effective for failures in the Internet. On the other hand the main complication with using OSR is the problem of achieving very high throughput data transmissions [1].

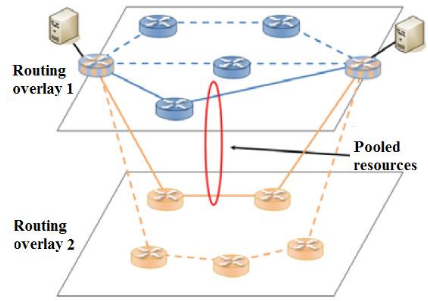

Figure 1. Pooling of resources in transport virtualization

6. TRANSPORT VIRTUALIZATION

A transport resource can be defined as an agent which is able to forward data to specified destination for example, a link, a route or a path. NV, simply facilitates sharing of resources. But, TV involves creation of virtual resources and can be assumed as an alternative mode of NV [2]. The concept of TV is motivated by the multiple source download notion in Peer-to-peer systems. The idea of storage resource in peer-to-peer systems is transferred to the data transport resources in TV. Thus, the physical location of the transport resource doesn't matter as long as the resource is accessible. In TV, an abstract data transport resource is formed as a combination of multiple physical or overlay data transport resources located in different physical networks and this process is called as resource pooling as shown in figure1 [1] [2]. This resource pooling is facilitated by implementing a mechanism on multihomed nodes which enable access to multiple paths or multiple networks. The resources thus selected can be used exclusively or concurrently and it is even feasible to select the cheapest or fastest resources from the available resources to pool them together in order to form a high capacity pipe [2]. Thus, the concept of TV augments the competence of future networks.TV can solve the problem of high capacity transport confronted by OSR through the combination of the multiple overlay paths into single large and high capacity transport pipe by using CMT [1].

7. CONCURRENT MULTI PATH TRANSFER

The concept of multihoming spawns a drastic architectural change in today's non-multihomed networks. Resilience critical Internet applications augments the demand for multihomed network sites. When multiple networks are nested together in order to guarantee that application requirements are met effectively, it is crucial to select more than one path for transmitting data simultaneously and such transfer of data is called CMT. This mechanism consolidates multiple paths from different overlays into a single virtual high-capacity pipe. The combined paths are used parallelly by sending data packets concurrently and this principle is also known as stripping [5].The consolidation of multiple paths attains a direct increase in throughput and a higher reliability as the system does not rely on a single path anymore. Besides increase in the throughput CMT also facilitates higher network utilization by network operators, provides more bandwidth and better resiliency for the user. The idea behind CMT is to utilize the additional paths that are being ignored by the present internet system [3] [5]. However, CMT introduces additional complexity which will be addressed in the forthcoming sections.

7.1 Stripping mechanism

The stripping mechanism constitutes a first instance of refinement of the concept of NV, the idea of TV. Two or more overlay paths are combined and used in parallel by sending data packets concurrently and this principle is called as Stripping. In this mechanism, the data to be transmitted is divided into small parts as shown in figure 2 and these parts are transmitted by different parallel overlay links. These parts of data are reassembled at the destination. At the end of transmission, the parts of data sent can arrive out of order at the destination router due to the stochastic varying delay induced by different paths. The out-of order parts degrades the performance of the application [2]. To avoid this, a re-sequencing buffer is used at the receiving router. One of the main problem with the re-sequencing buffer is that when it is filled completely and the receiving router is waiting for other packets which are yet to arrive, there may be drop in packets. To reduce this loss, the re-sequencing buffer occupancy must be minimized [1].

7.2 Challenges faced by CMT

The main challenges encountered by CMT are:

a) **Minimizing the re-sequencing buffer occupancy:** One of the key research challenge of CMT is the re-sequencing buffer occupancy. Mechanisms have to be developed which minimize the occupancy of re-sequencing buffer.
b) **Selection of paths:** The characteristics of the path effect the reliability and overall throughput between the source and destination during transmission. There must be a mechanism to distribute data among used paths and to choose the appropriate paths for concurrent transmission of data [2].

7.3 Re-sequencing buffer occupancy in CMT

The influence of path delay and its distribution on buffer size can be investigated by time discrete, event-based simulation assuming a continuous data stream as stated in [5]. The stream is divided into parts which are sent in parallel on different paths. The delay on the paths is modelled by discrete delay distributions.

7.3.1 Effect of delay distribution

In paper [5] the impact of the type of delay distribution on buffer occupancy is investigated and in order to evaluate the system behavior under highly different conditions, three different path delay distributions like Gaussian, uniform and bimodal are considered. When two concurrent paths having Gaussian delay distributions are considered, it is observed that high buffer occupancies are not common whereas for two bimodal distributions the buffer occupancy is very high. This shows that the re-sequencing buffer occupancy varies with the type of delay distributions in the paths. In the next scenario, three concurrent paths are used with different delay distributions where, up to 100 packets might be transmitted over different paths and have to be stored in buffer till the next packet in sequence arrives. Here, it can be noticed that the buffer occupancy is smallest for three Gaussian distributions and is highest for three bimodal distributions.

7.4 Path selection criteria

Selection of pooled resources or a potential set of paths is critical in TV .Generally, a good path is considered to be one which has a short transmission delay. Hence, the mean packet delay on a path is a crucial aspect for path selection. However, in the presence of concurrent paths for transmission, the interaction between those paths is supposed to be complex. The complexity of path selection can be investigated by considering three concurrent paths.as analysed in [2]. The delay distributions used for this setting are negative-binomial distributions with two different mean delays.

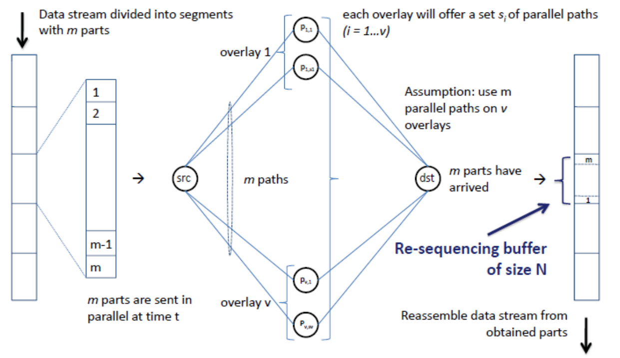

Figure 2. Stripping mechanism

Four different combinations of paths are considered as follows:

a) All three path distributions having same low mean delay
b) All three path distributions having same high mean delay
c) Two paths with low mean delay and one with high mean delay
d) One path with low mean delay and two with high mean delay

Upon analysing the cumulative distribution function of re-sequencing buffer occupancy for the above considered four cases as carried out in [2], we can notice that case a and b have almost similar distributions for buffer occupancy and illustrates that the pure delay has almost negligible impact on the buffer occupancy. Comparison of cases c and d yields few noteworthy points. It is remarkable that case d with two high path delays outperforms case c with two low path delays, in terms of buffer occupancy. Apparently, higher the number of paths with low delay, better the performance. But, this is obviously not true as observed in case 4. When we examine case 3 in detail, we can observe that transfer of a single packet is quick in low delay paths compared to the transfer via high delay paths. Within stipulated time, a low delay path transfers more packets compared to high delay path. As a result of this, a low delay path readily increases the re-sequencing buffer occupancy. This justifies that high delay paths are predominant over low delay paths in terms of re-sequencing buffer occupancy.

As discussed in [2] the recent research in Voice-over-IP, VOIP systems illustrates that a constant high delay or low delay may not have considerable impact on the Quality of Experience, QOE of an application. Thus, considering various mentioned factors it is significant to choose a higher mean delay path than a path with lower delay variation for the sake of relieving re-sequencing buffer and avoiding packet losses.

Further, analysis pertaining to influence of mean path delay and delay variation was carried out in [2], under various scenarios considering two paths to be selected already and varying the characteristics of third path. They observed that when the mean delay of the third path increases beyond the path with a higher mean delay, the mean buffer occupancy increases firmly. However, when the mean delay of the third path is between the two means of other paths, the mean buffer occupancy is low. Thus, a high delay variance degrades the CMT performance.

8. CONCLUSIONS

CMT has many advantages over other transmission mechanisms due to its high throughput and resilience. The use of concurrent paths will introduce inevitable out-of-order packet delivery and this effect can be levelled with the presence of a re-sequencing buffer at the destination and careful selection of paths. The path delay and its distributions play a vital role in minimizing the re-sequencing buffer occupancy. It is observed that when three Gaussian distributions are used the buffer occupancy is less whereas when three bimodal distributions are used it is high. It is also observed that low delay path increases the buffer occupancy. When three paths are considered varying the characteristic of only one path, it is noticed that mean delay of the third path when higher than the other two paths is directly proportional to the buffer occupancy and when it is in between the mean delay of two paths then the buffer occupancy is low.

Future work can be focused on the coordination of TV and CMT mechanisms in different overlays. Other works include investigation of more path selection criteria, detailed performance evaluation on how to find the required network resources which are optimal for use. In the mentioned simulation study, only one mean delay is considered. Further research can be done considering the second moment of delay as it determines the coefficient of variation of the delay which also has high impact on the buffer occupancy.

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