Evaluating Overlay Network Management
Performance and Effectiveness

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Abstract - As overlay networks emerge as platforms to enhance application performance and content delivery within distributed systems, the need to monitor their effectiveness and reliability is becoming more of a focus. Overlay networks attempt to utilize various utilities to manage the transfer of data, but these utilities and the networks themselves can have a negative impact on synchronous overlay networks and the underlying physical network. This paper intends to present an evaluation process for the various network management utilities and data monitoring methods available to overlay network managers and interpret the results of that evaluation to compare the effectiveness of each utility or method. The proposed evaluation process will provide managers with the ability to assess and interpret performance and efficiency results of various overlay networks in their own environments to determine if the network structure needs alterations or enhancements.

Keywords: Overlay Networks, Overlay Types, Overlay Performance

1 Introduction

Overlay networks are built on top of other networks to provide services that are not available in the original network. They contain nodes which are connected by virtual links that utilize paths in the underlying networks. This connectivity permits more effective sharing of large amounts of information and resources. Overlay networks permit network managers to increase the performance of their existing environments by increasing their routing capabilities, increasing their security, reducing traffic congestion across the network, and increasing the flexibility of the size of the network without the involvement of service providers. Network developers and application users can design and implement communication methods and protocols, like data routing and file sharing management, by utilizing the Internet. Data routing can be configured to detect network congestion and utilize metrics to select less crowded paths.

However, these benefits come with drawbacks. In most cases, increased overhead and additional complexity occur when overlay networks are implemented. Additional overhead becomes a management issue when layers are added to the networking stack because they require that additional packet headers be processed. Sometimes the additional packets are redundant and cause an increase in the processing times. This constantly increasing traffic traveling across the overlays can overload the network and consume all the available network resources. Adding more layers to a network also makes it more complicated to manage. Overlay networks adapt to changes in network conditions and topology, which can make management information obsolete with even a simple change in the overlay. To compensate for the dynamic state of the network, overlays must be designed to let the network recover and recreate network structure when failures occur. The more functionality you add using layers, the more you expose your network to unintended reactions between the implemented layers. Overlay networks tend to be designed to work independently from each other, but this can create bottlenecks that reduce the performance of the overlays and the underlying network. Therefore, overlays should be designed to incorporate management tools that will reduce complexity and keep the network working efficiently.

The additional challenges of overlay networks can make it difficult to accurately evaluate the network properties. Network managers need to be able to assess the impact of multiple overlay networks coexisting in their environments and determine whether the benefits outweigh the consequences of the overlay implementation.

The most common overlay networks used include security, peer-to-peer, content delivery, and routing. Peer-to-peer networks allow end nodes to share files. Examples include services like BitTorrent, Napster and Gnutella. Content delivery overlays work to cache content and services to reduce access delays and transport data costs. Security overlay networks are used to enhance the protection of communication. Similar to content delivery overlays, security overlay networks can change the routing and caching behavior of the data traveling across the network to enhance the security or privacy of the communication. Routing overlay networks exist to control and direct data across the networks. Routing overlays provide alternate paths for data movement than what they would have initially traveled in the original network. This paper proposes a set of evaluation points for managers to use to perform the assessment of the
routing overlays to determine if implementation is beneficial to the environment.

2 Literature Review

Much of the available research focuses on the explanation of overlay networks and defining the various types of networks [1][2][4]. Other research focuses on specific types of overlay networks and tools [7][9][11]. The existing research does a good job presenting the benefits and drawbacks of overlay networks, whether they are generalizing overlay networks or selecting a specific type of overlay to discuss. Much of the research material presents theorems and formulae in great detail that may deter some readers due to complexity and ultra-technical language. There is a need to present a more generalized description of the specific evaluation points that managers should periodically review to ensure quality network performance.

3 Design Considerations

Routing overlay networks are intended to enhance existing routing functions and performance. The effectiveness of that enhancement depends greatly on the interaction of data between the overlay and the underlay networks. The ability of the overlay networks to redirect or recover from network congestion or interruptions is significantly affected by the use of the interconnection points of the two networks.

Overlay networks can have performance and overhead impact on the services being provided, such as routing. The design of an overlay network should include the ability to scale itself to a particular service within a group. Adding functionality via an overlay should not affect performance, because the new topology layer should not interfere with the existing protocols. In general, combining the right equipment with a correctly configured overlay can result in improved network performance with minimal overhead.

When creating overlay networks, designers should consider the drawbacks of implementing an overlay. Primarily, the consideration of increased overhead related to the management of the overlay and the increased processing of each data packet are key concepts to address in the network design. The processing of packets increases due to the delivery, processing, and retransmission of each packet. Additionally, the designer must determine the best method of integrating the overlay with the existing physical network. This aspect can be hindered by the creator’s lack of knowledge of the physical network and/or inability to control the physical network. Therefore, although the implementation of an overlay may assist packets in finding alternate paths that improve the latency experience by the end-user, designers should be careful to consider the alternate result of redirecting data over an overlay path that is detrimental to latency speeds.

Hop-by-hop reliability over overlay networks is an important consideration for effective design. Creators of overlay networks must select a reliable protocol to achieve reliability. Otherwise, the loss of data packets could take a long time to detect and result in higher traffic volumes as retransmitted data packets and acknowledgements are sent over multiple hops within the overlay to recover the missed packets. When creating an overlay, designers should also take into account the potential loss of intermediate nodes or disconnection of overlay links. Intermediate nodes are important elements of the overlay because they handle the reliability and congestion controls for their immediate neighbors, making it essential that an overlay design include redundancy for these nodes in the event of outages.

Designers should incorporate a distributed backup service into the layout of the overlay network. This backup can be used to provide the state of a failed node to any other operational node in the network. At a minimum, state information should include the neighbor links of the node, repair information, and application specific data. In order to deal with the possibility of restored backup information in cases of failed nodes, overlays should be designed to cope with minimal inconsistencies. Additionally, to ensure the application of these backup services, designers should also incorporate a per-node failure detector that can be used to test the status of network nodes. Ideally, the design should incorporate the ability of the network to eventually detect any failed node while ensuring that active nodes are not assumed to be failing.

There are several overlay service network topologies that appear in various research literatures. Each topology is a viable option with its own benefits and drawbacks. Designers should consider their environment and select the best fit for their needs.

3.1 Full Mesh Overlay Topology

![Fig. 1. [13]](image)

Fig. 1 is an example of a full mesh overlay topology. As illustrated, every node in the overlay network is neighbors with every other node in the overlay. This creates a scenario where several links pass through the same common underlay network link. In this type of overlay topology, the overlay
nodes may not be able to control and/or retrieve resource information on the links due to potential transmission of traffic through IP-layer links. The drawback to this is that the nodes have to continuously send packets to neighbor nodes to retrieve performance and path information.

3.2 Spanning Tree Overlay Topology

Fig. 2 illustrates the application of a 2-minimum spanning tree overlay topology. The dashed lines and solid lines represent two different spanning trees. These two spanning trees are combined to produce the overlay topology. This overlay is considered the lowest cost option among the tree options presented here. The trees utilize minimal overlapping in the overlay links and produce an effective overlay service network topology.

3.3 Mesh Tree Overlay Topology

Fig. 3 provides an example of a Mesh-Tree topology. The solid lines indicate a spanning tree and the dashed lines illustrate the added mesh links. Mesh-Tree topologies are constructed by creating the spanning tree to connect the overlay nodes, then connecting related nodes via mesh links. This approach has been particularly effective in improving the resilience of overlay networks.

3.4 Adjacent Connection Overlay Topology

Fig. 4 shows an example of an Adjacent Connection topology where no overlay node is present on the underlying path of the overlay link that connects any of the other overlay nodes. This topology uses the IP-layer topology information to construct the overlay and makes the assumption that the overlay nodes will have access to the IP-layer path information.

Network designers should also include bandwidth considerations and performance level information from existing networks, if available, to incorporate limits and requirements into their overlay design.

4 Performance Evaluation Criteria

To be considered effective, overlay networks must deliver performance and reliability that outweighs the management, overhead, and associated costs. There are key characteristics that can provide the ability to perform quantitative analysis for the performance on overlay networks.

4.1 Searching Hops

The multiple links created by an overlay network can considerably increase the performance of the network by reducing latency and shaky communication. The basic question for evaluation of performance in this case is, if a packet originates from a specific location and is addressed for a specific group, where should the packet be sent for forwarding?

The answer will depend on the relationship between the physical and overlay networks and how the packet is disseminated across the network. Theoretically, a deterministic decision will need to be made because of the existence of multiple viable paths within the intertwined networks. Since packets are not broadcast everywhere across the network, only the nodes on the network that are joined to the destination group should receive the broadcast.
Researchers have developed several platforms to assist designers in the computations of shortest paths from node to node. For example, Spines specifically uses an all pairs shortest path algorithm to compute the shortest path from every node to every other node and update pathways when changes occur in the network topology of the overlay. Once computed, the per sender, per group routing determination is completed by evaluating the links based on their destination information and removing, or pruning, the route from the tree. Spines then utilizes the same routing information for subsequent packets from the same sender to the same receiver until a topology change occurs. Once a topology change occurs, the computation and storage of the routing information is recalculated.

4.2 Efficiency and Scalability

The efficiency of an overlay network can be traced back to specific parameters that are able to be set to enhance the performance, but managers must consider if the level of performance is worth the tradeoff in overhead. Each parameter described below impacts the volume of the overhead in different ways.

Epoch, the interval at which the probes run to update route information, governs how frequently route computations occur. If this is a larger number, there is less overhead impact on the performance. However, a smaller epoch number will improve the validity of the network state information and retain the latest valid route paths.

The level of overhead associated with the exchange of state information and path computation is measured in connectivity. If the average connectivity is set at a larger setting, a larger number of nodes are included in the neighbors used to re-direct traffic during congested times. When more neighbors are included in the re-routing process, the level of overhead to manage the network information increases.

Although the number of nodes in an overlay is directly proportionate to the number of alternate paths available for data traffic, the level of overhead is also directly affected. The more overlay nodes, the greater the level of overhead. Researchers are investigating if the settings of other overlay parameters can be set to permit larger overlay networks.

In environments where there are significant numbers of overlay networks, it would be ideal to set a maximum length of overlay routes. Routes that travel through more than 2-3 overlay links should be limited to reduce inefficient path routes and extraneous data traffic congestion.

4.3 Robustness

The robustness of a network refers to how a network will maintain an acceptable level of service during fault events or challenges to normal network operations. This characteristic is generally evaluated by examining how the diameter of the network is changing.

The diameter consists of the longest path between any two nodes in the overlay network. This metric typically measures the maximum time for information to propagate across the network. The size of the largest component and the number of connected components also captures the robustness of a network by measuring the availability of the network.

Networks are generally considered to be more robust if the diameter is low and the availability is high. The easiest interpretation of this assumption is that if the diameter were to increase, or the number of components on the network increased, the result would be a decrease in the robustness and performance of the overlay network.

5 Future Work and Conclusions

This paper presents the best evaluation points to utilize in determining the effects of network enhancements and overlay implementations. Evaluating data results from these specific characteristics will provide network managers with information to determine the effectiveness of an overlay implementation in their environment to enhance performance. Further research on the optimal values of these data points and methods or processes to compute those values would warrant further investigation. Ideally, this research would establish a test environment with a fixed physical layer and implement various overlay topology scenarios while evaluating parameter settings in each topology type.

6 References


