On Designing the Overlay Topology of ROMCA (Resilient Overlay for Mission Critical Applications)

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Abstract: Inadequate end-to-end Quality of Service (QoS) and resilience support still exists across the Internet as it is difficult to achieve cooperation between the Autonomous Systems (AS) that are operated independently by Internet Service Providers (ISP). The use of an Overlay Network (ON) deployed on top of the Internet is viewed as one of the effective strategies to provide some measure of service quality and requires little change to the existing operations of the wide-area Internet.

An overlay network can be implemented with or without the network provider involvement. Currently, most research addresses network provider-dependent ONs. In this paper, we focus on analyzing and formulating the topological design problem in the context of a network-provider-independent overlay architecture named ROMCA (Resilient Overlay for Mission Critical Applications) based on previous work. Simulation results show that the overlay topology constructed exploiting underlying Internet path information can achieve good performance while maintaining low overhead.

1 Introduction

There is a growing demand for the applications to be delivered over the Internet; however, the Internet only provides "best effort" packet transport. Furthermore, the *de facto* inter-domain routing protocol that deployed for routing across multi-ASes - the Border Gateway Protocol (BGP) - is characterized by re-convergence times of several minutes or longer [1, 2]. So for mission critical applications that require high reliability and are particularly sensitive to network outages and performance degradation, additional mechanisms are needed. Till now, Overlay Networks (ON) have been used to support applications such as Peer-to-Peer (P2P) [3], multicast communications [4], QoS-guaranteed delivery [5, 6] and resilience-guaranteed services [7, 8]. As ONs require little change to the current Internet structure and operation, ON is viewed as one of the most effective solutions to the above-mentioned challenges.

An ON is composed of selected nodes from the underlying network. These overlay nodes are then connected via virtual links which are usually IP-layer paths. According to whether the overlay network is operated with an ISP's support or not, an ON can be classified as network provider-dependent [5, 6, 9] or network provider-independent [7, 8]. There is little work addressing the topological construction problem in the latter case. Since the overlay network service provider usually has no direct control and limited information about the underlying architecture, probing and monitoring mechanisms are usually introduced to obtain the necessary information to make appropriate decisions for mitigating potential service problems within the underlying network. Furthermore, as Internet node connectivity exhibits "power-law" characteristics, meaning that a minority of nodes possess high connectivity whilst the rest usually have only several connections, the placement of the overlay nodes and virtual links between them are critical in order to balance the performance gain with the overhead introduced by monitoring and probing.

We focus on the overlay topology construction of the network-provider-independent overlay architecture named ROMCA. The rest of the paper is structured as follows. In Section 2, related work is discussed; we then analyze and formulate the problem of overlay topology construction in the context of the ROMCA architecture in Section 3; then in Section 4, initial simulation results and analysis are presented. Finally, conclusions and future work are outlined in Section 5.

2. Related Work

Overlay networks have been proved to be efficient in Guaranteeing QoS for the applications that traverse multiple ASes in the Internet [7, 10]. Since then, a moderate amount of work has addressed the problem of overlay topology design [11, 12, 13, 14, 15, 16, 17 and 18], mainly considering topological construction of network-provider-dependent overlays, such as the Service Overlay Network (SON) under the economic constraints. For example, [11] formulates the topology design problem of SON as an optimization problem with the objective of achieving least expenditure. Simulated annealing is employed as a heuristic to provide a solution for large-scale networks. Additional constraints, including overlay node location and the budget, are taken into consideration in the two proposed optimization models for SON in [12].

Work in [13] summarizes and compares the overhead and performance of different overlay topologies. It shows that the information from the underlying network is instrumental in building an efficient overlay topology. However, it is based on the assumption that the placement of the node is pre-determined. Complementary to this, the research in [14, 15, and 16] explores the overlay node placement problem with both experimental and simulation-based methods. More specifically, [14] proposes heuristic-based methods for selecting the overlay node candidates within an ISP domain based on data sets from the "traceroute" measurements. Similarly, [15] proposes an intuitive heuristic method for overlay node selection based on node degree factor. Nevertheless, all of these schemes need either the help of the ISP [14, 15] or auxiliary nodes, like landmark nodes [16].

Recently, [17] considers the design of overlay topology under multiple constraints for SON. It aims to minimize the economic cost while taking QoS into account. Our work is similar, but our aim is to maximize diversity of the virtual links whilst ensuring coverage of the ROMCA services. Moreover, we assume that ROMCA does not rely on network provider support and guidelines drawn from [8] are considered in the process of ROMCA overlay topology design.

3. ROMCA Topology Construction Formulation

3.1 Notations and Assumptions

- The overlay $G_o(V_o, E_o)$ is built on top of the physical Internet network $G_p(V_p, E_p)$; As a failure within one AS might affect on the operation of the whole domain, we assume at most one Overlay Gateway (OG) exists in an AS; Let $\{OG_i, i=1, \ldots, m\}$ denote the set of OG nodes;
- We assume IP layer routing employs least-cost-based routing protocols; Moreover, IP layer path information is available for the overlay topology construction;
- It is assumed that the customers of ROMCA originate only from an AS that has connection with no more than 3 other ASes (i.e. they originate in regional access networks rather than tier-I carrier networks); Let $\{C_j, j=1,\ldots, n\}$ denotes the set of potential customers.

3.2 Challenges and Contributions

- *Network provider independence*: defined as a network provider independent overlay, ROMCA faces the challenge that only underlying nodes with lower node degree (no more than 3) will join the architecture, which hasn't been considered in previous work. As the underlying physical paths this kind of node encounters have a higher chance to overlap with each other, it is necessary to solve the problem of how to build an overlay-link-disjoint topology. In this paper, physical information is assumed to be available based on the utility of the candidate nodes;
- *Selection of both the OG location and virtual links*: based on assumption that the OG node location is not pre-determined and the candidate nodes in the underlying network will apply to become OG nodes, the ROMCA topology problem consists of two sub-problems: the selection of overlay nodes and the placement of virtual links between each pair of overlay nodes.

3.3 Topological Construction Model

Upon a node's (N_t) request to become part of the ROMCA architecture, the Overlay Directory Services (ODS), which is responsible for constructing the overlay topology, will decide whether the candidate will be permitted to be an OG and also how many virtual links will be set up using the following variables:

$$U(N_t) = S_{tj}\!:\!\{D_{ti}\} \qquad (1)$$

Under the constraints:

$$ND(C_j) \le ND_{\text{limit}} \text{ , where j = 1,..., n} \quad (2)$$

$$ND(N_t) \le ND_{\text{limit}} \quad (3)$$

$$ND(OG_i) \le ND_{\max} \quad (4)$$

Physical Hop Number: $PH(OG_i, OG_k) \le PH_{\max}$, where $i \neq k$,i=1,…, m and k=1,…, m (5)

In equation 1, S_{tj} is the coverage variable that calculates N_t's contribution to ROMCA service coverage if the node is accepted and

$$S_{tj} = \begin{cases} 1, \text{if there is a customer } C_i \text{ that resides in the same AS as } N_t; \\ 0, \text{otherwise}; \end{cases} \quad (6)$$

So if S_{tj} equals 1, the node will be accepted as an OG node with no regard to its diversity degree as it contributes to an increase in the service coverage while the virtual links to be set up will be chosen according the $\{D_{ti}\}$ set. Otherwise, $\{D_{ti}\}$ will be used to determine if it is useful in the ROMCA topology and if it has no diversity, its request to become an OG will be rejected.

$\{D_{ti}\}$ is the diversity degree set for a given OG node. Each element of the set gives the diversity degree of the virtual link to an existing OG in the overlay topology. The degree of diversity is measured as the number of physical hops that the virtual link traverses that are not in common with any other virtual link, over the total number of hops along the virtual link path. The set is rank-ordered with virtual links possessing higher diversity degree coming first. The virtual link that is Most Diversified will be chosen First (MDF) to connect the new OG node to another OG node, bearing in mind the maximum node degree constraint.

As we know that the performance of the underlying network will change over time, so that QoS quality parameters should be taken into consideration for the dynamic overlay topology change and will be further investigated in the future work.

4. Simulation Results and Analysis

Simulations are carried out under the same failure scenario for 1000 independent trials using a real AS-level topology deduced from “traceroute” information [18]. The Failure Recovery Ratio (FRR) [13] and the percentage of physical hop number included in the overlay topology as compared with that of the Full Mesh (FM) overlay topology are used as performance parameters. For comparison purposes, Full Mesh and K (overlay node constraint)-Random Connection (RC) methods are included to build the overlay topology.

Table 1 Simulation Results under CN05 AS-level topology (84 nodes, 211 links)

OG number = 20	FM		K-RC		MDF	
Average ND (ND_{max}=6)	14		5.87		5.83	
Average physical hop number included and the percentage compared with that of FM	72.6	N/A	56.4	77.8%	67	92.3%
Average FRR	73%		64%		70%	

According to the simulation results shown in Table 1, the FM overlay topology can obtain optimal performance values as far as FRR is concerned as it includes all the possible alternative virtual links between the overlay node pairs, however it doesn’t consider the overlay node degree constraint. As the overlay path may overlap in the underlying physical network and an overlay node might be isolated under multiple failure scenarios, the FRR of full mesh method is not 100 percent. Furthermore, the FRR of the MDF method is close to that of full mesh topology. So, we can conclude that under the maximum node degree and the physical AS level hop constraints, the overlay topology constructed with the presence of physical information using the proposed method shows almost the same performance (i.e. FRR) as that of the FM topology, and it has a lower node degree thus lower overhead.

5. Conclusions and Future Work

This paper addresses the problem of topological design of a network-provider independent overlay architecture. As shown, when ROMCA is constructed with access to physical network information, it performs well in terms of the failure recovery ratio while having a lower node degree as compared to Full Mesh (FM) overlay. The proposed method only focuses on maximizing the utility of each individual node and can guarantee the maximum coverage by selecting the OGs and appropriate virtual links. However, the overall performance of the overlay network cannot be guaranteed to be optimal, a revised version of the algorithms proposed in [14] together with an ILP formulation is now being evaluated.

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