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# Resource Allocation of Overlay Routing Relay Nodes in Cost-Effective Approach

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**Abstract** —
*Networks operating on the inter-domain level are Overlay Networks. An overlay network is a computer network, which is built on the top of another network. Nodes in the overlay can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network.Overlay routing is a very attractive scheme that allows improving certain properties of the routing (such as delay or TCP throughput) without the need to change the standards of the current underlying routing. However, deploying overlay routing requires the placement and maintenance of overlay infrastructure. This gives rise to the following optimization problem: Find a minimal set of overlay nodes such that the required routing properties are satisfied. In this paper, we rigorously study this optimization problem. We show that it is NP-hard and derive a nontrivial approximation algorithm for it, where the approximation ratio depends on specific properties of the problem at hand. We examine the practical aspects of the scheme by evaluating the gain one can get over several real scenarios. The first one is BGP routing, and we show, using up-to-date data reflecting the current BGP routing policy in the Internet, that a relative small number of less than 100 relay servers is sufficient to enable routing over shortest paths from a single source to all autonomous systems (ASs), reducing the average path length of inflated paths by 40%. We also demonstrate that the scheme is very useful for TCP performance improvement (results in an almost optimal placement of overlay nodes) and for Voice-over-IP (VoIP) applications where a small number of overlay nodes can significantly reduce the maximal peer-to-peer delay.*

***Keywords*** — Overlay network; resource allocation

## I. Introduction

Nowadays the Internet is the basis for more overlaid networks that can be constructed in order to permit routing of messages to destinations not specified by an IP address. Overlay networks are used in telecommunication because of the availability of digital circuit switching equipment and optical fiber. Telecommunication transport networks and IP networks (that combined make up the broader Internet) are all overlaid with at least an optical fiber layer, a transport layer and an IP or circuit switching layers.

Overlay routing has been proposed in recent years as an effective way to achieve certain routing properties, without going into the long and tedious process of standardization and global deployment of a new routing protocol. For example, in [1], overlay routing was used to improve TCP performance over the Internet, where the main idea is to break the end-to-end feedback loop into smaller loops. This requires that nodes capable of performing TCP Piping would be resent along the route at relatively small distances. Other examples for the use of overlay routing are projects like RON [2] and Detour [3], where overlay routing is used to improve reliability. Yet another example is the concept of the “Global-ISP” paradigm introduced in [4], where an overlay node is used to reduce latency in BGP routing.

In order to deploy overlay routing over the actual physical infrastructure, one needs to deploy and manage overlay nodes that will have the new extra functionality. This comes with a non negligible cost both in terms of capital and operating costs. Thus, it is important to study the benefit one gets from improving the routing metric against this cost. In this paper, we concentrate on this point and study the minimum number of infrastructure nodes [5] that need to be added in order to maintain a specific property in the overlay routing. In the shortest-path routing over the Internet BGP-based routing example, this question is mapped to: What is the minimum number of relay nodes that are needed in order to make the routing between a groups of autonomous systems (ASs) use the underlying shortest path between them? In the TCP performance example, this may translate to: What is the minimal number of relay nodes needed in order to make sure that for each TCP connection, there is a path between the connection endpoints for which every predefined round-trip time (RTT),there is an overlay node capable of TCP Piping? Regardless of the specific implication in mind, we define a general optimization problem called the Overlay Routing Resource Allocation (ORRA) problem and study its complexity. It turns out that the problem is NP-hard, and we present a nontrivial approximation algorithm for it. Note that if we are only interested in improving routing properties between a single source node and a single destination, then the problem is not complicated, and finding the optimal number of nodes becomes trivial since the potential candidate for overlay placement is small, and in general any assignment would be good. However, when we consider one-to-many or many-to-many scenarios, then a single overlay node [6] may affect the path property of many paths, and thus choosing the best locations becomes much less trivial. test our general algorithm in three specific such cases, where we have a large set of source–destination pairs, and the goal is to find a minimal set of locations, such that using overlay nodes in [7] these locations allows to create routes (routes are either underlay routes or routes that use these new relay nodes) such that a certain routing property is satisfied.

The first scenario we consider is AS-level BGP routing, where the goal is to find a minimal number of relay node locations that can allow shortest-path routing between the source–destination pairs. Recall that routing in BGP is policy-based and depends on the business relationship between peering ASs, and as a result, a considerable fraction of the paths in the Internet do not go along a shortest path (see [5]). This phenomenon, called path inflation, is the motivation for this scenario. We consider a one-to-many setting where we want to improve routing between a single source and many destinations. This is the case where the algorithm power is most significant since, in the many-to-many setting, there is very little overlap between shortest paths, and thus not much improvement can be made over a basic greedy approach. Demonstrate, using real up-to-date Internet data, that the algorithm can suggest a relatively small set of relay nodes that can significantly reduce latency in current BGP routing.

The second scenario we consider is the TPC improvement. In this case, we test the algorithm on a synthetic random graph, and show that the general framework can be applied also to this case, resulting in very close-to-optimal results. The third scenario addresses overlay Voice-over-IP (VoIP) applications such as Skype (http://www.skype.com), Google Talk (http://www.google.com/talk/), and others. Such applications are becoming more and more popular offering IP telephone services for free, but they need abounded end-to-enddelay (or latency) between any pair of users to maintain a reasonable service quality. Show that our scheme can be very useful also in this case, allowing applications to choose asmallernumber of hubs, yet improving performance formany users. Note that the algorithmic model we use assumes a full knowledge of the underlying topology, the desired routing scheme, and the locations of the required endpoints. In general, the algorithm is used by the entity that needs the routing improvement and carries the cost of establishing and maintaining overlay nodes, using the best available topology information. For example, in the VoIP case, the VoIP application is establishing the overlay nodes, and thus the application can gain by using our approach.

The main contributions of this paper are as follows.

- We develop a general algorithmic framework that can be used in order to deal with efficient resource allocation in overlay routing.
- We develop a nontrivial approximation algorithm and prove its properties.
- We demonstrate the actual benefit one can gain from using our scheme in three practical scenarios, namely BPG routing, TCP improvement, and VoIP applications.

## II. RELATED WORK

Using overlay routing to improve network performance is motivated by many works that studied the inefficiency of varieties of networking architectures and applications. Analyzing a large set of data, Savage et al. [6] explore the question: How “good” is Internet routing from a user’s perspective considering round-trip time, packet loss rate, and bandwidth? They showed that in 30%–80% of the cases, there is an alternate routing path with better quality compared to the default routing path. In [7] and later in [1], the authors show that TCP performance is strictly affected by the RTT. Thus, breaking a TCP connection into low-latency sub connections improves the overall connection performance. In [5], [8], and [9], the authors show that in many cases, routing paths in the Internet are inflated, and the actual length (in hops) of routing paths between clients is longer than the minimum hop distance between them. Using overlay routing to improve routing and network performance has been studied before in several works. In [3], the authors studied the routing inefficiency in the Internet and used an overlay routing in order to evaluate and study experimental techniques improving the network over the real environment. While the concept of using overlay routing to improve routing scheme was presented in this work, it did not deal with the deployment aspects and optimization aspect of such infrastructure.

A resilient overlay network (RON), which is architecture for application-layer overlay routing to be used on top of the existing Internet routing infrastructure, has been presented in [2]. Similar to our work, the main goal of this architecture is to replace the existing routing scheme, if necessary, using the overlay infrastructure. This work mainly focuses on the overlay infrastructure (monitoring and detecting routing problems, and maintaining the overlay system), and it does not consider the cost associated with the deployment of such system. In [10], the authors study the relay placement problem, in which relay nodes should be placed in an intra domain network. An overlay path, in this case, is a path that consists of two shortest paths, one from the source to a relay node and the other from the relay node to the destination. The objective function in this work is to find, for each source–destination pair, an overlay path that is maximally disjoint from the default shortest path. This problem is motivated by the request to increase the robustness of the network in case of router failures. In [11], the authors introduce a routing strategy, which replaces the shortest-path routing that routes traffic to a destination via predetermined intermediate nodes in order to avoid network congestion under high traffic variability. Roy *et al.* [12] were the first to actually study the cost associated with the deployment of overlay routing infrastructure. Considering two main cases, resilient routing, and TCP performance, they formulate the intermediate node placement as an optimization problem, where the objective is to place a given number intermediate nodes in order to optimize the overlay routing, and suggested several heuristic algorithms for each application. Following this line of work, we study this resource allocation problem in this paper as a general framework that is not tied to a specific application, but can be used by any overlay scheme. Moreover, unlike heuristic algorithms, the approximation placement algorithm presented in our work, capturing any overlay scheme, ensures that the deployment cost is bounded within the algorithm approximation ratio.

## III. MODEL AND PROBLEM DEFINITION

Given a graph G=(V,E)describing a network, let $P_u$ be the set of routing paths that is derived from the underlying routing scheme, and let $P_o$ be the set of routing paths that is derived from the overlaying routing scheme (we refer to each path in $P_u$ and in $P_0$ as the underlying and overlaying path sets, respectively).Note that both $P_u$ and $P_o$ can be defined explicitly as a set of paths, or implicitly, e.g., as the set of shortest paths with respect to a weight function W:E->R over the edges. Given a pair of vertices s , t € V, denote by the set of overlay paths between s and t and , namely , and , the endpoints of p are s and t .

*Definition 1.* Given a graph G=(V,E), a pair of vertices(s,t) , a set of underlay paths $P_u$ , a set of overlay paths $P_0$ , and a set of vertices U is subset of V .We say that U covers (s,t) if there exists p € $P_o$ such that is a concatenation of one or more underlying paths, and the endpoints of each one of these underlay paths are in u U{s}{t}.

Intuitively speaking, the set of vertices, also called relay nodes, is used to perform overlay routing; from sources to destinations such that packets can be routed from one relay node to another using underlay paths. The Overlay Routing Resource Allocation (*ORRA*) problem is defined.

Using the assumption that single-hop paths are always in $P_u$, the set U=V is a trivial feasible solution to the *ORRA* problem.
Our objective, is to minimize the deployment cost of relay nodes, thus we define the *MIN-ORRA* problem

For instance, consider the graph depicted in Fig. 1, in which the underlying routing scheme is minimum hop count, and the
Overlaying routing scheme is the shortest path with respect to the edge length. In this case, the underlay path between s $_1$and
$t_1$ is (s1,v1,v2,v7,t1) while the over lay between them should be (s1,v1,v3,v4,v7,t1) or (s1,v5,v6,v2,v7,t1), Similarly, the underlay path between $s_2$ and $t_2$ is (s2,v2,v4,t2) , while the overlay path between them should be(s2,v6,v2,v7,v4,t2) or(s2,v6,v5,v1,v3,t2) . Deploying relay nodes on and $v_6$and $v_7$
implies that packets from $s_1$ to $t_1$ can be routed through the concatenation of the following underlay paths (s1,v5,v6) and , (v6,v2,v7) and (v7,t1) while packets from s2 to t2 can be routed through the concatenation of the following underlay paths(s2,v6)(v6,v2,v7) and (v7,v4,t2). Thus, u={$v_6$,$v_7$} is a feasible solution to the corresponding *ORRA* problem. If all the nodes have an equal weight w(v)=1 then one may observe that this is also an optimal solution .

## ON THE COMPLEXITY OF THE *ORRA* PROBLEM

I am study the complexity of the *ORRA* problem. In particular, we show that the -*ORRA* problem is NP-hard, and it cannot be approximated within a factor of (where is the minimum between the number of pairs and the number of vertices), using an approximation preserving reduction from the Set Cover (SC) problem [13], [14]. We also present an -approximation algorithm where is the number of vertices required to separate each pair with respect to the set of overlay paths .While the reduction and the hardness result hold even for the simple case where all nodes have an equal cost (i.e., the cost associated with a relay node deployment on each node is equal), the approximation algorithm can be applied for an arbitrary weight function, capturing the fact that the cost of deploying a relay node may be different from one node to another.

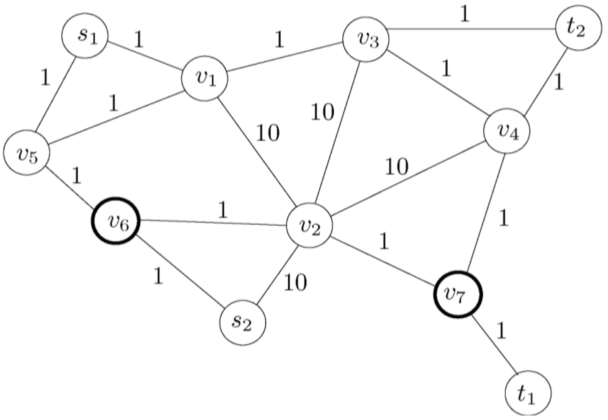
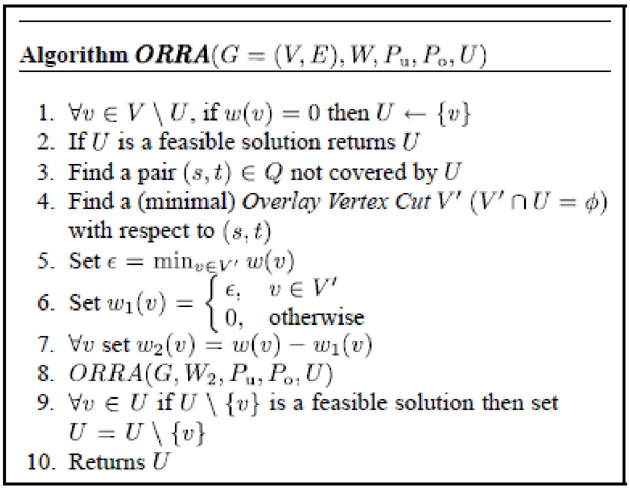


Fig. 1. **Overlay routing example: Deploying relay server on $v_6$ and $v_7$ enables overlay routing**.

The recursive algorithm, shown at the top of the next page, receives an instance of the *ORRA* problem (a graph, a nonnegative weight function over the vertices, a set of underlay and overlay paths and, respectively) and a set of relay nodes and returns a feasible solution to the problem. The set of relay nodes in the first call is empty (i.e.,U=0 ).



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Algorithm ORRA($G = (V, E), W, P_u, P_o, U$)

1. $\forall v \in V \setminus U$, if $w(v) = 0$ then $U \leftarrow \{v\}$
2. If $U$ is a feasible solution returns $U$
3. Find a pair $(s, t) \in Q$ not covered by $U$
4. Find a (minimal) Overlay Vertex Cut $V'$ ($V' \cap U = \phi$)
   with respect to $(s, t)$
5. Set $\epsilon = \min_{v \in V'} w(v)$
6. Set $w_1(v) = \begin{cases} \epsilon, & v \in V' \\ 0, & \text{otherwise} \end{cases}$
7. $\forall v$ set $w_2(v) = w(v) - w_1(v)$
8. $ORRA(G, W_2, P_u, P_o, U)$
9. $\forall v \in U$ if $U \setminus \{v\}$ is a feasible solution then set
   $U = U \setminus \{v\}$
10. Returns $U$
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At each iteration, the algorithm picks vertices with weight that is equal to zero until a feasible set is obtained (steps 1 and 2 of the algorithm). Thus, since at each iteration at least one vertex gets a weight that is equal to zero with respect to (steps 5–7), then in the worst case the algorithm stops after iterations and returns a feasible set. In Step 9, unnecessary vertices are removed from the solution, in order to reduce its cost. While this step may improve the actual performance of the algorithm, it is not required in the approximation analysis below and may be omitted in the implementation.

### BGP Routing Scheme

BGP is a policy-based interdomain routing protocol that is used to determine the routing paths between autonomous systems in the Internet. In practice, each AS is an independent business entity and the BGP routing policy reflects the commercial relationships between connected ASs. A customer– provider relationship between ASs means that one ASs (the customer) pays another AS (the provider) for Internet connectivity, a peer–peer relationship between ASs means that they have mutual agreement to serve their customers while a *sibling–sibling* relationship means that they have mutual- transit agreement (i.e., serving both their customers and providers). These business relationships between ASs induce a BGP export policy in which an AS usually does not export its providers and peers routes to other providers and peers [13], [14]. In [1] and [2], we showed that this route export policy indicates that routing paths do not contain so-called *valleys* nor *steps*. In other words, after traversing a *provider–customer* or a *peer–peer* link, a path cannot traverse a *customer–provider* or a *peer-peer* link. This routing policy may cause, among other things, that data packets will not be routed along the shortest path. For instance, consider the AS topology graph depicted in Fig. 2. In this example, a vertex represents an AS, and an edge represents a peering relationship between ASs.

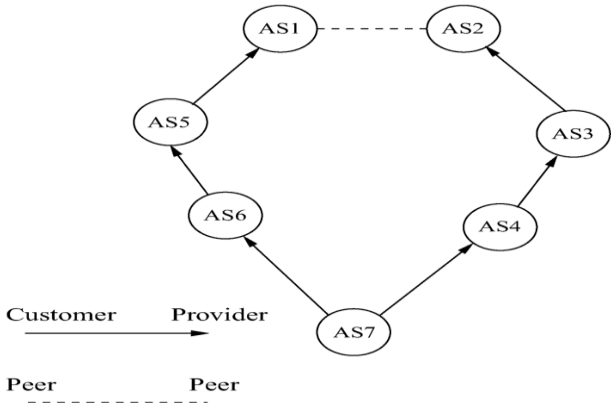

Fig 2: **BGP path inflation: The shortest valid path between AS6 and AS4 is longer than the shortest physical path between them**

While the length of the physical shortest path between AS6 and AS4 is two (using the path AS6, AS7, AS4), this is not a valid routing path since it traverses a valley. In this case, the length of the shortest *valid* routing path is five (using the path AS6, AS5, AS1, AS2, AS3, AS4). In practice, using real data gathered from 41 BGP routing tables, Gao and Wand [5] showed that about 20% of AS routing paths are longer than the shortest AS physical paths. While routing policy is a fundamental and important feature of BGP, some application may require to route data using the shortest physical paths.[3] In this case, using overlay routing, one can perform routing via shortest paths despite the policy. In this case, relay nodes should be deployed on servers located in certain carefully chosen ASs.

## IV CONCLUSION

While using overlay routing to improve network performance was studied in the past by many works both practical and theoretical, very few of them consider the cost associated with the deployment of overlay infrastructure. In this paper, we addressed this fundamental problem developing an approximation algorithm to the problem. Rather than considering a customized algorithm for a specific application or scenario, we suggested a general framework that fits a large set of overlay applications. Considering three different practical scenarios, we evaluated the performance of the algorithm, showing that in practice the algorithm provides close-to-optimal results. Many issues are left for further research. One interesting direction is an analytical study of the vertex cut used in the algorithm. It would be interesting to find properties of the underlay and overlay routing that assure a bound on the size of the cut. It would be also interesting to study the performance of our framework for other routing scenarios and to study issues related to actual implementation of the scheme. In particular, the connection between the cost in terms of establishing overlay nodes and the benefit in terms of performance gain achieved due to the improved routing is not trivial, and it is interesting to investigate it. The business relationship between the different players in the various use cases is complex, and thus it is important to study the economical aspects of the scheme as well. For example, the one-to-many BGP routing scheme can be used by a large content provider in order to improve the user experience of its customers. The VoIP scheme can be used by VoIP services (such as Skype) to improve call quality of their customers.

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Student

Guide