Towards a Service Oriented Internet

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SUMMARY Today’s Internet remains faithful to its original design that dates back more than two decades. In spite of tremendous diversity in users, as well as the sheer variety of applications that it supports, it still provides a single, basic service offering—unicast packet delivery. While this legacy architecture seemed adequate till recently, it cannot support the requirements of newer services and applications which are demanded by the growing, and increasingly sophisticated, user population. The traditional way to solve this impasse has been by using overlay networks to address individual requirements. This does not address the fundamental, underlying problem, i.e., the ossification of the Internet architecture. In this paper, we describe the design of a new Service Oriented Internet framework that enables the flexible and effective deployment of new applications and services. The framework we describe utilizes the existing IP network and presents the abstraction of a service layer that enables communication between service end-points and can better support requirements such as availability, robustness, mobility, etc., that are demanded by the newly emerging applications and services.

key words: service-oriented, overlays, architecture

1. Introduction

Over the course of the last two decades, the Internet has been transformed from an academic network to a ubiquitous communication infrastructure. Today’s Internet is very much an integral part of society, underlying many key commercial, cultural and social activities. In stark contrast to this transformation, the architectural design of the Internet remain unchanged since its beginning. As was the case when first deployed, the Internet today supports the same (single) basic communication paradigm: best-effort unicast packet delivery, or stated differently—packet delivery between two fixed end interfaces. While this basic design has so far endured, this is no longer the case; the requirements of emerging services and applications are very hard to support (given the design). The tension arises from the fact that these new applications, which are quite hard to deploy (effectively) with today’s Internet architecture, are crucial for the future growth and evolution of the Internet. The traditional communication paradigm, i.e., that of communication between fixed end hosts is somewhat outdated. For instance, when people perform a search engine lookup, say using Google, any of the thousands of Google servers can be be pressed into service; the identity of the particular server is irrelevant from the user’s point of view. Thus, we argue that communication between service end-points is a more powerful paradigm than the traditional model.

However, supporting such a paradigm is very hard with today’s Internet. Consequently, application requirements such as availability, reliability, mobility, quality of service, etc., are incredibly difficult to support. Take for instance the notion of availability in the context of a video streaming application. Supporting availability, in this case, requires the ability to migrate a streaming session to a different server during the lifetime of the video session. However, in the existing design, a binding between the client and a server needs to be established before any video frames are transferred. If the particular server were to fail, the session will abort, even though there may be other available servers that can serve up the same video frames.

The traditional way to address such requirements has been to deploy various ad-hoc mechanisms piecemeal. Examples include the deployment of content distribution networks, application specific overlay networks, etc. However, it is important to realize that these approaches are intended as a short term solution and do not address the underlying problem.

In this paper, we present a new architecture, which we term the “Service Oriented Internet” or SOI, that is best described as an efficient, generic, unifying framework to easily allow new services and applications to be deployed. SOI uses the underlying IP fabric to actually carry the bits and presents the abstraction of a service layer, that forwards packets between service end points. In the design of the SOI architecture, we introduce three key abstractions: (1) the notion of a service cloud, which is simply a collection of service entities that are deployed by a service provider. The simplest example would be a cooperating hierarchy of web proxy servers; (2) a new two-level, location-independent addressing scheme; and (3) a new abstract service layer that is used to forward packets (to the appropriate service end-points).

2. Service Oriented Internet

Overlay networks have emerged as an effective way to implement functionality which otherwise would require signif-
Significant change at the IP layer; they can be realized with very little overhead or infrastructure support. A set of end-nodes can form an overlay network without any additional support from the underlying network (or the ISP’s carrying traffic between the nodes). However, this transparency comes at some cost. Firstly, by being completely oblivious of the underlying network layer, there are certain inefficiencies that cannot be avoided; very often, an overlay neighbor could actually be very far away in terms of the IP level network. Second, in most cases, overlays provide services (or realize applications) that are mandated on a well behaved underlying network. Presently, ISPs do not differentiate between traffic forwarded over an overlay and other traffic sharing the same network. Providing handles for the network to identify, and differentiate, packets carried over an overlay, is important from the view of supporting QoS requirements. Third, if we were to imagine a number of overlay networks on the same underlying network, each of them would have to replicate some common functions. For example, consider a situation where overlay A provides a streaming video service and overlay B is used for multicast video conferencing. Both overlays deliver real-time traffic; hence, both are likely to perform active measurements to support path selection and forwarding. Clearly, this replication is clearly inefficient. The obvious improvement is to decouple the active measurement component from the overlay operation and allow the different overlays to share a common measurement infrastructure. A similar idea has been discussed in [1], where the authors advocate a routing underlay that takes over the common tasks.

The underlying idea that lies behind our architecture is that services can be deployed as overlays, but to address the performance limitations of the overlays and to ensure support for the requirements of newer applications, we also need an underlying infrastructure which addresses the specific shortcomings of the traditional overlay paradigm. In the rest of the paper, we focus on the details of such an infrastructure.

We distinguish between data transport networks, which roughly correspond to the existing autonomous systems (and the IP networks), and service overlay networks (SON), each of which provides a well defined service (or set of services). The role of the data transport networks is to provide bit-pipes to the service overlay networks that ride on top. On the other hand, service overlay networks, provide specific value-added services to subscribers. For instance, we can think of VoIP service clouds, or content distribution clouds (think of the entire Akamai infrastructure as a cloud). Each of these are operated by service providers and generally have several distributed locations at which they interface with the data networks. Requests from clients are routed over the data network to the nearest (or most appropriate) point of entry into a particular service cloud, and subsequently served by some host inside the cloud. This high level description is depicted in Fig. 1, with the data networks shown towards the bottom of the figure and the service clouds near the top. Note that the framework defines how data is routed to the border of the service clouds, but not how it is handled (or transported) internally. Service providers can use arbitrary mechanisms that best satisfy their goals and purposes.

The logical decoupling between the data network domains and the service networks allows the independent evolution of each. This logical independence is an artifact of completely separating the addressing, routing and forwarding mechanisms in the two realms. A service cloud could implement each of these mechanisms as best suits its needs. There are three elements that are key to this separation, namely: a new naming and addressing scheme that is a significant departure from the existing IP addressing scheme, service gateways (SG), and service points-of-presence (S-PoP).

2.1 Key Abstractions

The SOI architecture is built on top of the existing IP infrastructure, and provides a common platform for flexibly deploying new Internet services and effectively supporting their diverse requirements. The architecture is based on three key abstractions, described below.

Service Clouds are collections of service entities (servers, proxies, caches, etc.) that are deployed over the Internet
to collectively and collaboratively provide a set of application/information services to users. Each of these clouds is a “virtual service overlay network” that is commonly owned and managed by a single provider or a consortium of application service providers, and it relies on the underlying IP data network domains for data delivery across the Internet. Each service cloud has one or more interfaces that interface with the infrastructure; we refer to these as service points-of-presence (S-PoPs). Objects enter or exit a service cloud only via its S-PoPs.

Service-oriented addressing scheme: The central idea of the SOI architecture is a new two-level addressing scheme that provides location-independent identification of service clouds and objects within these clouds. Each service cloud is uniquely identified by a fixed-length service id (sid); and an object within a service cloud is specified by a (generally variable-length) object id (oid). The syntax and semantics of sid are globally defined and centrally administered, just like today’s IP addresses (or rather network prefixes). On the other hand, the syntax and semantics of oid are defined by individual service providers (the mapping to host is scope limited to the service cloud), and thus are service-specific.

Service (routing/delivery) layer: Underlying the SOI architecture is a new service layer abstraction that, logically, sits just above the IP network layer in the protocol stack. Corresponding to the two-level (sid, oid) addressing scheme, the service layer introduces two new network elements with distinct functions: service gateways (SGs) and service points-of-promise (S-PoPs). SGs can be viewed as extensions of the underlying network domains, and are typically deployed at the edge of a network domain. They are responsible for routing and service delivery across network domains, i.e., overlay forwarding is performed by SGs using the sid in the address. S-PoPs are the interface points of a service cloud with the network domains, and are thus logically a part of the service cloud (and hence are oid-aware). They are responsible for delivering objects within a service cloud. SGs and S-PoPs work together to support flexible end to end delivery.

Data destined for any particular service cloud must necessarily transit at least one SG (and S-PoP). Note that the former is owned and operated by individual network domains. This provides a way for the network domain to accurately identify and track traffic meant for the overlay networks.

3. SOI Architecture

In this section, we present the key components of the proposed SOI architecture, describe basic operations and walk through a typical transaction.

3.1 Addressing and Name Resolution

The name resolution stage returns return a two level (sid, oid) address. A key observation in the design is that the two identifiers are resolved independently and at different locations. Seen at a very high level, the sid mapping is performed external to the service cloud, while the oid mapping is performed inside the cloud. The advantages of this will become clear shortly.

Under the proposed SOI architecture, each application/information service provider who wants to deploy services over the Internet is assigned a single fixed-length (32 bit) service id, which is administered by a central authority. This is a departure from the IP addressing scheme, where a “cloud” (network domain) is assigned a contiguous range of addresses (address block or network prefix). Each service cloud can be roughly thought of as corresponding to an organization currently having a second tier (e.g., yahoo.com, msn.com, real.com) or third tier (e.g., shop.msn.com, nu.ac.cn) domain name. Such domain names will be retained in our SOI architecture as the names of service clouds, and are referred to as service names. To resolve the service name of a service cloud to its assigned sid, we can reuse the current DNS infrastructure (extending it so that names resolve to sid’s), or build a similar service name resolution system. The specific details of the service name resolution are out of the scope of this paper. It is important to note that caching the mappings locally requires only a small amount of memory—the number of service names is significantly smaller than the number of domain names in the current DNS system, and moreover, service-name-to-sid mappings are essentially static. Hence, service name resolution can be done with very little overhead (on the shared infrastructure).

In contrast to the sid space, the oid space is defined by each individual service cloud, with its own syntax and semantics. This gives each service cloud the most flexibility and efficiency for defining its own object naming and addressing system. It also offloads many service-specific functions (e.g., object resolution, internal routing, load balancing, etc.) to individual service clouds, which leads to a socially optimal solution. Providers that want more complicated mechanisms to perform the name resolution are free to do so, but only within the cloud. In addition, hiding the syntax and semantics of a service cloud’s oid space from outsiders makes it more secure. This makes it very difficult for an attacker to launch a DoS attack targeting a particular server, since the corresponding oid can be dynamically remapped.

Service Layer: For convenience, we refer to a service-layer protocol data unit as a service object. Figure 2 shows an abstract representation of a service object header. The

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††Note that the separation between data transport domains and service clouds is purely logical. It is possible, though not required, that the service cloud forwards data internally over the existing IP infrastructure.

†††Note that the IP address is still used to forward packets between neighboring SG’s.

This is not a strict requirement, and is just a suggestion that reflects our belief that most current service providers fall into these categories.
header is partitioned into two logical sections, the sid part and oid part. Associated with both destination sid (dst sid) and source sid (src sid) is an additional 32-bit service modifier, which is defined by a service cloud to influence the forwarding of service objects. The service modifier contains two types of information: S-PoP attribute and service attribute (see Fig. 5 for an example). The S-PoP attribute describes the properties of S-PoPs, and in general contains two sub-fields, an S-PoP level and an S-PoP id. For example, using S-PoP attributes, a service cloud can organize its S-PoPs in a certain hierarchy to best meet its needs. The service attributes are used to indicate a preference for different service classes, next hops, etc. Multiple service attribute sub-fields can be defined as appropriate. We illustrate this with an example in Sect. 4.

When a service object is generated, both the sid and oid parts of the header are filled appropriately by an application program (e.g., a browser). Figure 3 shows the relative position of the service layer in the protocol stack. Also shown are the layers of the stack that are interpreted by the different entities along the path. This should clarify that the service layer lies above the IP layer, and is independent of it. The service layer consists of two sub-layers: the common service gateway layer where only sid’s dictate how objects are forwarded among service clouds; and the service-specific delivery layer where oid’s are used in the forwarding decision (inside a service cloud).

**Service Gateway:** The data plane function of an SG is to forward a service object to an appropriate next-hop on the path to the destined service cloud (either an adjacent S-PoP, or another SG), using the dst sid (or perhaps both dst sid and src sid) and associated service modifier(s). For this purpose, each SG maintains a service routing table (similar to an IP routing table), constructed by participating in the service gateway routing protocol (SGRP), the control plane function of an SG. The service routing table contains mappings from a dst sid (and, if specified, an associated service modifier) to a next-hop SG/S-PoP (specified by IP address). From operational stand point of view, we expect the SGs to be deployed by the Autonomous Systems.

**Service Point-of-Presence:** An S-PoP plays two major roles: 1) it cooperates with SGs to route and forward service objects to/from the service cloud it proxies for; and 2) it cooperates with other S-PoPs in the service cloud to route and forward a service object within the service cloud. The latter role is determined by the service-specific routing protocol and forwarding mechanisms employed by the service cloud. The internal operation of the service cloud will not be addressed here, but an example is discussed in Sect. 4.

**Service Gateway Routing Protocol:** This protocol is responsible for constructing the forwarding (or service routing) tables on all the Service Gateways. The protocol is similar in scope to the Border Gateway Protocol [2] in the sense that it distributes “reachability.” BGP distributes reachability to end network domains identified by prefixes; in contrast, SGRP distributes reachability to service clouds, identified by service id’s. While we use BGP as a starting point in the design of SGRP, we incorporate further design principles that help avoid some of the associated problems: slow convergence, lack of support for traffic engineering, excessive routing churn, scalability, etc. In the rest of this section, we briefly describe the key aspects of SGRP.

At a very high level, SGRP involves three distinct operations: first, when a new S-PoP is deployed, it needs to register with nearby SG(s); this inserts a direct entry in the SG’s forwarding tables; second, the SG that receives the registration can now deliver packets meant for the particular service cloud and this mapping—between the SG and the service id corresponding to the newly deployed S-PoP—needs to be propagated to all the other SG’s; and third, the SG’s exchange topology state messages to construct and maintain a graph of SG’s over which SGRP messages are exchanged. In the following, we discuss each of these distinct operations.

**S-PoP registration and advertisement:** When a new S-PoP of a service cloud is deployed in the Internet, it must announce its presence so that SG’s may begin to direct traffic (specifically service pdu’s) to the said S-PoP. This is done by the S-PoP registering itself with SGs that it is adjacent to. In the registration process, the S-PoP will tell the nearby

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††This is but one possible interpretation. Since the SG does not need to understand the exact semantics of the modifiers, the service cloud can define them appropriately.

††This adjacency is logical and not physical; messages are exchanged over the IP network and might go over multiple router hops. However, it is reasonable to expect that service providers will deploy S-PoP’s near existing SG’s.
SGs about two things: the sid of the service cloud it is prox-
ying, and a set of supported service modifiers. The latter de-
scribe specific capabilities satisfied by the said S-PoP (dis-
tinct S-PoPs may support different capabilities for the same
service). For instance, consider the example of accessing
web content over a cellphone. Clearly, the content will have
to be customized to the (minimal) cellphone interface and
requires client specific behavior from the web server. Ser-
vice modifiers can be used to differentiate between S-PoP’s
that can serve content to cellphones, and those that cannot.
Then, requests originating from cellphones can be directed
to the appropriate servers. Thus, the S-PoP registration cre-
ates a mapping between the SG, the service id of the cloud
and the service modifiers. Service pdu’s will be forwarded
to the S-PoP, by the SG, only if the service modifiers match
the published capabilities.

Importantly, the service modifiers are opaque to the
SGs, i.e., SGs do not associate any semantic meaning with
the registered modifiers. They simply treat them as “pat-
terns,” or regular expressions, that are matched as a con-
tition to forward packets to a particular S-PoP. The single
exception to this case is the null service modifier: this par-
ticular expression matches everything, i.e., any traffic (des-
tined to the service cloud) can be forwarded to an S-PoP that
publishes a null service modifier. This “opaqueness” allows
service providers to associate a range of forwarding behav-
iors using distinct modifiers.

Service reachability propagation: After the initial regis-
tration, the SGs have a forwarding pointer to the local S-PoP.
This information is then disseminated to the other SGs in the
network using service reachability advertisements. SRA’s
are constructed based on the registration information from
the adjacent S-PoPs. Simply, an SRA specifies all the ser-
vice clouds that can be reached via a particular S-PoP. The single
exception to this case is the null service modifier: this par-
ticular expression matches everything, i.e., any traffic (des-
tined to the service cloud) can be forwarded to an S-PoP that
publishes a null service modifier. This “opaqueness” allows
service providers to associate a range of forwarding behav-
iors using distinct modifiers.

Messages and data objects in the service layer, i.e., between SG’s, are forwarded over a logical SG graph; logical because SGs bear IP addresses and
are organized into an overlay network on top of the IP net-
work. SG’s establish adjacencies by exchanging messages
with each other. Note that since these may be over multi-
ple IP hops, the necessary address information may have to
be distributed in other ways: either statically configured or
distributed using BGP announcements. However, once SGs
establish the necessary adjacencies, they exchange topology
state advertisements to construct and maintain the logical
SG graph. The connectivity information described by these
messages will include, in addition to the status of the adja-
cency, attributes describing dynamic properties such as de-
lay, effective bandwidth, etc. Importantly, and in contrast to
BGP, the protocol is soft-state; periodic messages update the
dynamic attributes of the adjacencies.

A very important consideration in designing the proto-
col are the existing commercial relationships between ASes.
A consequence of this is that an SG might have only an
approximate topology map. This may lead to inefficient
choices when the end SG, for a packet being forwarded, is
far away. However, this is less of a concern when S-PoP’s
are widely deployed and there is a good chance of a nearby
S-PoP being available to receive the packets.

4. Example

In this section we use an example, namely multimedia con-
tent distribution, to demonstrate the key features of our ar-
chitecture. This example is particularly relevant because the
service provider must support a range of service-types and
object instances to be delivered over the same infrastructure.
In addition, such a service would benefit from flexibility in
the SGs to forward traffic over a set of next-hops. The ser-
vice modifiers that we describe allow just such a capability;
next-hops may be associated with specific modifiers, or al-
ternatively, an SG may forward the same packet to multiple
next-hops (to support swarm style forwarding). In general,
the service provider may dictate specific forwarding behav-
ior (by controlling how service modifiers are announced by
S-PoPs).

Consider a service cloud that provides multimedia con-
tent delivery services. To support such an application effec-
The S-PoPs register with the neighboring SGs of the underlying network domains, and advertise their presence and service capabilities (represented by a set of bit-patterns for the service modifiers it can handle). SGs formulate service reachability advertisements (SRAs) for the service cloud and propagate them (perhaps after filtering or aggregating. From SRAs that it receives, an SG builds entries in its (service) routing table. It should be emphasized that SGs do not need to understand the syntax and semantics of service modifiers defined by individual service clouds. All that is required is the ability to manipulate regular expressions and perform table look-ups.

The cacheability service attribute of content can be embedded in an HTML (or XML) page publicized by the service cloud, and filled accordingly by a client program when a request is generated. Upon receiving a request for a popular object of the service cloud, an SG will forward it to a nearby level-3 S-PoP (a local cache), if one exists. On the other hand, requests for other content will always be forwarded to a level-2 S-PoP, or a level-1 S-PoP if there is one close by. If a request for a popular object cannot be satisfied by a local cache (i.e., a cache miss), the level-3 S-PoP will automatically re-direct the request to a nearby level-2 S-PoP by changing the value of the S-PoP level sub-field from 3 to 2, and forwarding it to a nearby SG. If a level-3 S-PoP fails, a nearby SG, upon learning of the failure, will cease forwarding requests to it, and instead will forward them to a nearby level-2 S-PoP. In case of a level-2 S-PoP failure, an SG can automatically forward requests to another level-2 or level-1 S-PoP. In addition, an overloaded level-2 S-PoP can perform load-balancing by re-directing requests to a lightly-loaded level 2 S-PoP by specifying its S-PoP id (instead of the default value 0) in the S-PoP id sub-field.

## 5. Related Work

We introduce the abstraction of a service layer that takes care of the service delivery from end to end. A somewhat similar notion is described in [4] where the authors advocate a “content layer” that forwards packets based on the resource name (that will be carried in packets). Given that names are generally unconstrained in length, this is somewhat unrealistic. There has been considerable research carried out in the area of using overlay networks to realize applications that are otherwise hard to deploy natively; for instance, multicast [5], [6], multimedia broadcast distribution [7], resilient routing [8] and even content distribution. However, these suffer from scalability and performance issues. Our architecture provides a way to address these shortcomings by means of a underlying substrate that will allow these applications to scale.

The idea of supporting QoS over the Internet by means of overlays is discussed in [9], [10]. Such an idea fits very well into our framework, and suggest possible ways of deploying overlays that require QoS support such as multimedia delivery, VoIP etc.

Perhaps the idea that comes closest to ours is that of

![A three-level S-PoP hierarchy.](image)

### Fig. 4

### Table: S-PoP hierarchy

<table>
<thead>
<tr>
<th>S-PoP level</th>
<th>S-PoP id</th>
<th>Service attribute sub-fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fig. 5

### Service modifier.
In this work, the overlay paradigm is taken further to provide a common “indirection infrastructure” that is interposed between the two parties in a transaction. This indirection decouples the sender and receiver—which enables essential service primitives such as multicast, anycast, host mobility etc. Our own work (in comparison) is broader in scope and addresses a different set of problems.

Our work does not address the issue of how routing and forwarding are performed inside individual service clouds. In fact, this should be seen as a feature of our design: individual clouds are free to design and deploy their own mechanisms internally, completely unfettered by how packets are forwarded externally. We do note however, that there exist several well studied methods that may be adopted for this purpose [12]–[14].

6. Conclusion

In this paper, we highlighted the inadequacies of the current Internet design to satisfy the requirements of emerging Internet applications. The traditional way to satisfy these requirements by using overlay networks. However, as discussed, overlay networks fail to address the design shortcomings of the Internet. While it is important for the future evolution of the Internet to facilitate the deployment of these applications, it is impractical to do away with the current Internet design and start over. The SOI architecture that we describe in this paper provides a compromise between these two choices. It reuses the existing IP infrastructure, but at the same time provides the required abstractions that allow requirements such as availability, robustness, mobility and quality of service to be supported. The framework enables the easy deployment of new applications and services that cannot be supported within the confines of the current Internet design. A significant development since we embarked upon this work is the maturity of the PlanetLab infrastructure, which is intended to be an open research platform for internet design and start over. The SOI architecture that we describe in this paper provides a compromise between these two choices. It reuses the existing IP infrastructure, but at the same time provides the required abstractions that allow requirements such as availability, robustness, mobility and quality of service to be supported. The framework enables the easy deployment of new applications and services that cannot be supported within the confines of the current Internet design. A significant development since we embarked upon this work is the maturity of the PlanetLab infrastructure, which is intended to be an open research platform for deploying and testing internet-scale services [15]. At the present time, we are investigating the possibility of deploying our framework on the PlanetLab network.

References

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