Routing in a Multi-provider Internet

Status of this Memo

Abstract

   This document was prepared by the author on behalf of the Internet
   Architecture Board (IAB). It is offered by the IAB to stimulate
   discussion.

   Over the past few years the Internet has undergone significant
   changes. Among them is the emergence of multiple Network Service
   Providers, where resources that provide Internet-wide IP connectivity
   (routers, links) are controlled by different organizations. This
   document presents some of the issues related to network layer routing
   in a multi-provider Internet, and specifically to the unicast
   routing.

1. Network Service Providers vs Network Service Subscribers

   Within the current routing paradigm the service offered by a provider
   at the network layer (IP) is the set of destinations (hosts) that can
   be reached through the provider. Once a subscriber establishes direct
   connectivity to a provider, the subscriber can in principle reach all
   the destinations reachable through the provider. Since the value of
   the Internet-wide connectivity service offered by a provider
   increases with the number of destinations reachable through the
   provider, providers are motivated to interconnect with each other.

   In principle a provider need not offer the same service (in terms of
   the set of destinations) to all of its subscribers -- for some of the
   subscribers the provider may restrict the services to a subset of the
   destinations reachable through the provider. In fact, for certain
   types of subscribers constrained connectivity could be seen as part
   of the service offered by a provider.

   In a multi-provider environment individual providers may be driven by
   diverse and sometimes even conflicting goals and objectives. Some of
   the providers exist to provide connectivity to only a specific group

of Network Service Subscribers. Other providers place no constraints
on the subscribers that can subscribe to them, as long as the
subscribers pay the fee charged by the providers. Some of the
providers place certain constraints on the reselling of the
connectivity services by organizations (e.g., other providers)
attached to the providers. Some of the providers may be operated by
companies that are subject to specific regulations (e.g., regulated
monopoly), while other providers are completely unregulated. The
scope of geographical coverage among providers varies from a small
region (e.g., county, town) to a country-wide, international, or even
intercontinental.

There is no centralized control over all the providers in the
Internet. The providers do not always coordinate their efforts with
each other, and quite often are in competition with each other.

Despite all the diversity among the providers, the Internet-wide IP
connectivity is realized via Internet-wide distributed routing, which
involves multiple providers, and thus implies certain degree of
cooperation and coordination. Therefore, there is a need to balance
the providers' goals and objectives against the public interest of
Internet-wide connectivity and subscribers' choices. Further work is
needed to understand how to reach the balance.

2. Routing Requirements

   Conceptually routing requirements can be classified into the
   following three categories: source preferences, destination
   preferences, and constraints on transit traffic. Source preferences
   allow an originator of a packet to exert control over the path to a
   destination. Destination preferences allow a destination to exert
   control over the path from a source to the destination. Constraints
   on transit traffic allow a provider to control the traffic that can
   traverse through the resources (routers, links) controlled by the
   provider.

   From a conceptual point of view the requirements over the degree of
   control for source and destination preferences may vary from being
   able to just provide connectivity (regardless of the path), to being
   able to select immediate providers, to more complex scenarios, where
   at the other extreme a subscriber may want to have complete control
   over the path selection.

   From a conceptual point of view the requirements over the degree of
   control for transit traffic may vary from control based only on the
   direct physical connectivity (controlling the set of organizations
   directly connected to the provider), to being able to restrict
   traffic to a particular set of sources or destinations, or a

combination of particular sources and destinations, or even take into
account the paths to/from these sources and/or destinations.

In view of a potentially wide variety of routing requirements, we
need to get a better understanding on the relative practical
importance of various routing requirements. In practice organizations
usually don't formulate their routing requirements in a vacuum. For
example, since the primary role of a provider is to provide services
to a set of subscribers, the provider usually formulates its routing
requirements based on the set of the routing requirements of the
subscribers the provider is expected to serve.

Support for various routing requirements should take into account the
overhead and the scope of the overhead associated with those
requirements. A situation where an organization can unilaterally
impose routing information overhead on other organization (e.g., by
requiring the other organization to maintain an additional routing
information) should be viewed as undesirable. The cost of supporting
a particular routing requirement should not be borne by organizations
that do not benefit from supporting that requirement. Ideally the
routing system should allow to shift the overhead associated with a
particular routing requirement towards the entity that instigates the
requirement (for example, there is a need to carefully balance the
overhead associated with maintaining a state needed for multi-hop
header compression vs carrying explicit forwarding information on a
per packet basis). Organizations with simple routing requirements
shouldn't bear the same routing information overhead as organizations
with complex routing requirements.

A situation where the overhead associated with supporting a
particular routing requirement has to be carried by every entity
(e.g., router, host) within an organization that would like to impose
the requirement could be viewed as undesirable. An organization
should be able to instantiate its routing requirements in a more or
less central fashion, for example by utilizing just some of the
routers.

Even if the scope of the routing information overhead is purely
local, there is a need to perform a careful analysis of the tradeoff
between the potential benefits and the cost associated with
supporting various routing requirements.

3. Encapsulation

The technique of encapsulation allows for the creation of a "virtual"
IP overlay over an existing IP infrastructure. This has certain
implications for the Internet routing system.

In the presence of encapsulation, a provider may no longer be able to
constrain its transit traffic to a particular set of ultimate sources
and/or destinations, as a packet may be encapsulated by some router
along the path, with the original source and/or destination addresses
being "hidden" (via encapsulation) at the Network layer. Likewise,
encapsulation may affect source and destination preferences, as a
source (or a destination) may either (a) be unaware of the
encapsulation, or (b) have little or no control over the encapsulated
segment of a path.

Further work is needed to understand the implications of the overlay
capabilities created via encapsulation on the semantics of routing
requirements, as well as the interaction among the routing
requirements by the entities that form the overlay and the entities
that form the underlying infrastructure.

4. Price Structure and its Impact on Routing

Routing among providers, as well as between providers and subscribers
may be influenced by the price structure employed by the providers,
as well as the usage pattern of the subscribers. A provider can view
routing as a mechanism that allows the provider to exert control over
who can use the provider's services. A subscriber can view routing as
a mechanism that allows the subscriber to exert control over the
price it pays for the Internet connectivity.

The need to exert control has to be carefully balanced against the
cost of the routing mechanisms needed to provide such control. In a
competitive market one could question the viability of a mechanism
whose incremental cost would be greater than the saving recovered by
the mechanism -- competitive pressure or alternate mechanisms are
likely to push providers and subscribers towards choosing the
cheapest mechanism.

5. Scalability

One of the key requirements imposed on the Internet routing is its
ability to scale. In addition to conventional metrics for scalability
(e.g., memory, CPU, bandwidth), we need to take into account
scalability with respect to the human resources required to operate
the system. The need for deployment of CIDR already showed that a
routing scheme that scales linearly with respect to the number of
connected networks, or even to the number of connected organizations
is unacceptable today, and is likely to be unacceptable in the long
term. It is not clear whether routing that scales linearly with the
number of providers is going to be acceptable in the long term.

Scaling implies that the Internet routing system needs to have
powerful mechanisms to provide routing information
aggregation/abstraction.

In the absence of Internet-wide coordination and in the presence of
competition among the providers, the aggregation/abstraction
mechanisms should minimize preconditions as well as limit the amount
of required inter-provider coordination. Ideally the routing system
should allow a provider to control the amount of its local resources
needed to deal with the routing overhead based on considerations that
are purely local to the provider.

One of the side effects of the routing information
aggregation/abstraction is that some of the routing information is
going to be lost. This may impact route optimality and even the
ability to find an existing route. The need for routing information
aggregation/abstraction also implies certain homogeneity of the
information to be aggregated/abstracted. This needs to be counter-
balanced against the potential diversity of routing requirements.

As a way to deal with the routing information loss due to
aggregation/abstraction, we need to explore mechanisms that allow
routing that is based on the on-demand acquisition of subsets of
unaggregated information.

The overhead associated with supporting specific routing requirements
has a direct impact on the overall scalability of the Internet
routing system. We need to get a better understanding of how various
routing requirements impact scalability. When the impact is
significant, and the requirements have practical importance we need
to develop mechanisms that allow the impact to be reduced.

6. Hierarchical Routing

Classless Inter-Domain Routing (CIDR) (RFC1518, RFC1519) that is used
today for scalable Internet-wide routing is based on the technique of
hierarchical routing. Essential to this technique is the assumption
that Network layer addresses assigned to individual entities (e.g.,
hosts, routers) reflect the position of these entities within the
network topology -- addresses are said to be "topologically
significant". With CIDR addresses assigned to most of the individual
sites are expected to reflect providers the sites are connected to --
CIDR uses "provider-based" addresses.

One of the fundamental consequences of using hierarchical routing is
that in order to preserve topological significance of network
addresses, changes in the network topology may need to be accompanied
by the corresponding changes in the addresses. Presence of multiple

providers serving the same geographical area implies that a
subscriber should be able to switch from one provider to another.
Since such a switch implies changes in the Internet topology, it
follows that to retain topological significance of the (provider-
based) addresses within the subscriber, the subscriber has to change
the addresses of all of its entities -- the process known as
"renumbering". There are already tools to facilitate this process --
Dynamic Host Configuration Protocol (DHCP). However, DHCP is not yet
widely deployed. Further work is needed to improve these tools, get
them widely deployed, and to integrate them with Domain Name System
(DNS).

Multi-level hierarchical routing allows for recapturing additional
routing information (routing entropy) due to the mismatch between
addresses and topology at a particular level in the routing hierarchy
at some higher level in the hierarchy (e.g., at an exchange point
among providers). This enables the routing system to contain the
scope of entities impacted by the mismatch. Containing the scope of
entities could be an important factor to facilitate graceful
renumbering. Further work is needed to develop appropriate
deployment strategies to put these capabilities in place.

It is important to emphasize that the requirement to maintain
topologically significant addresses doesn't need to be applied
indiscriminately to all the organizations connected to the Internet
-- hierarchical routing requires that most, but not all addresses be
topologically significant. For a large organization it could be
sufficient if the set of destinations within the organization can be
represented within the Internet routing system as a small number of
address prefixes, even if these address prefixes are independent of
the providers that the organization uses to connect to the Internet
("provider-independent" addresses). The volume of routing information
that a large organization would inject into the Internet routing
system would be comparable to the (aggregated) routing information
associated with a large number of small organizations.

Existence of multiple providers allows a subscriber to be
simultaneously connected to more than one provider (multi-homed
subscribers). CIDR offers several alternatives for handling such
cases. We need to gain more operational experience as well as better
understand tradeoffs associated with the proposed alternatives.

An alternative to CIDR address assignment is to assign addresses
based purely on the geographical location. However, address
assignment that reflects geographical location of an entity implies
that either (a) the Internet topology needs to be made sufficiently
congruent to the geography, or (b) addresses aren't going to be
topologically significant. In the former case we need to understand

the driving forces that would make the topology congruent to the
geography. In the latter case techniques other than hierarchical
routing need to be developed.

7. Routing Information Sharing

While ensuring Internet-wide coordination may be more and more
difficult, as the Internet continues to grow, stability and
consistency of the Internet-wide routing could significantly benefit
if the information about routing requirements of various
organizations could be shared across organizational boundaries. Such
information could be used in a wide variety of situations ranging
from troubleshooting to detecting and eliminating conflicting routing
requirements. The scale of the Internet implies that the information
should be distributed. Work is currently underway to establish
depositories of this information (Routing Registries), as well as to
develop tools that analyze, as well as utilize this information.

8. Summary

In this section we enumerate some of the issues that the IAB thinks
should be brought to the attention of the Internet community.

The following two tasks require the most immediate attention:

   - further work is needed to develop technologies that facilitate
     renumbering

   - further work is needed to investigate feasibility of routing
     information aggregation above the direct (immediate) provider
     level

The following tasks are viewed as medium term:

   - further work is needed to get a better understanding on the
     relative practical importance of various routing requirements

   - further work is needed to understand of how various routing
     requirements impact scalability of the routing system

   - further work is needed to investigate alternatives to
     hierarchical routing

Finally, the following tasks are viewed as long term:

   - further work is needed to understand and utilize the benefits of
     routing information sharing

        - further work is needed to understand the implications of virtual
          overlays created via encapsulation

        - further work is needed to understand how different price
          structures influence routing requirements

        - further work is needed to understand how to balance the
          providers' goals and objectives against the public interest of
          Internet-wide connectivity and subscribers' choices.

9. Conclusions

   This document presents some of the issues related to routing in a
   multi-provider Internet. There are no doubt routing-related areas
   that are not covered in this document. For instance, such areas as
   multicast routing, or routing in the presence of mobile hosts, or
   routing in the presence of a large shared media (e.g., ATM) aren't
   discussed here. Further work is needed to understand the implications
   of a multi-provider Internet on these areas.

   The impact of multi-provider Internet goes well beyond just routing,
   and percolates into such areas as network management,
   troubleshooting, and others. Further work is needed to assess the
   implications of multi-provider environment on these areas, as well as
   to understand the interaction among all these areas from a system-
   wide perspective.

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Security Considerations

   Security issues are not discussed in this memo.

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