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Application of the Border Gateway Protocol in the Internet

Status of this Memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

Abstract

This document, together with its companion document, "A Border Gateway Protocol 4 (BGP-4)", define an inter-autonomous system routing protocol for the Internet. "A Border Gateway Protocol 4 (BGP-4)" defines the BGP protocol specification, and this document describes the usage of the BGP in the Internet.

Information about the progress of BGP can be monitored and/or reported on the BGP mailing list (bgp@ans.net).

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1. Introduction

This memo describes the use of the Border Gateway Protocol (BGP) [1] in the Internet environment. BGP is an inter-Autonomous System routing protocol. The network reachability information exchanged via BGP provides sufficient information to detect routing loops and enforce routing decisions based on performance preference and policy constraints as outlined in RFC 1104 [2]. In particular, BGP exchanges routing information containing full AS paths and enforces routing policies based on configuration information.

As the Internet has evolved and grown over in recent years, it has become painfully evident that it is soon to face several serious scaling problems. These include:

- Exhaustion of the class-B network address space. One fundamental cause of this problem is the lack of a network class of a size which is appropriate for mid-sized organization; class-C, with a maximum of 254 host addresses, is too small while class-B, which allows up to 65534 addresses, is too large to be densely populated.

- Growth of routing tables in Internet routers are beyond the ability of current software (and people) to effectively manage.

- Eventual exhaustion of the 32-bit IP address space.

It has become clear that the first two of these problems are likely to become critical within the next one to three years. Classless inter-domain routing (CIDR) attempts to deal with these problems by

proposing a mechanism to slow the growth of the routing table and the need for allocating new IP network numbers. It does not attempt to solve the third problem, which is of a more long-term nature, but instead endeavors to ease enough of the short to mid-term difficulties to allow the Internet to continue to function efficiently while progress is made on a longer-term solution.

BGP-4 is an extension of BGP-3 that provides support for routing information aggregation and reduction based on the Classless inter-domain routing architecture (CIDR) [3]. This memo describes the usage of BGP-4 in the Internet.

All of the discussions in this paper are based on the assumption that the Internet is a collection of arbitrarily connected Autonomous Systems. That is, the Internet will be modeled as a general graph whose nodes are AS's and whose edges are connections between pairs of AS's.

The classic definition of an Autonomous System is a set of routers under a single technical administration, using an interior gateway protocol and common metrics to route packets within the AS and using an exterior gateway protocol to route packets to other AS's. Since this classic definition was developed, it has become common for a single AS to use several interior gateway protocols and sometimes several sets of metrics within an AS. The use of the term Autonomous System here stresses the fact that, even when multiple IGPs and metrics are used, the administration of an AS appears to other AS's to have a single coherent interior routing plan and presents a consistent picture of which destinations are reachable through it.

AS's are assumed to be administered by a single administrative entity, at least for the purposes of representation of routing information to systems outside of the AS.

2. BGP Topological Model

When we say that a connection exists between two AS's, we mean two things:

Physical connection: There is a shared Data Link subnetwork between the two AS's, and on this shared subnetwork each AS has at least one border gateway belonging to that AS. Thus the border gateway of each AS can forward packets to the border gateway of the other AS without resorting to Inter-AS or Intra-AS routing.

BGP connection: There is a BGP session between BGP speakers in each of the AS's, and this session communicates those routes that can be used for specific destinations via the advertising AS.

> Throughout this document we place an additional restriction on the BGP speakers that form the BGP connection: they must themselves share the same Data Link subnetwork that their border gateways share. Thus, a BGP session between adjacent AS's requires no support from either Inter-AS or Intra-AS routing. Cases that do not conform to this restriction fall outside the scope of this document.

Thus, at each connection, each AS has one or more BGP speakers and one or more border gateways, and these BGP speakers and border gateways are all located on a shared Data Link subnetwork. Note that BGP speakers do not need to be a border gateway, and vice versa. Paths announced by a BGP speaker of one AS on a given connection are taken to be feasible for each of the border gateways of the other AS on the same shared subnetwork, i.e. indirect neighbors are allowed.

Much of the traffic carried within an AS either originates or terminates at that AS (i.e., either the source IP address or the destination IP address of the IP packet identifies a host internal to that AS). Traffic that fits this description is called "local traffic". Traffic that does not fit this description is called "transit traffic". A major goal of BGP usage is to control the flow of transit traffic.

Based on how a particular AS deals with transit traffic, the AS may now be placed into one of the following categories:

> stub AS: an AS that has only a single connection to one other AS. Naturally, a stub AS only carries local traffic.
>
> multihomed AS: an AS that has connections to more than one other AS, but refuses to carry transit traffic.
>
> transit AS: an AS that has connections to more than one other AS, and is designed (under certain policy restrictions) to carry both transit and local traffic.

Since a full AS path provides an efficient and straightforward way of suppressing routing loops and eliminates the "count-to-infinity" problem associated with some distance vector algorithms, BGP imposes no topological restrictions on the interconnection of AS's.

3. BGP in the Internet

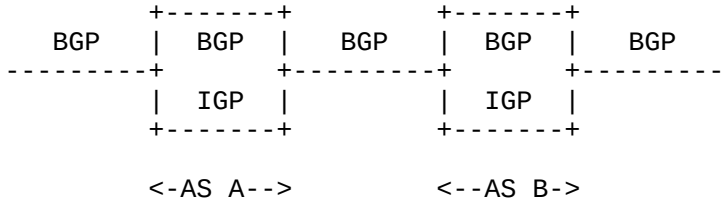
3.1 Topology Considerations

The overall Internet topology may be viewed as an arbitrary interconnection of transit, multihomed, and stub AS's. In order to minimize the impact on the current Internet infrastructure, stub and multihomed AS's need not use BGP. These AS's may run other protocols (e.g., EGP) to exchange reachability information with transit AS's. Transit AS's using BGP will tag this information as having been learned by some method other than BGP. The fact that BGP need not run on stub or multihomed AS's has no negative impact on the overall quality of inter-AS routing for traffic that either destined to or originated from the stub or multihomed AS's in question.

However, it is recommended that BGP be used for stub and multihomed AS's as well. In these situations, BGP will provide an advantage in bandwidth and performance over some of the currently used protocols (such as EGP). In addition, this would reduce the need for the use of default routes and in better choices of Inter-AS routes for multihomed AS's.

3.2 Global Nature of BGP

At a global level, BGP is used to distribute routing information among multiple Autonomous Systems. The information flows can be represented as follows:



This diagram points out that, while BGP alone carries information between AS's, both BGP and an IGP may carry information across an AS. Ensuring consistency of routing information between BGP and an IGP within an AS is a significant issue and is discussed at length later in Appendix A.

3.3 BGP Neighbor Relationships

The Internet is viewed as a set of arbitrarily connected AS's. Routers that communicate directly with each other via BGP are known as BGP speakers. BGP speakers can be located within the same AS or in different AS's. BGP speakers in each AS communicate with each other

to exchange network reachability information based on a set of policies established within each AS. For a given BGP speaker, some other BGP speaker with which the given speaker communicates is referred to as an external peer if the other speaker is in a different AS, while if the other speaker is in the same AS it is referred to as an internal peer.

There can be as many BGP speakers as deemed necessary within an AS. Usually, if an AS has multiple connections to other AS's, multiple BGP speakers are needed. All BGP speakers representing the same AS must give a consistent image of the AS to the outside. This requires that the BGP speakers have consistent routing information among them. These gateways can communicate with each other via BGP or by other means. The policy constraints applied to all BGP speakers within an AS must be consistent. Techniques such as using a tagged IGP (see A.2.2) may be employed to detect possible inconsistencies.

In the case of external peers, the peers must belong to different AS's, but share a common Data Link subnetwork. This common subnetwork should be used to carry the BGP messages between them. The use of BGP across an intervening AS invalidates the AS path information. An Autonomous System number must be used with BGP to specify which Autonomous System the BGP speaker belongs to.

4. Requirements for Route Aggregation

A conformant BGP-4 implementation is required to have the ability to specify when an aggregated route may be generated out of partial routing information. For example, a BGP speaker at the border of an autonomous system (or group of autonomous systems) must be able to generate an aggregated route for a whole set of destination IP addresses (in BGP-4 terminology such a set is called the Network Layer Reachability Information or NLRI) over which it has administrative control (including those addresses it has delegated), even when not all of them are reachable at the same time.

A conformant implementation may provide the capability to specify when an aggregated NLRI may be generated.

A conformant implementation is required to have the ability to specify how NLRI may be de-aggregated.

A conformant implementation is required to support the following options when dealing with overlapping routes:

- Install both the less and the more specific routes

- Install the more specific route only

- Install the less specific route only

- Install neither route

Certain routing policies may depend on the NLRI (e.g. "research" versus "commercial"). Therefore, a BGP speaker that performs route aggregation should be cognizant, if possible, of potential implications on routing policies when aggregating NLRI.

5. Policy Making with BGP

BGP provides the capability for enforcing policies based on various routing preferences and constraints. Policies are not directly encoded in the protocol. Rather, policies are provided to BGP in the form of configuration information.

BGP enforces policies by affecting the selection of paths from multiple alternatives and by controlling the redistribution of routing information. Policies are determined by the AS administration.

Routing policies are related to political, security, or economic considerations. For example, if an AS is unwilling to carry traffic to another AS, it can enforce a policy prohibiting this. The following are examples of routing policies that can be enforced with the use of BGP:

1. A multihomed AS can refuse to act as a transit AS for other AS's. (It does so by only advertising routes to destinations internal to the AS.)

2. A multihomed AS can become a transit AS for a restricted set of adjacent AS's, i.e., some, but not all, AS's can use the multihomed AS as a transit AS. (It does so by advertising its routing information to this set of AS's.)

3. An AS can favor or disfavor the use of certain AS's for carrying transit traffic from itself.

A number of performance-related criteria can be controlled with the use of BGP:

1. An AS can minimize the number of transit AS's. (Shorter AS paths can be preferred over longer ones.)

2. The quality of transit AS's. If an AS determines that two or more AS paths can be used to reach a given destination, that AS can use a variety of means to decide which of the candidate AS

paths it will use. The quality of an AS can be measured by such things as diameter, link speed, capacity, tendency to become congested, and quality of operation. Information about these qualities might be determined by means other than BGP.

3. Preference of internal routes over external routes.

For consistency within an AS, equal cost paths, resulting from combinations of policies and/or normal route selection procedures, must be resolved in a consistent fashion.

Fundamental to BGP is the rule that an AS advertises to its neighboring AS's only those routes that it uses. This rule reflects the "hop-by-hop" routing paradigm generally used by the current Internet.

6. Path Selection with BGP

One of the major tasks of a BGP speaker is to evaluate different paths from itself to a set of destination covered by an address prefix, select the best one, apply appropriate policy constraints, and then advertise it to all of its BGP neighbors. The key issue is how different paths are evaluated and compared. In traditional distance vector protocols (e.g., RIP) there is only one metric (e.g., hop count) associated with a path. As such, comparison of different paths is reduced to simply comparing two numbers. A complication in Inter-AS routing arises from the lack of a universally agreed-upon metric among AS's that can be used to evaluate external paths. Rather, each AS may have its own set of criteria for path evaluation.

A BGP speaker builds a routing database consisting of the set of all feasible paths and the list of destinations (expressed as address prefixes) reachable through each path. For purposes of precise discussion, it's useful to consider the set of feasible paths for a set of destinations associated with a given address prefix. In most cases, we would expect to find only one feasible path. However, when this is not the case, all feasible paths should be maintained, and their maintenance speeds adaptation to the loss of the primary path. Only the primary path at any given time will ever be advertised.

The path selection process can be formalized by defining a complete order over the set of all feasible paths to a set of destinations associated with a given address prefix. One way to define this complete order is to define a function that maps each full AS path to a non-negative integer that denotes the path's degree of preference. Path selection is then reduced to applying this function to all feasible paths and choosing the one with the highest degree of preference.

In actual BGP implementations, the criteria for assigning degree of preferences to a path are specified as configuration information.

The process of assigning a degree of preference to a path can be based on several sources of information:

1. Information explicitly present in the full AS path.

2. A combination of information that can be derived from the full AS path and information outside the scope of BGP (e.g., policy routing constraints provided as configuration information).

Possible criteria for assigning a degree of preference to a path are:

- AS count. Paths with a smaller AS count are generally better.

- Policy considerations. BGP supports policy-based routing based on the controlled distribution of routing information. A BGP speaker may be aware of some policy constraints (both within and outside of its own AS) and do appropriate path selection. Paths that do not comply with policy requirements are not considered further.

- Presence or absence of a certain AS or AS's in the path. By means of information outside the scope of BGP, an AS may know some performance characteristics (e.g., bandwidth, MTU, intra-AS diameter) of certain AS's and may try to avoid or prefer them.

- Path origin. A path learned entirely from BGP (i.e., whose endpoint is internal to the last AS on the path) is generally better than one for which part of the path was learned via EGP or some other means.

- AS path subsets. An AS path that is a subset of a longer AS path to the same destination should be preferred over the longer path. Any problem in the shorter path (such as an outage) will also be a problem in the longer path.

- Link dynamics. Stable paths should be preferred over unstable ones. Note that this criterion must be used in a very careful way to avoid causing unnecessary route fluctuation. Generally, any criteria that depend on dynamic information might cause routing instability and should be treated very carefully.

7. Required set of supported routing policies

Policies are provided to BGP in the form of configuration information. This information is not directly encoded in the protocol. Therefore, BGP can provide support for very complex routing policies. However, it is not required that all BGP implementations support such policies.

We are not attempting to standardize the routing policies that must be supported in every BGP implementation; we strongly encourage all implementors to support the following set of routing policies:

1. BGP implementations should allow an AS to control announcements of BGP-learned routes to adjacent AS's. Implementations should also support such control with at least the granularity of a single address prefix. Implementations should also support such control with the granularity of an autonomous system, where the autonomous system may be either the autonomous system that originated the route, or the autonomous system that advertised the route to the local system (adjacent autonomous system). Care must be taken when a BGP speaker selects a new route that can't be announced to a particular external peer, while the previously selected route was announced to that peer. Specifically, the local system must explicitly indicate to the peer that the previous route is now infeasible.

2. BGP implementations should allow an AS to prefer a particular path to a destination (when more than one path is available). At the minimum an implementation shall support this functionality by allowing to administratively assign a degree of preference to a route based solely on the IP address of the neighbor the route is received from. The allowed range of the assigned degree of preference shall be between 0 and 2^(31) - 1.

3. BGP implementations should allow an AS to ignore routes with certain AS's in the AS_PATH path attribute. Such function can be implemented by using the technique outlined in [2], and by assigning "infinity" as "weights" for such AS's. The route selection process must ignore routes that have "weight" equal to "infinity".

8. Interaction with other exterior routing protocols

The guidelines suggested in this section are consistent with the guidelines presented in [3].

An AS should advertise a minimal aggregate for its internal destinations with respect to the amount of address space that it is actually using. This can be used by administrators of non-BGP 4 AS's to determine how many routes to explode from a single aggregate.

A route that carries the ATOMIC_AGGREGATE path attribute shall not be exported into either BGP-3 or EGP2, unless such an exportation can be accomplished without exploding the NLRI of the route.

8.1 Exchanging information with EGP2

This document suggests the following guidelines for exchanging routing information between BGP-4 and EGP2.

To provide for graceful migration, a BGP speaker may participate in EGP2, as well as in BGP-4. Thus, a BGP speaker may receive IP reachability information by means of EGP2 as well as by means of BGP-4. The information received by EGP2 can be injected into BGP-4 with the ORIGIN path attribute set to 1. Likewise, the information received via BGP-4 can be injected into EGP2 as well. In the latter case, however, one needs to be aware of the potential information explosion when a given IP prefix received from BGP-4 denotes a set of consecutive A/B/C class networks. Injection of BGP-4 received NLRI that denotes IP subnets requires the BGP speaker to inject the corresponding network into EGP2. The local system shall provide mechanisms to control the exchange of reachability information between EGP2 and BGP-4. Specifically, a conformant implementation is required to support all of the following options when injecting BGP-4 received reachability information into EGP2:

- inject default only (0.0.0.0); no export of any other NLRI

- allow controlled deaggregation, but only of specific routes; allow export of non-aggregated NLRI

- allow export of only non-aggregated NLRI

The exchange of routing information via EGP2 between a BGP speaker participating in BGP-4 and a pure EGP2 speaker may occur only at the domain (autonomous system) boundaries.

8.2 Exchanging information with BGP-3

This document suggests the following guidelines for exchanging routing information between BGP-4 and BGP-3.

To provide for graceful migration, a BGP speaker may participate in BGP-3, as well as in BGP-4. Thus, a BGP speaker may receive IP

reachability information by means of BGP-3, as well as by means of BGP-4.

A BGP speaker may inject the information received by BGP-4 into BGP-3 as follows.

If an AS_PATH attribute of a BGP-4 route carries AS_SET path segments, then the AS_PATH attribute of the BGP-3 route shall be constructed by treating the AS_SET segments as AS_SEQUENCE segments, with the resulting AS_PATH being a single AS_SEQUENCE. While this procedure loses set/sequence information, it doesn't affect protection for routing loops suppression, but may affect policies, if the policies are based on the content or ordering of the AS_PATH attribute.

While injecting BGP-4 derived NLRI into BGP-3, one needs to be aware of the potential information explosion when a given IP prefix denotes a set of consecutive A/B/C class networks. Injection of BGP-4 derived NLRI that denotes IP subnets requires the BGP speaker to inject the corresponding network into BGP-3. The local system shall provide mechanisms to control the exchange of routing information between BGP-3 and BGP-4. Specifically, a conformant implementation is required to support all of the following options when injecting BGP-4 received routing information into BGP-3:

- inject default only (0.0.0.0), no export of any other NLRI

- allow controlled deaggregation, but only of specific routes; allow export of non-aggregated NLRI

- allow export of only non-aggregated NLRI

The exchange of routing information via BGP-3 between a BGP speaker participating in BGP-4 and a pure BGP-3 speaker may occur only at the autonomous system boundaries. Within a single autonomous system BGP conversations between all the BGP speakers of that autonomous system have to be either BGP-3 or BGP-4, but not a mixture.

9. Operations over Switched Virtual Circuits

When using BGP over Switched Virtual Circuit (SVC) subnetworks it may be desirable to minimize traffic generated by BGP. Specifically, it may be desirable to eliminate traffic associated with periodic KEEPALIVE messages. BGP includes a mechanism for operation over switched virtual circuit (SVC) services which avoids keeping SVCs permanently open and allows it to eliminates periodic sending of KEEPALIVE messages.

This section describes how to operate without periodic KEEPALIVE messages to minimise SVC usage when using an intelligent SVC circuit manager. The proposed scheme may also be used on "permanent" circuits, which support a feature like link quality monitoring or echo request to determine the status of link connectivity.

The mechanism described in this section is suitable only between the BGP speakers that are directly connected over a common virtual circuit.

9.1 Establishing a BGP Connection

The feature is selected by specifying zero Hold Time in the OPEN message.

9.2 Circuit Manager Properties

The circuit manager must have sufficient functionality to be able to compensate for the lack of periodic KEEPALIVE messages:

- It must be able to determine link layer unreachability in a predictable finite period of a failure occurring.
- On determining unreachability it should:
    - start a configurable dead timer (comparable to a typical Hold timer value).
    - attempt to re-establish the Link Layer connection.
- If the dead timer expires it should:
    - send an internal circuit DEAD indication to TCP.
- If the connection is re-established it should:
    - cancel the dead timer.
    - send an internal circuit UP indication to TCP.

9.3 TCP Properties

A small modification must be made to TCP to process internal notifications from the circuit manager:

- DEAD: Flush transmit queue and abort TCP connection.

- UP: Transmit any queued data or allow an outgoing TCP call to proceed.

9.4 Combined Properties

Some implementations may not be able to guarantee that the BGP process and the circuit manager will operate as a single entity; i.e. they can have a separate existence when the other has been stopped or has crashed.

If this is the case, a periodic two-way poll between the BGP process and the circuit manager should be implemented. If the BGP process discovers the circuit manager has gone away it should close all relevant TCP connections. If the circuit manager discovers the BGP process has gone away it should close all its connections associated with the BGP process and reject any further incoming connections.

10. Conclusion

The BGP protocol provides a high degree of control and flexibility for doing interdomain routing while enforcing policy and performance constraints and avoiding routing loops. The guidelines presented here will provide a starting point for using BGP to provide more sophisticated and manageable routing in the Internet as it grows.

Appendix A. The Interaction of BGP and an IGP

This section outlines methods by which BGP can exchange routing information with an IGP. The methods outlined here are not proposed as part of the standard BGP usage at this time. These methods are outlined for information purposes only. Implementors may want to consider these methods when importing IGP information.

This is general information that applies to any generic IGP.

Interaction between BGP and any specific IGP is outside the scope of this section. Methods for specific IGP's should be proposed in separate documents. Methods for specific IGP's could be proposed for standard usage in the future.

Overview

By definition, all transit AS's must be able to carry traffic which originates from and/or is destined to locations outside of that AS. This requires a certain degree of interaction and coordination between BGP and the Interior Gateway Protocol (IGP) used by that particular AS. In general, traffic originating outside of a given AS is going to pass through both interior gateways (gateways that support the IGP only) and border gateways (gateways that support both the IGP and BGP). All interior gateways receive information about external routes from one or more of the border gateways of the AS via the IGP.

Depending on the mechanism used to propagate BGP information within a given AS, special care must be taken to ensure consistency between BGP and the IGP, since changes in state are likely to propagate at different rates across the AS. There may be a time window between the moment when some border gateway (A) receives new BGP routing information which was originated from another border gateway (B) within the same AS, and the moment the IGP within this AS is capable of routing transit traffic to that border gateway (B). During that time window, either incorrect routing or "black holes" can occur.

In order to minimize such routing problems, border gateway (A) should not advertise to any of its external peers a route to some set of exterior destinations associated with a given address prefix X via border gateway (B) until all the interior gateways within the AS are ready to route traffic destined to these destinations via the correct exit border gateway (B). In other words, interior routing should converge on the proper exit gateway before/advertising routes via that exit gateway to external peers.

A.2 Methods for Achieving Stable Interactions

The following discussion outlines several techniques capable of achieving stable interactions between BGP and the IGP within an Autonomous System.

A.2.1 Propagation of BGP Information via the IGP

While BGP can provide its own mechanism for carrying BGP information within an AS, one can also use an IGP to transport this information, as long as the IGP supports complete flooding of routing information (providing the mechanism to distribute the BGP information) and one pass convergence (making the mechanism effectively atomic). If an IGP is used to carry BGP information, then the period of desynchronization described earlier does not occur at all, since BGP information propagates within the AS synchronously with the IGP, and the IGP converges more or less simultaneously with the arrival of the new routing information. Note that the IGP only carries BGP information and should not interpret or process this information.

A.2.2 Tagged Interior Gateway Protocol

Certain IGPs can tag routes exterior to an AS with the identity of their exit points while propagating them within the AS. Each border gateway should use identical tags for announcing exterior routing information (received via BGP) both into the IGP and when propagating this information to other internal peers (peers within the same AS). Tags generated by a border gateway must uniquely identify that particular border gateway--different border gateways must use different tags.

All Border Gateways within a single AS must observe the following two rules:

1. Information received from an internal peer by a border gateway A declaring a set of destination associated with a given address prefix to be unreachable must immediately be propagated to all of the external peers of A.

2. Information received from an internal peer by a border gateway A about a set of reachable destinations associated with a given address prefix X cannot be propagated to any of the external peers of A unless/until A has an IGP route to the set of destinations covered by X and both the IGP and the BGP routing information have identical tags.

These rules guarantee that no routing information is announced externally unless the IGP is capable of correctly supporting it. It

also avoids some causes of "black holes".

One possible method for tagging BGP and IGP routes within an AS is to use the IP address of the exit border gateway announcing the exterior route into the AS. In this case the "gateway" field in the BGP UPDATE message is used as the tag.

An alternate method for tagging BGP and IGP routes is to have BGP and the IGP agree on a router ID. In this case, the router ID is available to all BGP (version 3 or higher) speakers. Since this ID is already unique it can be used directly as the tag in the IGP.

A.2.3 Encapsulation

Encapsulation provides the simplest (in terms of the interaction between the IGP and BGP) mechanism for carrying transit traffic across the AS. In this approach, transit traffic is encapsulated within an IP datagram addressed to the exit gateway. The only requirement imposed on the IGP by this approach is that it should be capable of supporting routing between border gateways within the same AS.

The address of the exit gateway A for some exterior destination X is specified in the BGP identifier field of the BGP OPEN message received from gateway A (via BGP) by all other border gateways within the same AS. In order to route traffic to destination X, each border gateway within the AS encapsulates it in datagrams addressed to gateway A. Gateway A then performs decapsulation and forwards the original packet to the proper gateway in another AS.

Since encapsulation does not rely on the IGP to carry exterior routing information, no synchronization between BGP and the IGP is required.

Some means of identifying datagrams containing encapsulated IP, such as an IP protocol type code, must be defined if this method is to be used.

Note that, if a packet to be encapsulated has length that is very close to the MTU, that packet would be fragmented at the gateway that performs encapsulation.

A.2.4 Pervasive BGP

If all routers in an AS are BGP speakers, then there is no need to have any interaction between BGP and an IGP. In such cases, all routers in the AS already have full information of all BGP routes. The IGP is then only used for routing within the AS, and no BGP

routes are imported into the IGP.

For routers to operate in this fashion, they must be able to perform a recursive lookup in their routing table. The first lookup will use a BGP route to establish the exit router, while the second lookup will determine the IGP path to the exit router.

Since the IGP carries no external information in this scenario, all routers in the AS will have converged as soon as all BGP speakers have new information about this route. Since there is no need to delay for the IGP to converge, an implementation may advertise these routes without further delay due to the IGP.

A.2.5 Other Cases

There may be AS's with IGPs which can neither carry BGP information nor tag exterior routes (e.g., RIP). In addition, encapsulation may be either infeasible or undesirable. In such situations, the following two rules must be observed:

1. Information received from an internal peer by a border gateway A declaring a destination to be unreachable must immediately be propagated to all of the external peers of A.

2. Information received from an internal peer by a border gateway A about a reachable destination X cannot be propagated to any of the external peers of A unless A has an IGP route to X and sufficient time has passed for the IGP routes to have converged.

The above rules present necessary (but not sufficient) conditions for propagating BGP routing information to other AS's. In contrast to tagged IGPs, these rules cannot ensure that interior routes to the proper exit gateways are in place before propagating the routes to other AS's.

If the convergence time of an IGP is less than some small value X, then the time window during which the IGP and BGP are unsynchronized is less than X as well, and the whole issue can be ignored at the cost of transient periods (of less than length X) of routing instability. A reasonable value for X is a matter for further study, but X should probably be less than one second.

If the convergence time of an IGP cannot be ignored, a different approach is needed. Mechanisms and techniques which might be appropriate in this situation are subjects for further study.

References

[1] Rekhter Y., and T. Li, "A Border Gateway Protocol 4 (BGP-4), RFC 1771, T.J. Watson Research Center, IBM Corp., cisco Systems, March 1995.

[2] Braun, H-W., "Models of Policy Based Routing", RFC 1104, Merit/NSFNET, June 1989.

[3] Fuller, V., Li, T., Yu, J., and K. Varadhan, "Supernetting: an Address Assignment and Aggregation Strategy", RFC1519, BARRNet, cisco, MERIT, OARnet, September 1993.

Security Considerations

Security issues are not discussed in this memo.

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