                Considerations in Validating the Path in BGP

IESG Note

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   is related to IETF work done in WG RPSEC, but this does not prevent
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Abstract

   This document examines the implications of hop-by-hop forwarding,
   route aggregation, and route filtering on the concept of validation
   within a BGP Autonomous System (AS) Path.

1. Background

   A good deal of thought has gone into, and is currently being given
   to, validating the path to a destination advertised by BGP. The
   purpose of this work is to explain the issues in validating a BGP AS
   Path, in the expectation that it will help in the evaluation of
   schemes seeking to improve path validation. The first section
   defines at least some of the types of questions a BGP speaker
   receiving an update from a peer not in the local autonomous system
   (AS) could ask about the information within the routing update. The
   following sections examine the answers to these questions in
   consideration of specific deployments of BGP.

The examples given in this document are intended to distill
deployments down to their most critical components, making the
examples easier to understand and consider. In many situations, the
specific path taken in the example may not be relevant, but that does
not nullify the principles considered in each example. It has been
suggested that these examples are "red herrings", because they do not
illustrate actual problems with specific policies. On the contrary,
these examples are powerful because they are simple. Any topology in
which one of these example topologies is a subtopology will exhibit
the characteristics explained in this document. Rather than focusing
on a specific topology, then dismissing that single topology as a
"corner case", this document shows the basic issues with assertions
about the AS Path attribute within BGP. These generalized issues can
then be applied to more specific cases.

With the heightened interest in network security, the security of the
information carried within routing systems running BGP, as described
in [RFC4271], is being looked at with great interest. While there
are techniques available for securing the relationship between two
devices exchanging routing protocol information, such as [BGP-MD5],
these techniques do not ensure various aspects of the information
carried within routing protocols are valid or authorized.

The following small internetwork is used to examine the concepts of
validity and authorization within this document, providing
definitions used through the remainder of the document.

    10.1.1.0/24--(AS65000)---(AS65001)--(AS65002)

Assume a BGP speaker in AS65002 has received an advertisement for
10.1.1.0/24 from a BGP speaker in AS65001, with an AS Path of {65000,
65001}.

1.1. Is the Originating AS Authorized to Advertise Reachability to the
      Destination?

The most obvious question the receiving BGP speaker can ask about
this advertisement is whether or not the originating AS, in this case
AS65000, is authorized to advertise the prefix contained within the
advertisement, in this case 10.1.1.0/24. Whether or not a BGP
speaker receiving a route to 10.1.1.0/24 originating in AS65000 can
verify that AS65000 is, indeed, authorized to advertise 10.1.1.0/24
is outside the scope of this document.

1.2. Is the Path Contained in the Advertised Routing Information Valid?

   If a BGP speaker receives an advertisement from a peer outside the
   local autonomous system (AS), the peer sending the update has a path
   to the destination prefix in the update. Specifically, are the
   autonomous systems within the internetwork connected in such a way
   that the receiver, following the AS Path listed in the BGP update
   itself, can reach the originating AS listed in the received AS Path?
   Within this document, this is called path validation.

   Path validation, in the context of this small internetwork, asserts
   that when a BGP speaker in AS65002 receives an advertisement from a
   BGP speaker in AS65001 with the AS Path {65000, 65001}, the speaker
   can assume that AS65001 is attached to the local AS, and that AS65001
   is also attached to AS65000.

1.3. Is the Advertisement Authorized?

   There are at least three senses in which the readvertisement of a
   received advertisement can be authorized in BGP:

   o The transmitter is authorized to advertise the specific routing
      information contained in the route. This treats the routing
      information as a single, atomic unit, regardless of the
      information the route actually contains. A route to 10.1.1.0/24
      and another route to 10.1.0.0/16 are considered completely
      different advertisements of routing information, so an AS may be
      authorized to advertise 10.1.0.0/16 without regard to its
      authorization to advertise 10.1.1.0/24, since these are two
      separate routes. This is called route authorization throughout
      this document.

   o The transmitter is authorized to advertise the specific reachable
      destination(s) contained in the route. This treats the routing
      information as a set of destinations. 10.1.1.0/24 is contained
      within 10.1.0.0/16, and authorization to advertise the latter
      implies authorization to advertise the former. This is called
      reachability authorization throughout this document.

   o The transmitter is authorized to transit traffic to the
      destinations contained within the route. This ties the concepts
      of the route to what the route is used for. If a BGP speaker is
      advertising reachability to 10.1.1.0/24, it is authorized to
      transit traffic to all reachable destinations within 10.1.1.0/24
      along the path advertised. This is called transit authorization
      throughout this document.

There is considerable tension between these three definitions of
authorization; much of this document is built around exploring the
relationships between these different types of authorization, and how
they may, or may not, work in various internetworks. One of the
conclusions reached by this document is that route authorization,
reachability authorization, and transit authorization are often at
odds with each other. Showing one type of authorization to be true
does not show any other types of authorization to be true, and route
authorization is of questionable value because of the intertwined
nature of these three types of authorization in a routing system.

1.4. Will Traffic Forwarded to an Advertising Speaker Follow the
      Described AS Path?

   If a BGP speaker receives an advertisement from a peer not in the
   local AS, will traffic forwarded to the peer advertising the update
   follow the path described in the AS Path? In this document, this is
   called forwarding consistency.

   In terms of the small example internetwork, if a BGP speaker in
   AS65002 receives an advertisement from a peer in AS65001 for the
   destination 10.1.1.0/24, with an AS Path {65000, 65001}, will traffic
   forwarded to the BGP speaker in AS65001 actually be forwarded through
   routers within AS65001, then AS65000, to reach its destination?

1.5. Is a Withdrawing Speaker Authorized to Withdraw the Routing
      Information?

   If an advertisement is withdrawn, the withdrawing BGP peer was
   originally advertising the prefix (or was authorized to advertise the
   prefix). This assertion is out of the scope of this document.

2. Analysis

   To begin, we review some of the concepts of routing, since we need to
   keep these concepts fixed firmly in place while we examine these
   questions. After this, four examples will be undertaken with BGP to
   show the tension between the various types of authorization in a path
   vector routing system.

2.1. A Short Analysis of Routing

   Routing protocols are designed, in short, to discover a set of
   loop-free paths to each reachable destination within a network (or
   internetwork). The loop-free path chosen to reach a specific
   destination may not be the shortest path, and it may not always be

the "best" path (depending on the definition of "best"), but it
should always be a loop-free path, otherwise the routing protocol has
failed.

This sheds some light on the purpose of the path included in a path
vector protocol's routing update: the path is there to prove the path
is loop free, rather than to provide any other information. While
Dijkstra's Sender Policy Framework (SPF) and the Diffusing Update
Algorithm (DUAL) both base their loop-free path calculations on the
cost of a path, path vector protocols, such as BGP, prove a path is
loop free by carrying a list of nodes the advertisement itself has
traversed. BGP specifically uses an AS Path-based mechanism to prove
loop freeness for any given update so each AS along the path may
implement local policy without risking a loop in the routing system
caused by competing metrics.

We need to keep this principle in mind when considering the use of
the path carried in a path-vector protocol, and its use by a
receiving BGP speaker for setting policy or gauging the route's
security level.

2.2. First Example: Manual Intervention in the Path Choice

In the small network:

                +---(AS65002)---+
(AS65000)--(AS65001)   (AS65004)--10.1.1.0/24
                +---(AS65003)---+

A BGP speaker in AS65000 may receive an advertisement from a peer
that 10.1.1.0/24 is reachable along the path {65004, 65002, 65001}.
Based on this information, the BGP speaker may forward packets to its
peer in AS65001, expecting them to take the path described. However,
within AS65001, the network administrator may have configured a
static route making the next hop to 10.1.1.0/24 the edge router with
AS65003.

It's useful to note that while [RFC4271] states: "....we assume that
a BGP speaker advertises to its peers only those routes that it
itself uses...", the definition of the term "use" is rather loose in
all known widely deployed BGP implementations. Rather than meaning:
"A BGP speaker will only advertise destinations the BGP process on
the speaker has installed in the routing table", it generally means:
"A BGP speaker will only advertise destinations that the local
routing table has a matching route installed for, no matter what
process on the local router installed the route". A naive reaction
may be to simply change the BGP specifications and all existing
implementations so a BGP speaker will only advertise a route to a

peer if the BGP process on the router actually installed the route in
the local routing table. This, however, ignores the complex
interactions between interior and exterior gateway protocols, which
most often run on the same device, and the complexities of route
origination.

Although this is an "extreme" example, since we can hardly claim the
information within the routing protocol is actually insufficient, we
still find this example instructive in light of the questions
outlined in Section 1:

o Is the AS Path valid? The AS Path the receiving BGP speaker in
   AS65000 receives from its peer in AS65001, {65004, 65002, 65001),
   does exist, and is valid.

o Is the advertisement authorized? Since we have no knowledge of
   any autonomous system level policy within this network, we have no
   way of answering this question. We can assume that AS65001 has
   both route and reachability authorization, but it is difficult to
   see how transit authorization can be accomplished in this
   situation. Even if the BGP speaker in AS65000 could verify
   AS65001 is authorized to transit AS65002 to reach 10.1.1.0/24,
   this implies nothing about the authorization to transit traffic
   through the path traffic will actually take, which is through
   AS65003.

o Is the AS Path consistent with the forwarding path (does
   forwarding consistency exist)? No, the advertised AS Path is
   {65004, 65002, 65001}, while the actual path is {65004, 65003,
   65001}.

From this example, we can see forwarding consistency is not possible
to validate in a deployed network; just because a BGP speaker
advertises a specific path to reach a given destination, there is no
reason to assume traffic forwarded to the speaker will actually
follow the path advertised. In fact, we can reason this from the
nature of packet-forwarding networks; each router along a path makes
a completely separate decision about where to forward received
traffic. Any router along the path could actually change the path
due to network conditions without notifying, in any way, upstream
routers. Therefore, at any given time, an upstream router may be
forwarding traffic along a path that no longer exists, or is no
longer optimal, and downstream routers could be correcting the
forwarding decision by placing the traffic on another available path
unknown to the upstream router.

As a corollary, we can see that authorizing transit through a
specific AS Path is not possible, either. If the source of a

specific flow cannot know what path the traffic within that flow will
take to reach the destination, then there is no meaningful sense in
which downstream routers can authorize the source to use available
paths for transiting traffic.

2.3. Second Example: An Unintended Reachable Destination

In this internetwork, we assume a single policy: the system
administrator of AS65000 would not like the destination 10.1.1.0/24
to be reachable from any autonomous system beyond AS65001. In other
words, 10.1.1.0/24 should be reachable within AS65001, but not to
autonomous systems connected to AS65001, such as AS65002.

10.1.1.0/24---(AS65000)---(AS65001)---(AS65002)

The system administrator can implement this policy by causing BGP
speakers within AS65000 to advertise 10.1.1.0/24 to peers within
AS65001 with a signal that the BGP speakers in AS65001 should not
readvertise the reachability of this routing information. For
example, BGP speakers in AS65000 could advertise the route to
10.1.1.0/24 with the NO_ADVERTISE community attached, as described in
[RFC4271]. If the BGP speakers in AS65001 are configured to respond
to this community (and we assume they are for the purposes of this
document) correctly, they should accept this advertisement, but not
readvertise reachability to 10.1.1.0/24 into AS65002.

However, unknown to the system administrator of AS65000, AS65001 is
actually advertising a default route to AS65002 with an AS Path of
{65001}, and not a full routing table. If some host within AS65002,
then, originates a packet destined to 10.1.1.1, what will happen?
The packet will be routed according to the default route from AS65002
into AS65001. Routers within AS65001 will forward the packet along
the 10.1.1.0/24 route, eventually forwarding the traffic into
AS65000.

o Is the AS Path valid? This is a difficult question to answer,
   since there are actually two different advertisements in the
   example. From the perspective of the BGP speaker in AS65002
   receiving a default route in an advertisement from a peer in
   AS65001, the AS Path to the default route is valid. However,
   there is no route to 10.1.1.0/24 for the BGP speaker in AS65002 to
   examine for validity, so the question appears to be out of scope
   for this example.

o Is the AS Path consistent with the forwarding path (is there
  forwarding consistency)? From the perspective of a BGP speaker in
  AS65002, traffic forwarded to AS65001 towards a destination within
  10.1.1.0/24 is going to actually terminate within AS65001, since

that is the entire AS Path for the default route. However, this
traffic actually transits AS65001 towards AS65000. Therefore,
forwarding consistency does not exist in this example, in which we
are dealing with a case of aggregation, and as Section 9.1.4 of
[RFC4271], in reference to aggregated routing information, states:
"Forwarding along such a route does not guarantee that IP packets
will actually traverse only ASes listed in the AS_PATH attribute
of the route".

2.3.1. Advertisement Authorization

   Is the advertisement authorized? This example higlights the tension
   between the three different types of authorization. The three
   following sections discuss issues with different advertisements
   AS65001 may send to AS65002.

2.3.1.1. Valid Unauthorized Aggregates

   The first issue that comes up in this example is the case where there
   is no expectation of authorization for aggregation. The most common
   example of this is the advertising and accepting of the default route
   (0/0). This is a common practice typically done by agreement between
   the two parties. Obviously, there is not an authorization process
   for such an advertisement. This advertisement may extend
   reachability beyond the originator's intention (along the lines of
   the previous example). It may cause packets to take paths not known
   by the sender (since the path on 0/0 is simply the advertising AS).
   It may violate other security constraints. This places limits on the
   power and applicability of efforts to secure the AS path and AS
   policies. It does not vitiate the underlying value in such efforts.

2.3.1.2. Owner Aggregation

   In the current instantiation of IP address allocation, an AS may
   receive authorization to advertise 10.1.0.0/16, for instance, and may
   authorize some other party to use (or own) 10.1.1.0/24, a subblock of
   the space authorized. This is called a suballocation.

   For instance, in this example, if AS65001 were authorized to
   originate 10.1.0.0/16, it could advertise 10.1.0.0/16 towards
   AS65002, rather than a default route. Assume there is some form of
   authorization mechanism AS65002 can consult to verify AS65001 is
   authorized to advertise 10.1.0.0/16. In this case, AS65002 could
   examine the authorization of AS65001 to originate 10.1.0.0/16, and
   assume that if AS65002 is authorized to advertise 10.1.0.0/16, it is
   also authorized to transit traffic towards every possible subblock of
   (every destination within) 10.1.0.0/16. To put this in more distinct
   terms:

o AS65002 verifies route authorization by examining the
   authorization of AS65001 to advertise 10.1.0.0/16.

o AS65002 assumes destination authorization, that AS65001 has the
   authorization to advertise every possible subblock of 10.1.0.0/16,
   because AS65001 is authorized to advertise 10.1.0.0/16.

o AS65002 assumes transit authorization, that AS65001 has the
   authorization to transit traffic to every possible subblock of
   10.1.0.0/16, because AS65001 is authorized to advertise
   10.1.0.0/16.

From the example given, however, it is obvious route authorization
does not equal destination or transit authorization. While AS65001
does have route authorization to advertise 10.1.0.0/16, it does not
have destination authorization to advertise 10.1.1.0/24, nor transit
authorization for destinations with 10.1.1.0/24.

The naive reply to this would be to simply state that destination and
transit authorization should not be assumed from route authorization.
However, the problem is not that simple to resolve. The assumption
of destination authorization and transit authorization are not
decisions AS65002 actually makes; they are embedded in the way the
routing system works. The route itself, within the design of
routing, carries these implications.

Why does routing intertwine these three types of authorization? Most
simply, because AS65002 does not have any information about subblocks
that are part of 10.1.0.0/16. There is no way for AS65002 to check
for destination and transit authorization because this information is
removed from the system altogether. In order to show destination and
transit authorization, this information must be reinjected into the
routing system in some way.

For instance, considering destination authorization alone, it is
possible to envision a system where AS65001, when suballocating part
of 10.1.0.0/16 to the originator, must also obtain permission to
continue advertising the original address block as an aggregate, to
attempt to resolve this problem. However, this raises some other
issues:

o If the originator did not agree to AS65001 advertising an
   aggregate containing 10.1.1.0/24, then AS65001 would be forced to
   advertise some collection of advertisements not containing the
   suballocated block.

o If AS65001 actually does obtain permission to advertise the
   aggregate, we must find some way to provide AS65002 with

information about this authorization for each possible subblock of
10.1.0.0/16.

In other words, either AS65002 must receive the actual routes for
each suballocation of 10.1.0.0/16, or it must receive some form of
authorization allowing AS65001 to advertise each suballocation of
10.1.0.0/16. This appears to defeat the purpose of aggregation,
rendering routing systems much less scalable than current design
allows. Further, this does not resolve the issue of how AS65002
would actually know what all the suballocations of 10.1.0.0/16
actually are. Some possible solutions could be:

o The suballocator must advertise all suballocations. This could
   potentially expose business relationships and patterns that many
   large commercial providers do not want to expose, and degrades the
   hierarchical nature of suballocation altogether.

o The IP address space must be reconstructed so everyone using IP
   address space will know, based on the construction of the IP
   address space, what subblocks exist. For instance, the longest
   allowed subblock could be set at a /24, and authorization must be
   available for every possible /24 in the address space, either for
   origination, or as part of an aggregate. This sort of solution
   would be an extreme burden on the routing system.

2.3.1.3. Proxy Aggregation

It is also possible for AS65001 to have some form of agreement with
AS65002 to aggregate blocks of address space it does not own towards
AS65002. This might be done to reduce the burden on BGP speakers
within AS65002. This is called proxy aggregation. While proxy
aggregation is rare, it is useful to examine the result of agreed
upon proxy aggregation in this situation.

Assume AS65001 has an advertisement for 10.1.0.0/24 from some unknown
source, and decides to advertise both 10.1.0.0/24 and 10.1.1.0/24 as
10.1.0.0/23 to AS65002. If there exists an agreement for AS65001 to
advertise proxy aggregates to AS65002, the latter will accept the
advertisement regardless of any attached authorization to advertise.
This may represent a security risk for AS65002, but it might be seen
as an acceptable risk considering the trade-offs, from AS65002's
perspective.

The problem is, however, this also impacts the policies of AS65000,
which is originating one of the two routes being aggregated by
AS65001. There is no way for AS65002 to know about this policy, nor
to react to it, and there is actually no incentive for AS65002 to
react to a security threat posed to AS65000, which it has no direct

relationship with. There doesn't appear to be any immediately
available solution to this problem, other than to disallow proxy
aggregation, even between two cooperating autonomous systems.

2.3.2. Implications

The basic problem is that AS65002 assumes when AS65001 advertises an
authorized route containing 10.1.1.0/24, either through a valid
unauthorized aggregate, an owner aggregated route, or a proxy
aggregation, AS65001 also has destination authorization for the
subblock 10.1.1.0/24, and transit authorization for destinations
within 10.1.1.0/24. These are, in fact, invalid assumptions, but
they are tied to the way routing actually works. This shows the
value of route authorization is questionable, unless there is some
way to untie destination and transit authorization from route
advertisements, which are deeply intertwined today.

2.4. Third Example: Following a Specific Path

This example is slightly more complex than the last two. Given the
following small network, assume that A and D have a mutually agreed
upon policy of not allowing traffic to transit B to reach
destinations within 10.1.1.0/25.

```
10.1.1.0/25--A---B---C---D
             |       |   |
             E-------F---G
```

Assume the following:

o A advertises 10.1.1.0/25 to B, and 10.1.1.0/24 to E.

o B advertises 10.1.1.0/25 {B,A} to C.

o E advertises 10.1.1.0/24 {E,A} to F, filtering 10.1.1.0/25 {E,A}
   based on some local policy.

o F advertises 10.1.1.0/24 {F,E,A} to C and to G.

o C advertises 10.1.1.0/24 {C,F,E,A} to D, filtering 10.1.1.0/25
   {B,A} based on some local policy.

o G advertises 10.1.1.0/24 {G,F,E,A} to D.

o D chooses 10.1.1.0/24 {C,F,E,A} over 10.1.1.0/24 {G,F,E,A}.

What path will traffic forwarded to C destined to hosts within
10.1.1.0/25 actually follow?

o D forwards this traffic to C, since its best path is through
   10.1.1.0/24 {C,F,E,A}.

o C forwards this traffic to B, since its best path is through
   10.1.1.0/25 {B,A}.

o B forwards this traffic to A, since its best path is through
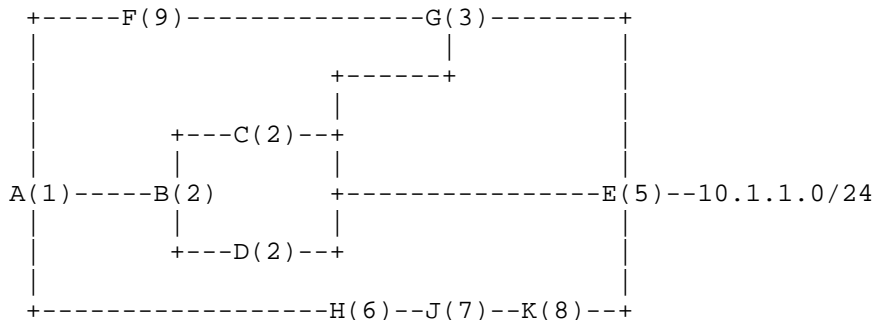   10.1.1.0/25 {A}.

Considering this result:

o Is the AS Path valid? Both {G, F, E, A} and {C, F, E, A} are
   valid AS Paths, so both AS Paths in this example are valid.

o Is the advertisement authorized? Assuming A is authorized to
   advertise 10.1.1.0/24, and all the autonomous systems in the
   example are authorized to readvertise 10.1.1.0/24, the route is
   authorized. However, C does not have destination nor transit
   authorization to 10.1.1.0/25, since B is the best path from C to
   10.1.1.0/25, and D and A have explicit policies not to transit
   this path. In effect, then C does not have destination or transit
   authorization for 10.1.1.0/24, because it contains 10.1.1.0/25.

o Is the AS Path consistent with the forwarding path (is there
   forwarding consistency)? While C is advertising the AS Path {C,
   F, E, A} to D to reach destinations within 10.1.1.0/24, it is
   actually forwarding along a different path to some destinations
   within this advertisement. Forwarding consistency does not exist
   within this internetwork.

In this example, A assumes that D will receive both the advertisement
for 10.1.1.0/24 and the advertisement for 10.1.1.0/25, and will be
able to use the included AS Path to impose their mutually agreed on
policy not to transit B. Information about 10.1.1.0/25, however, is
removed from the routing system by policies outside the knowledge or
control of A or D. The information remaining in the routing system
implies D may correctly route to destinations within 10.1.1.0/25
through C, since 10.1.1.0/25 is contained within 10.1.1.0/24, which C
is legally advertising.

The tension between route authorization, destination authorization,
and transit authorization can be seen clearly in this slightly more
complex example. Route authorization implies destination and transit
authorization in routing, but route authorization does not include
destination or prefix authorization in this example.

2.5. Fourth Example: Interior and Exterior Paths Mismatch

   This is the most complex example we will cover in this document. It
   can be argued that the configuration described in this example is a
   misconfiguration, but we have chosen this example for its simplicity,
   as an illustration of the complexity of the interaction between
   interior and exterior gateway protocols within an autonomous system.
   BGP route reflectors, particularly when configured in a hierarchy,
   provide many examples of forwarding inconsistency, but they are much
   more complex than this small example.

```
   +-----F(9)---------------G(3)--------+
   |                  |                 |
   |               +------+             |
   |               |                    |
   |        +---C(2)--+                  |
   |        |         |                  |
A(1)-----B(2)       +---------------E(5)--10.1.1.0/24
   |        |         |                  |
   |        +---D(2)--+                  |
   |                                     |
   +-----------------H(6)--J(7)--K(8)--+
```

   In this diagram, each router is labeled, with the AS in which it is
   contained, in parenthesis following the router label. As its best
   path to 10.1.1.0/24:

      o Router E is using its local (intra-AS) path.

      o Router C is using the path through AS3.

      o Router D is using the path through Router E.

      o Router B is using the path through Router E.

   Examining the case of Router B more closely, however, we discover
   that while Router B prefers the path it has learned from Router E,
   that path has been advertised with a next hop of Router E itself.
   However, Router B's best path to this next hop (i.e., Router E), as
   determined by the interior routing protocol, is actually through
   Router C. Thus, Router B advertises the path {2, 5} to Router A, but
   traffic actually follows the path {2, 3, 5} when Router B receives
   it.

   The system administrator of AS1 has determined there is an attacker
   in AS3, and has set the policy on router A to avoid any route with
   AS3 in the AS Path. So, beginning with this rule, it discards the
   path learned from AS9. It now examines the two remaining paths,

learned from AS2 (B) and AS6, and determines the best path is {2, 5},
through AS2 (B). However, unknown to A, AS2 (B) is also connected to
AS3, and is transiting traffic to AS5 via the path {2, 3, 5}.

Returning to our questions:

o Is the AS Path valid? The AS Path {2, 3, 5} is a valid AS Path.

o Is the route authorized? Assuming each AS along the path is
   authorized to originate, or readvertise, 10.1.1.0/24, the route is
   authorized. Destination authorization is also clear in this
   situation, since 10.1.1.0/24 is the single destination throughout
   the example. Transit authorization is a little more difficult to
   determine, since the traffic doesn't actually flow along the AS
   Path contained in the routing advertisement. It's impossible to
   claim the AS Path {2,3,5} is a valid path from either the route
   originator or the traffic originator, since that AS Path is not
   the AS Path advertised. Essentially, Router E assumes transit
   authorization from route authorization, when there is no way to
   determine that AS3 is actually authorized to transit traffic to
   10.1.1.0/24.

o Is the AS Path consistent with the forwarding path (is there
   forwarding consistency)? The advertised AS Path is {2, 5}, while
   the traffic forwarded to the destination actually transits {2, 3,
   5}. Forwarding is not consistent in this example.

3. Summary

   The examples given in this document are not the only possible
   examples of forwarding that is inconsistent with the advertised AS
   Path; [ROUTINGLOGIC] also provides some examples, as well.
   [ASTRACEROUTE] provides some interesting background on the practical
   impact of forwarding that is inconsistent with the advertised AS
   Path, in the context of attempting to trace the actual path of
   packets through a large internetwork, running BGP as an exterior
   gateway protocol.

   Routing strongly intertwines the concepts of route authorization,
   destination authorization, and transit authorization. If a BGP
   speaker is authorized to advertise a specific route, routing assumes
   that it is also authorized to advertise every possible subblock
   within the destination prefix, and the advertiser is authorized to
   transit packets to every destination within the route. By surveying
   these examples, we see that route authorization does not, in fact,
   equal destination authorization or transit authorization, calling
   into question the value of route authorization.

There are no easy or obviously scalable solutions to this problem.

4. Acknowledgements

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   on this document. We would also like to thank Joel Halpern for his
   work in clarifying many sections of the document, including
   additional text in critical sections.

5. Security Considerations

   This document does not propose any new extensions or additions to
   existing or proposed protocols, and so does not impact the security
   of any protocol.

6. Informative References

   [ASTRACEROUTE] Feamster, N. and H. Balakrishnan, "Towards an Accurate
                  ASLevel Traceroute Tool", SIGCOMM ACM SIGCOMM, 2003.

   [BGP-MD5]   Heffernan, A., "Protection of BGP Sessions via the TCP
                  MD5 Signature Option", RFC 2385, August 1998.

   [RFC4271]   Rekhter, Y., Ed., Li, T., Ed., and S. Hares, Ed., "A
                  Border Gateway Protocol 4 (BGP-4)", RFC 4271, January
                  2006.

   [ROUTINGLOGIC] Feamster, N. and H. Balakrishnan, "Towards a Logic for
                  Wide Area Routing", SIGCOMM ACM SIGCOMM Worshop on
                  Future Directions in Network Architecture, Germany,
                  August 2003.

   [SOBGP]   White, R., "Architecture and Deployment Considerations
                  for Secure Origin BGP (soBGP)", Work in Progress.

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