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J. Uttaro
AT&T
E. Chen
Cisco Systems
B. Decraene
Orange
J. Scudder
Juniper Networks
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Support for Long-lived BGP Graceful Restart
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Abstract

In this document we introduce a new BGP capability termed "Long-lived Graceful Restart Capability" so that stale routes can be retained for a longer time upon session failure. In addition a new BGP community "LLGR_STALE" is introduced for marking stale routes retained for a longer time. We also specify that such long-lived stale routes be treated as the least-preferred, and their advertisements be limited to BGP speakers that have advertised the new capability. Use of this extension is not advisable in all cases, and we provide guidelines to help determine if it is.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

Historically, routing protocols in general and BGP in particular have been designed with a focus on correctness, where a key part of "correctness" is for each network element's forwarding state to converge toward the current state of the network as quickly as possible. For this reason, the protocol was designed to remove state advertised by routers which went down (from a BGP perspective) as quickly as possible. Over time, this has been relaxed somewhat, notably by BGP Graceful Restart [RFC4724]; however, the paradigm has remained one of attempting to rapidly remove "stale" state from the network.

Over time, two phenomena have arisen that call into question the underlying assumptions of this paradigm. The first is the widespread adoption of tunneled forwarding infrastructures, for example MPLS. Such infrastructures eliminate the risk of some types of forwarding loops that can arise in hop-by-hop forwarding, and thus reduce one of the motivations for strong consistency between forwarding elements. The second is the increasing use of BGP as a transport for data less closely associated with packet forwarding than was originally the case. Examples include the use of BGP for autodiscovery (VPLS [RFC4761]) and filter programming (FLOWSPEC [RFC5575]). In these cases, BGP data takes on a character more akin to configuration than to traditional routing.

The observations above motivate a desire to offer network operators the ability to choose to retain BGP data for a longer period than has hitherto been possible when the BGP control plane fails for some reason. Although the semantics of BGP Graceful Restart [RFC4724] are close to those desired, several gaps exist, most notably in maximum time for which "stale" information can be retained -- Graceful Restart imposes a 4095 second upper bound.

In this document we introduce a new BGP capability termed "Long-lived Graceful Restart Capability" so that stale information can be retained for a longer time across a session reset. We also introduce a new BGP community, "LLGR_STALE", to mark such information. Such stale information is to be treated as least-preferred, and its advertisement limited to BGP speakers that support the new capability. Where possible, we reference the semantics of BGP Graceful Restart [RFC4724] rather than specifying similar semantics in this document.

The expected deployment model for this extension is that it will only be invoked for certain address families. This is discussed in more detail in the Deployment Considerations section (Section 5). When used, its use may be combined with that of traditional Graceful Restart, in which case it is invoked only after the traditional Graceful Restart interval has elapsed, or it may be invoked

immediately. Apart from the potential to greatly extend the timer, the most obvious difference between Long-Lived and traditional Graceful Restart is that in the Long-Lived version, routes are "depreferenced", that is, treated as least-preferred, whereas in the traditional version, route preference is not affected. The design choice to treat Long-Lived Stale routes as least-preferred was informed by the expectation that they might be retained for a (potentially) almost unbounded period of time, whereas in the traditional Graceful Restart case, stale routes are retained for only a brief interval. In the GR case, the tradeoff between advertising new route status (at the cost of routing churn) and not advertising it (at the cost of suboptimal or incorrect route selection) is resolved in favor of not advertising, and in the LLGR case, it is resolved in favor of advertising new state.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Definitions

Depreference, Depreferenced: A route is said to be depreferenced if it has its route selection preference reduced in reaction to some event.

GR: Abbreviation for "Graceful Restart" [RFC4724], also sometimes referred to herein as "conventional Graceful Restart" or "conventional GR" to distinguish it from the "Long-lived Graceful Restart" defined by this document.

Helper: Or "helper router". During Graceful Restart or Long-lived Graceful Restart, the router that detects a session failure and applies the listed procedures. [RFC4724] refers to this as the "receiving speaker".

LLGR: Abbreviation for "Long-lived Graceful Restart".

LLST: Abbreviation for "Long-lived Stale Time".

Route: We use "route" to mean any information encoded as a BGP NLRI and set of path attributes. As discussed above, the connection between such routes and installation of forwarding state may be quite remote.

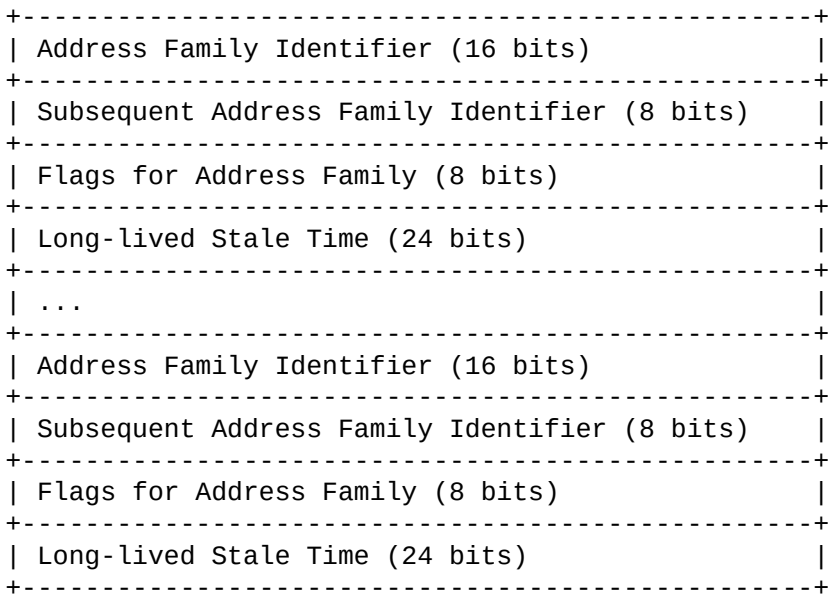
3. Protocol Extensions

A new BGP capability and two new BGP communities are introduced.

3.1. Long-lived Graceful Restart Capability

The "Long-lived Graceful Restart Capability" is a new BGP capability [RFC5492] that can be used by a BGP speaker to indicate its ability to preserve its state according to the procedures of this document. This capability MUST be advertised in conjunction with the Graceful Restart capability [RFC4724], see the "Use of Graceful Restart Capability" section (Section 4.1).

The capability value consists of one or more tuples <AFI, SAFI, Flags, Long-lived Stale Time> as follows:



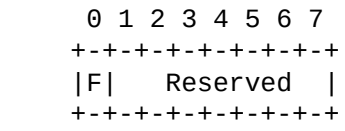
The meaning of the fields are as follows:

Address Family Identifier (AFI), Subsequent Address Family Identifier (SAFI):

The AFI and SAFI, taken in combination, indicate that the BGP speaker has the ability to preserve its forwarding state for the address family during a subsequent BGP restart. Routes may be explicitly associated with a particular AFI and SAFI using the encoding of [RFC4760] or implicitly associated with <AFI=IPv4, SAFI=Unicast> if using the encoding of [RFC4271].

Flags for Address Family:

This field contains bit flags relating to routes that were advertised with the given AFI and SAFI.



The most significant bit is used to indicate whether the state for routes that were advertised with the given AFI and SAFI has indeed been preserved during the previous BGP restart. When set (value 1), the bit indicates that the state has been preserved. This bit is called the "F bit" since it was historically used to indicate preservation of Forwarding State. Use of the F bit is detailed in the Session Resets section (Section 4.2).

The remaining bits are reserved and MUST be set to zero by the sender and ignored by the receiver.

Long-lived Stale Time:

This time (in seconds) specifies how long stale information (for the AFI/SAFI) may be retained (possibly in conjunction with the period specified by the "Restart Time" in the Graceful Restart Capability, if present).

3.2. LLGR_STALE Community

We introduce a new BGP community [RFC1997] "LLGR_STALE" (value: TBD). It can be used to mark stale routes retained for a longer period of time. Such long-lived stale routes are to be handled according to the procedures specified in the Operation section (Section 4).

An implementation MAY allow users to configure policies that accept, reject, or modify routes based on the presence or absence of this community.

3.3. NO_LLGR Community

We introduce a new BGP community "NO_LLGR" (value: TBD). It can be used to mark routes which a BGP speaker does not want treated according to these procedures, as detailed in the Operation section (Section 4).

An implementation MAY allow users to configure policies that accept, reject, or modify routes based on the presence or absence of this community.

4. Operation

A BGP speaker MAY use BGP Capabilities Advertisements [RFC5492] to advertise the "Long-lived Graceful Restart Capability" to indicate its ability to retain state and perform related procedures specified in this document. The setting of the parameters for an AFI/SAFI depends on the properties of the BGP speaker, network scale, and local configuration.

In the presence of the "Long-lived Graceful Restart Capability", the procedures specified in [RFC4724] and [I-D.ietf-idr-bgp-gr-notification] continue to apply unless explicitly revised by this document.

4.1. Use of Graceful Restart Capability

The Graceful Restart capability MUST be advertised in conjunction with the LLGR capability. If it is not so advertised, the LLGR capability MUST be disregarded. The purpose for mandating that both be used in conjunction is to enable reuse of certain base mechanisms that are common to both "flavors", notably origination, collection and processing of EoR, as well as the finite state machine modifications and connection reset logic introduced by GR.

We observe that if support for conventional Graceful Restart is not desired for the session, the conventional GR phase can be skipped by omitting all AFI/SAFI from the GR capability, advertising a Restart Time of zero, or both. The Session Resets section (Section 4.2) discusses the interaction of conventional and long-lived GR.

4.2. Session Resets

BGP Graceful Restart [RFC4724], updated by [I-D.ietf-idr-bgp-gr-notification], defines conditions under which a BGP session can reset and have its associated routes retained. If such a reset occurs for a session for which the LLGR Capability has also been exchanged, the following procedures apply.

If the Graceful Restart Capability that was received does not list all AFI/SAFI supported by the session, then for those non-listed AFI/SAFI the GR "Restart Time" shall be deemed zero. Similarly, if the received LLGR Capability does not list all AFI/SAFI supported by the session, then for those non-listed AFI/SAFI the "Long-lived Stale Time" shall be deemed zero.

The following text in Section 4.2 of the GR specification [RFC4724] no longer applies:

> If the session does not get re-established within the "Restart Time" that the peer advertised previously, the Receiving Speaker MUST delete all the stale routes from the peer that it is retaining.

and the following procedures are specified instead:

After the session goes down and before the session is re-established, the stale routes for an AFI/SAFI MUST be retained. The interval for which they are retained is limited by the sum of the "Restart Time" in the received Graceful Restart Capability and the "Long-lived Stale Time" in the received Long-lived Graceful Restart Capability. These timers MAY be modified by local configuration.

If the value of the "Restart Time" or the "Long-lived Stale Time" is zero, the duration of the corresponding period would be zero seconds. So, for example, if the "Restart Time" is zero and the "Long-lived Stale Time" is nonzero, only the procedures particular to LLGR would apply. Conversely, if the "Long-lived Stale Time" is zero and the "Restart Time" is nonzero, only the procedures of GR would apply. If both are zero, none of these procedures would apply, only those of the base BGP specification (although EoR would still be used as detailed in [RFC4724]). And finally, if both are nonzero, then the procedures would be applied serially -- first those of GR, then those of LLGR. We observe that during the first interval, while the procedures of GR are in effect, route preference would not be affected, while during the second interval, while LLGR procedures are in effect, routes would be treated as least-preferred as specified elsewhere in this document.

Once the "Restart Time" period ends (including the case that the "Restart Time" is zero), the LLGR period is said to have begun and the following procedures MUST be performed:

- The helper router MUST start a timer for the "Long-lived Stale Time". If the timer for the "Long-lived Stale Time" expires before the session is re-established, the helper MUST delete all the stale routes from the neighbor that it is retaining.

- The helper router MUST attach the LLGR_STALE community for the stale routes being retained. Note that this requirement implies that the routes would need to be readvertised, to disseminate the modified community.

- If any of the routes from the peer have been marked with the NO_LLGR community, either as sent by the peer, or as the result of a configured policy, they MUST NOT be retained, but MUST be removed as per the normal operation of [RFC4271].

- The helper router MUST perform the procedures listed under Section 4.3.

Once the session is re-established, the procedures specified in [RFC4724] apply for the stale routes irrespective of whether the stale routes are retained during the "Restart Time" period or the "Long-lived Stale Time" period. However, in the case of consecutive restarts (i.e, the session goes down before the EoR is received) the previously marked stale routes MUST NOT be deleted before the timer for the "Long-lived Stale Time" expires.

Similarly to [RFC4724], once the session is re-established, if the F bit for a specific address family is not set in the newly received LLGR Capability, or if a specific address family is not included in the newly received LLGR Capability, or if the LLGR and accompanying GR Capability are not received in the re-established session at all, then the Helper MUST immediately remove all the stale routes from the peer that it is retaining for that address family.

If a "Long-lived Stale Time" timer is running for a peer, it MUST NOT be updated (other than by manual operator intervention) until the peer has established and synchronized a new session. The session is termed "synchronized" once the EoR has been received from the peer.

The value of the "Long-lived Stale Time" in the capability received from a neighbor MAY be reduced by local configuration.

While the session is down, the expiration of the "Long-lived Stale Time" timer is treated analogously to the expiration of the "Restart Time" timer in Graceful Restart. However, the timer continues to run once the session has re-established. The timer is not stopped, nor updated, until EoR is received from the peer. If the timer expires during synchronization with the peer, any stale routes that the peer has not refreshed, are removed. If the session subsequently resets prior to becoming synchronized, any remaining routes should be removed immediately.

4.3. Processing LLGR_STALE Routes

A BGP speaker that has advertised the "Long-lived Graceful Restart Capability" to a neighbor MUST perform the following upon receiving a route from that neighbor with the "LLGR_STALE" community, or upon attaching the "LLGR_STALE" community itself per Section 4.2:

- Treat the route as the least-preferred in route selection (see below). See the Risks of Depreferencing Routes section (Section 5.2) for a discussion of potential risks inherent in doing this.

- The route SHOULD NOT be advertised to any neighbor from which the Long-lived Graceful Restart Capability has not been received. The exception is described in the Optional Partial Deployment Procedure section (Section 4.7). Note that this requirement implies that such routes should be withdrawn from any such neighbor.

- The "LLGR_STALE" community MUST NOT be removed when the route is further advertised.

4.4. Route Selection

In this document, when we refer to treating a route as least-preferred, this means the route MUST be treated as less preferred than any other route that is not so treated. When performing route selection between two routes both of which are least-preferred, normal tie-breaking applies. Note that this would only be expected to happen if the only routes available for selection were least-preferred -- in all other cases, such routes would have been eliminated from consideration.

4.5. Multicast VPN

If LLGR is being used in a network that carries Multicast VPN (MVPN) traffic ([RFC6513],[RFC6514]), special considerations apply.

[RFC6513] defines the notion of the "Upstream PE" and the "Upstream Multicast Hop" (UMH) for a particular multicast flow. To determine the Upstream PE and/or the UMH for a particular flow, a particular set of comparable BGP routes (the "UMH-eligible" routes for that flow, as defined in [RFC6513]) is considered, and the "best" one (according to the BGP bestpath selection algorithm) is chosen. The UMH-eligible routes are routes with AFI/SAFI 1/1, 1/2, 2/1, or 2/2. When a router detects a change in the Upstream PE or UMH for a given flow, the router may modify its data plane state for that flow. For example, the router may begin to discard any packets of the flow that

it believes have arrived from the previously chosen Upstream PE or UMH. The assumption is that the newly chosen Upstream PE and/or UMH will make the corresponding changes, if necessary, to their own data plane states. In addition, if a router detects a change in the Uptream PE or UMH for a given flow, it may originate or readvertise (with different attributes) certain of the BGP MCAST-VPN routes (routes with SAFI 5) that are defined in [RFC6514]. The assumption is that the MCAST-VPN routes will be properly distributed by BGP to other routers that have data plane states for the given flow, i.e., that BGP will converge so that all routers handle the flow in a consistent manner.

However, if detection of a change to the Upstream PE or UMH is based entirely on stale routes, one cannot assume that BGP will converge; rather one must assume that the UMH-eligible routes and the MCAST-VPN routes are not being properly distributed. Since the purpose of the LLGR procedures is to try to keep the data flowing (by "freezing" the data plane states) when the control plane updates are not being properly distributed, it does not seem appropriate to react to changes that are based entirely on stale routes. Therefore, the following rules MUST be applied when a router is computing or recomputing the Upstream PE and/or the UMH for a given multicast flow:

- STALE routes (i.e., UMH-eligible routes with the LLGR_STALE attribute) are less preferable than non-STALE routes.

- If all the UMH-eligible routes for a given flow are STALE, then the Upstream PE and/or UMH for that flow is considered to be "stale".

- If the Upstream PE or UMH for a given multicast flow has already been determined, and the result of a new computation yields a new Upstream PE or UMH, but the Upstream PE or UMH is "stale" (as defined just above), then the Upstream PE and/or UMH for that flow MUST be left unchanged.

- If the Upstream PE or UMH for a given multicast flow has not already been determined, but is now determined to be STALE, the multicast flow is considered to have no reachable Upstream PE and/or UMH.

[RFC6514] also defines a set of route types with SAFI 5 ("MCAST-VPN" routes). LLGR can be applied to MCAST-VPN routes. However, the following MCAST-VPN route types require special procedures, as specified in this section:

- Leaf A-D routes

- C-multicast Shared Tree Join routes
- C-multicast Source Tree Join routes

Routes of these three types are always "targeted" to a particular upstream router. Depending on the situation, the targeted router may be the Upstream PE for a given flow or the UMH for a given flow. Alternatively, the targeted router may be determined by choosing the "best" route (according to the BGP bestpath algorithm) from among a set of comparable Intra-AS I-PMSI A-D routes, or from among a set of comparable Inter-AS I-PMSI A-D routes, or from among a set of comparable S-PMSI A-D routes. (See [RFC6513], [RFC6514], [RFC6625], and draft-ietf-mpls-seamless-mcast for details.) Once the target is chosen, it is identified in an IPv4-address-specific Route Target (RT) or an IPv6-address-specific RT that is attached to the route before the route is advertised. If the target for one of these routes changes, the value of the attached RT will also change. This in turn may cause the route to be advertised, readvertised, or withdrawn on specific BGP sessions.

For cases where the targeted router is the Upstream PE or the UMH for a particular flow, the rules given previously in this section apply. For example, if a Leaf A-D route is targeted to a flow's UMH, and all the relevant UMH-eligible routes are stale, the UMH is left unchanged. Thus the Leaf A-D route is not readvertised with a new RT.

In those cases where the targeted router for a given Leaf A-D route is selected by comparing a set of S-PMSI A-D routes, or where the targeted router for a given C-multicast Shared or Source Tree Join route is selected by comparing a set of Inter-AS I-PMSI A-D routes, the following rules MUST be applied:

- STALE routes (i.e., "I/S-PMSI A-D routes" with the LLGR_STALE attribute) are less preferable than non-STALE routes.

- If all the routes being considered are STALE, then the targeted router of the Leaf A-D route or C-multicast Shared or Source Tree Join route MUST NOT be changed.

This prevents a Leaf A-D route or C-multicast route from being targeted to a particular router if the relevant I/S-PMSI A-D routes from that router are stale. Since those routes are stale, it is likely that the Leaf A-D route or C-multicast route would not make it to the targeted router, in which case it is better to maintain the existing data plane states than to make changes that presuppose that the MCAST-VPN routes will be properly distributed.

4.6. Errors

If the LLGR capability is received without an accompanying GR capability, the LLGR capability MUST be ignored, that is, the implementation MUST behave as though no LLGR capability had been received.

4.7. Optional Partial Deployment Procedure

Ideally, all routers in an Autonomous System would support this specification before it was enabled. However, to facilitate incremental deployment, stale routes MAY be advertised to neighbors that have not advertised the Long-lived Graceful Restart Capability under the following conditions:

- The neighbors MUST be internal (IBGP or Confederation) neighbors.
- The NO_EXPORT community [RFC1997] MUST be attached to the stale routes.
- The stale routes MUST have their LOCAL_PREF set to zero. See the Risks of Depreferencing Routes section (Section 5.2) for a discussion of potential risks inherent in doing this.

If this strategy for partial deployment is used, the network operator should set LOCAL_PREF to zero for all LLGR routes throughout the Autonomous System. This trades off a small reduction in flexibility (ordering may not be preserved between competing LLGR routes) for consistency between routers which do, and do not, support this specification. Since consistency of route selection can be important for preventing forwarding loops, the latter consideration dominates.

4.8. Procedures When BGP is the PE-CE Protocol in a VPN

In VPN deployments, for example [RFC4364], BGP is often used as a PE-CE protocol. It may be a practical necessity in such deployments to accommodate interoperation with CEs that cannot easily be upgraded to support specifications such as this one. This leads to a problem: in this specification, we take pains to ensure that "stale" routing information will not leak beyond the perimeter of routers that support these procedures, so that it can be depreferenced as expected, and we provide a workaround (Section 4.7) for the case where one or more IBGP routers are not upgraded. However, in the VPN PE-CE case, the protocol in use is EBGP, and our workaround does not work since it relies on the use of LOCAL_PREF, an IBGP-only path attribute.

We observe that the principal motivation for restricting the propagation of "stale" routing information is the desire to prevent it from spreading without limit once it exits the "safe" perimeter. We further observe that VPN deployments are typically topologically constrained, making this concern moot. For this reason, an implementation MAY advertise stale routes over a PE-CE session, when explicitly configured to do so. That is, the second rule listed in Section 4.3 MAY be disregarded in such cases. All other rules continue to apply. Finally, if this exception is used, the implementation SHOULD by default attach the NO_EXPORT community to the routes in question, as an additional protection against stale routes spreading without limit. Attachment of the NO_EXPORT community MAY be disabled by explicit configuration, to accommodate exceptional cases.

See further discussion in Section 5.1.

5. Deployment Considerations

The deployment considerations discussed in [RFC4724] apply to this document. In addition, network operators are cautioned to carefully consider the potential disadvantages of deploying these procedures for a given AFI/SAFI. Most notably, if used for an AFI/SAFI that conveys traditional reachability information, use of a long-lived stale route could result in a loss of connectivity for the covered prefix. This specification takes pains to mitigate this risk where possible, by making such routes least-preferred and by restricting the scope of such routes to routers that support these procedures (or, optionally, a single Autonomous System, see "Optional Partial Deployment Procedure", above). However, according to the normal rules of IP forwarding a stale more-specific route, that has no non-stale alternate paths available, will still be used instead of a non-stale less-specific route. Networks in which the deployment of these procedures would be especially concerning include those which do not use "tunneled" forwarding (in other words, those using traditional hop-by-hop forwarding).

Implementations MUST NOT enable these procedures by default. They MUST require affirmative configuration per AFI/SAFI in order to enable them.

The procedures of this document do not alter the route resolvability requirement of [RFC4271] Section 9.1.2.1.. Because of this, it will commonly be the case that "stale" IBGP routes will only continue to be used if the router depicted in the next hop remains resolvable, even if its BGP component is down. Details of IGP fault-tolerance strategies are beyond the scope of this document. In addition to the foregoing, it may be advisable to check the viability of the next hop

through other means, see for example [I-D.ietf-idr-bgp-bestpath-selection-criteria]. This may be especially useful in cases where the next hop is known directly at the network layer, notably EBGP.

As discussed in this document, after a BGP session goes down and before the session is re-established, stale routes may be retained for up to two consecutive periods, controlled by the "Restart Time" and the "Long-lived Stale Time", respectively. During the first period routing churn would be prevented but with potential blackholing of traffic. During the second period potential blackholing of traffic may be reduced but routing churn would be visible throughout the network. The setting of the relevant parameters for a particular application should take into account the tradeoffs, the network dynamics and potential failure scenarios. If needed, the first period can be bypassed either by local configuration or by setting the "Restart Time" in the Graceful Restart Capability to zero and/or not listing the AFI/SAFI in that Capability.

The setting of the F bit (and the "Forwarding State" bit of the accompanying GR capability) depends in part on deployment considerations. The F bit can be understood as an indication that the Helper should flush associated routes (if the bit is left clear). As discussed in the Introduction, an important use case for LLGR is for routes that are more akin to configuration than to traditional routing. For such routes, it may make sense to always set the F bit, regardless of other considerations. Likewise, for control-plane-only entities such as dedicated route reflectors, that do not participate in the forwarding plane, it makes sense to always set the F bit. Overall, the rule of thumb is that if loss of state on the restarting router can reasonably be expected to cause a forwarding loop or black hole, the F bit should be set scrupulously according to whether state has been retained. Specifics of when the F bit is, and is not, set is implementation-dependent and may also be controlled by configuration.

5.1. When BGP is the PE-CE Protocol in a VPN

As discussed in Section 4.8, it may be necessary to advertise stale routes to a CE in some VPN deployments, even if the CE does not support this specification. In that case, the network operator configuring their PE to advertise such routes should notify the operator of the CE receiving the routes, and the CE should be configured to depreference the routes. Typical BGP implementations will be able to do this by matching on the LLGR_STALE community, and setting the LOCAL_PREF for matching routes to zero, similar to the procedure described in Section 4.7.

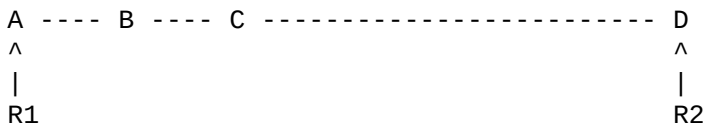
5.2. Risks of Depreferencing Routes

Depreferencing EBGP routes is considered safe, no different from the common practice of applying a routing policy to an EBGP session. However, the same is not always true of IBGP.

Consistent route selection is a fundamental tenet of IBGP correctness and safe operation in hop-by-hop routed networks. When routers within an AS apply different criteria in selecting routes, they can arrive at inconsistent route selections, potentially with the consequence of forming forwarding loops unless some form of tunneled forwarding is used to prevent "core" routers from making a (potentially inconsistent) forwarding decision based on the IP header.

This specification uses the state of a peering session as an input to the selection criteria, depreferencing routes that are associated with a session that has gone down but have not yet aged out. Since different routers within an AS might have different notions as to whether their respective sessions with a given peer are up or down, they might apply different selection criteria to routes from that peer. This could result in a forwarding loop forming between such routers.

For an example of such a forwarding loop, consider the following simple topology:



In this example, A - D are routers with a full mesh of IBGP sessions between them. The short links have unit cost, the long link has cost 5. Routers A and D are AS border routers, each advertising some route, R, into the AS -- these are denoted R1 and R2 in the diagram. In ordinary operation, it can be seen that routers B and C will select R1 for forwarding, and will forward toward A.

Suppose that the session between A and B goes down for some reason, and stays down long enough for LLGR processing to be invoked on B. Then on B, route R1 will be depreferenced, leading to the selection of R2 by B. However, C will continue to prefer R1. It can be seen that in this case, a forwarding loop for packets destined to R would form between B and C. (We note that other forwarding loop scenarios can be constructed for traditional GR, but are generally considered less severe since GR can remain in effect for a much more limited interval.)

The potential benefits of this specification can outweigh the risks discussed above, as long as care is exercised in deployment. The cardinal rule to be followed is, if a given set of routes are being used within an AS for hop-by-hop forwarding, it is NOT RECOMMENDED to enable LLGR procedures. If tunneled forwarding (such as MPLS) is used within the AS, or if routes are being used for purposes other than hop-by-hop forwarding, less caution is needed, though the operator should still carefully consider the consequences of enabling LLGR.

6. Security Considerations

The security implications of the LLGR mechanism defined within in this document are akin to those incurred by the maintenance of stale routing information within a network. This is particularly relevant when considering the maintenance of routing information that is utilised for service segregation - such as MPLS label entries.

For MPLS VPN services, the effectiveness of the traffic isolation between VPNs relies on the correctness of the MPLS labels between ingress and egress PEs. In particular, when an egress PE withdraws a label L1 allocated to a VPN1 route, this label MUST not be assigned to a VPN route of a different VPN until all ingress PEs stop using the old VPN1 route using L1.

Such a corner case may happen today, if the propagation of VPN routes by BGP messages between PEs takes more time than the label re-allocation delay on a PE. Given that we can generally bound worst case BGP propagation time to a few minutes (for example 2-5), the security breach will not occur if PEs are designed to not reallocate a previous used and withdrawn label before a few minutes.

The problem is made worse with BGP GR between PEs as VPN routes can be stalled for a longer period of time (for example 20 minutes).

This is further aggravated by the BGP LLGR extension proposed in this document as VPN routes can be stalled for a much longer period of time (for example 2 hours, 1 day).

Therefore, to avoid VPN breach, before enabling BGP LLGR, SPs needs to check how fast a given label can be reused by a PE, taking into account:

- The load of the BGP route churn on a PE (in term of number of VPN label advertised and churn rate).

- The label allocation policy on the PE (possibly depending upon the size of pool of the VPN labels (which can be restricted by hardware consideration or others MPLS usages), the label allocation scheme (for example per route or per VRF/CE), the re-allocation policy (for example least recently used label...)

Note that [RFC4781] which defines Graceful Restart Mechanism for BGP with MPLS is also applicable to BGP LLGR.

In addition to these considerations, the LLGR mechanism described within this document is considered to be complex to exploit maliciously - in order to inject packets into a topology, there is a requirement to engineer a specific LLGR state between two PE devices, whilst engineering label reallocation to occur in a manner that results in the two topologies overlapping. Such allocation is particularly difficult to engineer (since it is typically an internal mechanism of an LSR).

7. Examples of Operation

For illustrative purposes, we present a few examples of how this specification might be used in practice. These examples are neither exhaustive nor normative.

Consider the following scenario: A border router, ASBR1, has an IBGP peering with a route reflector, RR1, from which it learns routes. It has an EBGP peering with an external peer, EXT, to which it advertises those routes. The external peer has advertised the GR and LLGR Capabilities to ASBR1. ASBR1 is configured to support GR and LLGR on its session with RR1 and EXT. RR1 advertises a GR Restart Time of 1 (second) and a LLST of 3600 (seconds):

Time	Event
t	ASBR1's IBGP session with RR fails. ASBR1 retains RR's routes according to the rules of GR [RFC4724]
t+1	GR Restart Time expires. ASBR1 transitions RR's routes to long-lived stale by attaching the LLGR_STALE community and depreferencing them.

	However, since it has no backup routes, it continues to make use of them. It re-announces them to EXT with the LLGR_STALE community attached.	
t+1+3600	LLST expires. ASBR1 removes RR's stale routes from its own RIB and sends BGP updates to withdraw them from EXT.	

Next, imagine the same scenario but suppose RR1 advertised a GR Restart Time of zero, effectively disabling GR. Equally, ASBR1 could have used local configuration to override RR1's offered Restart Time, setting it to a locally-configured value of zero:

Time	Event
t	ASBR1's IBGP session with RR fails. ASBR1 transitions RR's routes to long-lived stale by attaching the LLGR_STALE community and depreferencing them. However, since it has no backup routes, it continues to make use of them. It re-announces them to EXT with the LLGR_STALE community attached.
t+0+3600	LLST expires. ASBR1 removes RR's stale routes from its own RIB and sends BGP updates to withdraw them from EXT.

Next, imagine the original scenario, but consider that the ASBR1-RR1 session comes back up and becomes synchronized 180 seconds after the failure was detected:

Time	Event
t	ASBR1's IBGP session with RR fails. ASBR1 retains RR's routes according to the rules of GR [RFC4724]
t+1	GR Restart Time expires. ASBR1 transitions RR's routes to long-lived stale by attaching the LLGR_STALE community and depreferencing them. However, since it has no backup routes, it continues to make use of them. It re-announces them to EXT with the LLGR_STALE community attached.

t+1+179	Session is reestablished and resynchronized. ASBR1 removes the LLGR_STALE community from RR1's routes and re-announces them to EXT with the LLGR_STALE community removed.

Finally, imagine the original scenario, but consider that EXT has not advertised the LLGR Capability to ASBR1:

Time	Event
t	ASBR1's IBGP session with RR fails. ASBR1 retains RR's routes according to the rules of GR [RFC4724]
t+1	GR Restart Time expires. ASBR1 transitions RR's routes to long-lived stale by attaching the LLGR_STALE community and depreferencing them. However, since it has no backup routes, it continues to make use of them. It withdraws them from EXT.
t+1+3600	LLST expires. ASBR1 removes RR's stale routes from its own RIB.

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9. Contributors

Clarence Filsfils
Cisco Systems
Brussels 1000
Belgium

Email: cf@cisco.com

Pradosh Mohapatra
Cumulus Networks

Email: pmohapat@cumulusnetworks.com

Yakov Rekhter
Juniper Networks

Email: yakov@juniper.net

Eric Rosen
Cisco Systems

Email: erosen@cisco.com

Rob Shakir
BT

Email: rob.shakir@bt.com

Adam Simpson
Alcatel-Lucent
600 March Road
Ottawa, Ontario K2K 2E6
Canada

Email: adam.simpson@alcatel-lucent.com

10. IANA Considerations

This document defines a new BGP capability - Long-lived Graceful Restart Capability. The Capability Code needs to be assigned by IANA.

This document introduces a new BGP community "LLGR_STALE" for marking the long-lived stale routes, and another community "NO_LLGR" to indicate that stale routes should not be retained. These community values need to be assigned by IANA.

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Authors' Addresses

James Uttaro
AT&T
200 S. Laurel Avenue
Middletown, NJ 07748
USA

Email: ju1738@att.com

Enke Chen
Cisco Systems
170 W. Tasman Drive
San Jose, CA 95134
USA

Email: enkechen@cisco.com

Bruno Decraene
Orange
38-40 Rue de General Leclerc
92794 Issy Moulineaux cedex 9
France

Email: bruno.decraene@orange.com

John G. Scudder
Juniper Networks
1194 N. Mathilda Ave
Sunnyvale, CA 94089
USA

Email: jgs@juniper.net