A Backup Route Aware Routing Protocol – Fast Recovery from Transient Routing Failures

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***Abstract*—As the Internet becomes the critical information infrastructure for both personal and business applications, survivable routing protocols need to be designed that maintain the performance of those services in the presence of failures. This paper examines the survivability of interdoamin routing protocols in the presence of routing failure events, and provides a backup route aware routing protocol that performs non-stop routing in the presence of failures. We demonstrate through simulation its effectiveness in preventing packet losses during transient routing failures.**

I. Introduction

As the Internet starts to carry more and more mission critical services such as Voice-over-IP (VoIP) applications and games, there is a growing demand for the Internet to provide reliable services. Unfortunately, failures are fairly common in the Internet due to various causes such as maintenance, router crash, fiber cuts, and misconfiguration. When such failures occur, routing protocols should be able to quickly find alternate paths to provide forwarding continuity. Nevertheless, widespread routing failures in the Internet have been observed in experimental studies [8], [9]. Previous studies have shown that end-to-end path performance degrades during routing convergence [2], [7], [8], [10], [14], [17]. Furthermore, during several failure events, such as failover and recovery events, in which the reachability of the destinations is not compromised, BGP exhibits short-term routing table inconsistencies caused by the asynchronous route computation. These inconsistencies may cause short-term failures or routing loops [5], [12], [17]. We refer to this transient loss of reachability as *transient routing failures*.

Techniques were proposed [3], [6] to prevent the occurrence of transient routing failures. Bonaventure et al [3] propose a solution using pre-established protection tunnels to reroute traffic during failures. This approach is appropriate for resolving the problem of transient routing failures occurring within an AS. However, preventing transient routing failures across several ASes is more challenging and expensive. A more recent method, R-BGP protects data forwarding from failover events by providing recovery paths [6]. The limitation of the protocol is that it only focuses on providing fast recovery from failover on AS level. It does not provide fast recovery for iBGP and does not consider auxiliary failure events associated with recovery events. Our approach, a Backup Route Aware Routing Protocol (BRAP) is a full-fledged protocol that can provide survivable interdomain routing.

Our major contributions are summarized as follows.

- In contrast to existing approach [6], we develop a protocol that integrates several techniques to achieve fast transient failure recovery from various failure events occurring in the Internet, including failover and recovery events. One important feature of our approach is that a router always has at least one alternate path in addition to the best path, which are used to forward packets upon a failure.
- We discuss the practicality of deploying BRAP in a typical BGP system, where routing policies conforming to commercial agreements between ASes and the hierarchical iBGP configurations are deployed.
- We evaluate the effectiveness of our approach using simulation. The results confirm that our approach can help ISPs to achieve non-stop interdomain routing and fast failure recovery.

The remainder of the paper is structured as follows. In Section II we describe traffic disruption due to various transient routing failures. In Section III, we describe BRAP in more detail. In Section IV, we show how to deploy BRAP in a typical BGP system. In Section V, we evaluate the effectiveness and efficiency of BRAP. Section VI presents related works, and we conclude in Section VII.

II. Packet Losses during Transient Routing Failures

In this section, we first define terminology through examples. And then, we illustrate how traffic disruption can happen during various failure events, such as network failure and repair events. In those two kinds of events, the destination is always physically connected with the network.

A. Definitions

BGP is a path vector protocol, in which each BGP router maintains routing information learned from neighbors and advertises the best route to its neighbors. If a router v's best path toward a destination is via router u, u is said to be the *primary neighbor* or *primary router* of v, while v is defined as the *upstream neighbor* of u. A router u is said to be the *backup neighbor* of router v if u is not the primary neighbor of v and u's best path to the same destination does not go through v. If

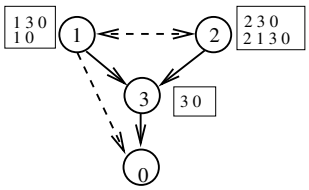
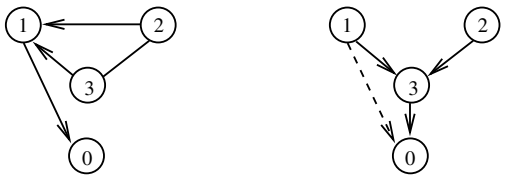


Fig. 1. Example used for illustrating concepts throughout the paper. The box around a node represents its routing table. The order of the paths indicates the local preference ranking for those paths. The solid arrow line represents a link in the best path, while the dashed line denotes a link in an alternative path.



(a) Before a recovery event (b) After a recovery event

Fig. 2. A transient failure experienced by router 2 during the link between router 0 and router 3 is recovered.

a router u is v's primary neighbor with respect to a destination, and v has a path to the destination not via u, the path is defined as a *reverse path* for router u. For example, in Fig. 1, router 3 is the primary neighbor of router 2 and router 1. Router 1 and 2 are the upstream neighbors of router 3. Router 1 and 2 are the backup neighbor of each other. Router 1 has an alternative path (1 0) not via its primary neighbor 3 so that the path is a reverse path.

B. Packet Losses During Failover and Recovery Events

First, we use an example shown in Fig. 1 to demonstrate packet loss during a failover event. Router 1 and 2 consider router 3 as next hop to access the destination. Since router 3 is the primary neighbor of router 1 and 2, router 1 and 2 are not allowed to advertise their best paths back to 3. Thus, router 3 does not realize the existence of the reverse path (1 0) at 1. Now suppose that the link between 3 and the destination fails. In this case, router 3 loses connection to the destination. In order to find other available paths, router 3 has to send a withdrawal message to activate 1 to select the reverse path. Before router 3 receives the new path from 1, it temporarily loses its connection to the destination.

We consider another example shown in Fig. 2 to demonstrate packet loss during a link repair event. In Fig. 2(a), router 1 uses the direct path (1 0) as its best route, and router 2 and 3 use the paths (2 1 0) and (3 1 0) as their best paths, respectively. Suppose that once the link between router 3 and 0 is recovered, router 3 switches to the direct path (3 0), and then propagates the path to 1 and 2. Suppose that router 1 will switch to the recovery path (1 3 0) as shown in Fig. 2(b). Suppose that according to their routing policy, router 1, 2 and 3 cannot propagate the path learned from one router to another. As a result, router 1 has to send a withdrawal message to 2 to withdraw its previous announced route. If the withdrawal message arrives at 2 earlier than the recovery path (2 3 0) sent by 3, router 2 will temporarily lose its connection to the destination. In addition, packet loss caused by a link recovery event can occur among iBGP routers. The temporary loss of reachability to a destination is due to the iBGP constraint, i.e., a route received from an iBGP router cannot be transited to another iBGP router.

III. Routing with Backup Route Information

In this section, we present BRAP in detail. We start by providing an overview of our approach. Then, we describe the update messages, route computation and packet forwarding procedures.

A. Overview

Our objective is to design a survivable routing that can locally provide alternate routes upon the occurrence of failures. To this end, we examine the potential recovery paths that we can add to BGP. The design of BRAP is centered around the possibility of routing with complete route information.

In theorem, the maximum number of possible paths at each BGP router equals to the number of its neighbors. This motivates us to design a full route aware routing protocol, i.e., a routing protocol taking advantage of complete routing information from neighbors. In order to implement full route aware routing, a router should be enabled to advertise an alternate path if its best path is not allowed to advertise due to loop prevention or routing policies. Thus, the general idea for BRAP is as follows:

> *A router should have such capability to advertise following policy compliant paths in addition to the best path: 1) a reverse path to its primary neighbor; and 2) a loop-free alternate path, defined as a temporary backup path, to its upstream neighbors.*

As long as a policy compliant path exists, BRAP can find and use the path to deliver data upon a failure occurring. For example, in Fig. 1, router 1 has reverse path (1 0) and advertises the path to its primary neighbor 3. Thus, router 3 has the best path (3 0) and the backup path (3 1 0). When the link between router 3 and 0 fails, 3 still has the reverse path so that it does not experience any transient routing failure. In Fig. 2, when the link between router 0 and 3 recovers, router 1 will switch to the recovery path and advertise a withdrawal to 2 due to its routing policy. In BRAP, instead of advertising a withdrawal to 2, router 1 advertises an alternative path. As a result, router 2 still has an available path via router 1 to the destination.

B. Identifying Reverse Neighbors

Based on the best path, a BGP router can identify its primary neighbor and backup neighbor. The primary neighbor is the next hop of the best path. If a neighbor provides an alternate path, the neighbor is characterized as a backup neighbor. However, there is no mechanism for a BGP router to know its upstream neighbor. In BRAP, we use an Alternate Route Update message (ARU) containing a reverse path to identify a router's upstream neighbor and reverse neighbor. A router

u can identify its reverse neighbor and upstream neighbor as follows. Suppose that u is the primary neighbor of v. If v has a reverse path, v sends u an ARU message containing the path. Upon receiving the ARU, u considers v as its reverse neighbor. If v does not have any reverse path, or propagation of the reverse path violates v's export policy, v advertises u an ARU message with empty path. Using this message, u can identify v as its upstream neighbor.

C. Route Selection

1) The Reverse Path: BRAP uses BGP's route selection function to select the reverse path among all possible paths except the best path. In particular, the rank of reverse paths should be the least preferable among all available paths. The intuition behind this is that using reverse paths might cause routing loops. Therefore, the reverse paths should be much less frequently used than other paths. Note that the reverse path should be a loop-free path, i.e., it does not contain the primary neighbor's AS number or cluster ID. If there are multiple alternative paths available, the reverse path is not necessarily the disjoint path with the best path, which is different with R-BGP implementation [6]. As we described before, R-BGP only provides failure recovery on AS level. Further, AS paths are too coarse to identify real disjoint paths. We will show the reason that BRAP does not require disjoint path in Section III-F.

2) Temporary Backup Path: Suppose that upon receiving a update, a router switches to the new path containing in the update. However, the new path cannot be advertised to the router's upstream neighbor due to the router's routing policies or iBGP constraint. Instead of advertising a withdrawal to the upstream neighbor, the router generates a new type message, Temporary Route Update message (TRU). A temporary backup path, which is one of the router's available paths and is allowed to advertise to the upstream neighbor, is inserted into the message. In BRAP, the temporary backup path, like the reverse path, is the least preferable among all available paths.

D. Reaction to Topology Changes

Upon receiving a withdrawal message, In BRAP, a router u needs to recompute the best path, and advertises the path if the best path changes, just like a BGP router. Assume that u has at least one reverse path. Once u loses its all paths except the reverse paths, it switches to one of the reverse paths from v. To simplify our analysis, we define the neighbor from which the selected reverse path is learned as the *primary reverse neighbor*. In this case, v is the primary reverse neighbor of u. Router u needs to perform the following tasks:

1) Selecting a new best path among all reverse paths.
2) Advertising the current best path to all neighbors except the primary reverse neighbor v.
3) Generating a reverse path notification message (RPN), which contains current best path, and sending the message to the primary reverse neighbor v.
4) Selecting a new reverse path from a neighbor w.
5) Generating an ARU message, which contains the new reverse path if the path does exist, or an empty path if there is no such path.
6) Advertising the ARU message to previous primary reverse neighbor v.

Here, we design a new message RPN, which is used to notify the primary reverse neighbor to update its routing table once a failover event leads to use the reverse path. The purpose of the ARU message is to notify previous primary reverse neighbor v the new reverse path. As a result, previous primary reverse neighbor v will become primary neighbor, and u becomes a reverse neighbor of v.

Upon receiving the RPN message from u, v needs to perform:

1) Removing the current best path, which is learned from neighbor u.
2) Using the route containing in the RPN message as current best path.
3) Advertising the best path to all neighbors except u.
4) Selecting a new reverse path and advertising an ARU message containing the new reverse path to its current primary neighbor.

Next, we consider the case that router u receives an announcement which contains a new path. Suppose that before receiving the message router u is the primary neighbor of v. Thus, after receiving the new path, u has at least two paths: the new path and previous best path before the event. Suppose that u chooses the new path as its best path, but the path is not allowed to advertise to v due to its routing policies or iBGP constraint. Router u selects a temporary backup path among all paths except the current best path, which is allowed to send to v, and propagates a TRU message containing the path to v. After v receives the TRU, it will forward traffic through the temporary backup path before it obtains a new path. Once u receives a update from v related to the destination, including BGP announcement or ARU, u will send a withdrawal message to v to withdraw the temporary backup path.

E. Packet Forwarding

Using the reverse path or temporary backup path might give rise to a routing loop or violate routing policies or iBGP constraint. In BRAP, we use following techniques:

- Interface-specific forwarding technique, which is described in work [19]. Based on this technique, a router can detect when its primary neighbor uses a reverse path. In particular, the reverse neighbor detects if it is receiving traffic from a neighbor to whom it would forward that traffic. If traffic fails the reverse forwarding check, then the traffic is forwarded along the reverse path. Note that this method can avoid one hop forwarding loop.
- MPLS-based solution. Our previous work [15] has shown that only intradomain routers can experience packet loss during recovery events. Therefore, an intradomain router can use MPLS to forward packets to its primary neighbor

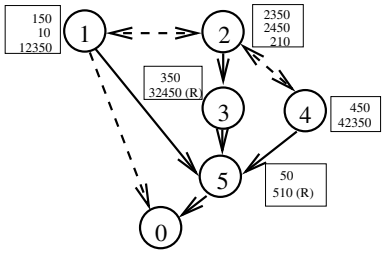


Fig. 3. Example used for illustrating how BRAP can tolerate any link failure in a network even though the reverse path and the best path might share some common links. In a routing table, an entry with "R" represents a reverse path received from a reverse neighbor.

along the temporary backup path. The MPLS protection LSP can be easily established by the primary neighbor and the upstream neighbor because they are in the same AS.

F. Properties of BRAP

BRAP implements backup route aware routing by adding reverse paths and temporary backup paths. Having such path information, BRAP can achieve fast failure recovery according to the following theorem (the proof is shown in the full version of this paper [16]).

Theorem 1 *For a given network with a given destination, if every primary router, which has one or more reverse neighbors, has at least one reverse path, the network can tolerate one single link failure occurring in the network.*

As we described before, BRAP does not require that the reverse paths must be disjoint with the best path. For example, in a network shown in Figure 3, all primary routers 3 and 5 have reverse paths. Even though router 3's reverse path (3 2 4 5 0) and best path (3 5 0) share link (5 0), the network can tolerate any link failure in the network. Note that router 5 only has one reverse path, which is from router 1. Router 3 and 4 cannot advertise their reverse paths to 5 because those paths are not loop-free paths. If router 1 considers path (1 2 3 5 0) as the reverse path, it cannot send the path to 5 because the path fails the loop check. As a result, router 5 does not have any reverse path and the network cannot tolerate link (5 0) failure. In this case, the primary neighbor (router 5) and the upstream neighbor (router 1) could negotiate the reverse path selection. Based on the theorem, we can protect a network, which could be a subset of the whole network, for example, an AS in the Internet. To tolerate any link failure occurring within an AS, we need to make sure that all routers inside the AS satisfy the theorem. In this case, the overhead for having reverse paths within an AS is much small.

IV. Practicality of Deploying BRAP in a Typical BGP System

In this section, we discuss the practicality of deploying BRAP in a typical BGP system. A typical BGP system means that every router in the system applies *typical routing policies* and the hierarchical iBGP configurations are deployed. In particular, the export routing policies are typically guided by the *no-valley* routing policy, in which an AS does not export its provider or peer routes to its providers or peers. The import routing policies are guided by the *prefer-customer* routing policy, in which each AS prefers its customer routes over its peer or provider routes. In a hierarchical iBGP structure, there are route reflectors, and a set of *edge routers*, which are router reflectors' clients.

We first consider deploying BRAP to interdomain routers. In our previous paper [15], we show that only non-tier 1's interdomain routers can experience packet loss during failover events, and no interdomain routers experiences packet loss during recovery events. In the full version of this paper [16], we show that the reverse neighbor of an interdomain router must be a upstream router inside a provider. Thus, an AS can deploy BRAP in its interdomain routers peering with its providers. Since the reverse paths only come from providers' routers, customers are willing to require their providers to provide fast failure recovery service – the reverse paths. At the same time, for the providers, such service is limited to subscribed customers so that they are also willing to advertise their reverse paths.

As we described before, Intradomain routers can experience packet loss during both failover and recovery events. Thus, an AS needs to enable BRAP at its intradomain routers. An AS can take advantage of MPLS or IP tunnels to forward packets when a reverse path or temporary backup path is used, which can be easily implemented inside a network.

V. Evaluation

In this section, we use simulation to measure the performance of BRAP in terms of the number of messages, transient failure duration. We implement BRAP based on the event-driven BGP simulator simBGP [1]. Each router has a random processing delay with uniform distribution between [0.001, 0.01] millisecond. Each link is assigned bandwidth 100MB and a queuing delay uniformly distributed between [0.01, 0.1] millisecond. The MRAI timer for eBGP sessions is set to 30 seconds and that for iBGP sessions is 5 seconds. In our simulator, when a node is ready to send routing message to one of its peer and if the MRAI timer for this peer is not set, we will artificially block the message with a duration uniformly distributed between [0,MRAI]. We also assign 200 msec to each node as the forwarding table updating delay.

The simulations are performed based on the AS level topologies provided by work [13] and router level topologies. That is, an AS consists of both iBGP and eBGP routers. In each simulation, we pick one AS to originate a destination prefix. When every router reaches stable states, we break one of the egress link of the origin AS. Because the ASes in the topologies are densely connected, the AS is still connect to the network, which triggers a failover event. We repeat the operation for every egress link of an AS for 5 times and perform the same process for every AS in a network. Besides, we also investigate the scenarios where the ghost-flushing and EPIC schemes are employed.

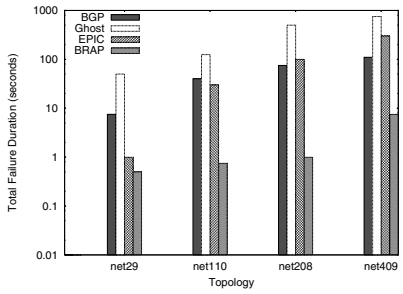


Fig. 4. The duration of transient forwarding failures.

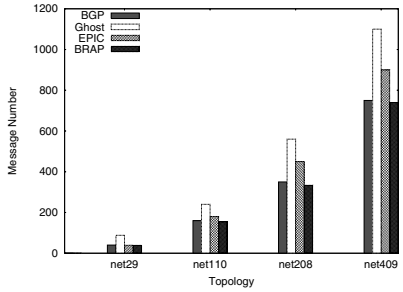


Fig. 5. Number of updates generated by BGP, Ghost, EPIC and BRAP during Failover events

We first compare the duration of transient failure in BRAP, BGP, Ghost and EPIC. We then examine the number of updates generated by them. As shown in Fig. 4, the X axis represents the topology where the simulations are performed. For example, "net 29" means the AS topology contains 29 AS nodes and so on. From Fig. 4, we observer that BRAP indeed provides fast transient failure recovery. Fig. 5 shows the message numbers generated by BRAP, BGP, Ghost and EPIC. As expected, BRAP generates less routing messages than BGP, Ghost and EPIC. From our simulation results, we find that BRAP can significantly accelerate the convergence speed and eliminate transient failures during the convergence process.

VI. Related Work

Previous studies have considered approaches to accelerate BGP route convergence, including ghost-flushing [4], BGP-RCN [11] and EPIC [18]. However, those approaches can not achieve non-stop forwarding, and even exacerbate transient routing failures.

Bonaventure *et. al* propose that a BGP router selectively establish protection tunnels to the relevant routers which can feed alternative routes to these routers in case of routing failures [3]. However, the ability that this approach provides is limited because a router needs to establish a tunnel with a right peer that can provide the alternative path.

Kushman et al [6] propose a mechanism that protects data forwarding from failover events by providing failover paths. The limitation of the proposal is that it only focuses on providing fast recovery upon failover events. None of the protocols we overview above are able to prevent the presence of a wide range of transient routing failures, but are rather focused on a particular failure.

VII. Conclusion

This paper presents a solution to provide a backup route aware routing protocol to fast failure recovery. The heart of our approach is the capability of redirecting traffic to a preestablished path that cannot be disrupted by routing dynamics. By using reverse paths and temporary backup paths, our approach can maximize the number of available paths so that it can provide fast failure recovery and more reliable end-to-end path performance.

Acknowledgments

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