XORP BGP Routing Daemon

Version 0.2

XORP Project
International Computer Science Institute
Berkeley, CA 94704, USA
feedback@xorp.org

March 10, 2003

1 Introduction

This document provides an overview of the XORP BGP Routing Daemon. It is intended to provide a starting point for software developers wishing to modify this software.

A router running BGP takes routes from peer routers, filters them, decides which of the alternative routes is the best, and passes the winner on to the other peers, possibly applying filters before passing the route on.

Our chosen architecture for our BGP implementation emphasizes extensibility and the separable testing of subsystems, rather than high performance or minimal memory footprint. However we believe that the performance and memory usage will be acceptable, even for backbone router implementations.

We implement BGP as a connected pipeline of "routing tables", each performing a specialized task. Figure 1 gives the general overview of classes involved in the core of the BGP process, but excludes the classes involved in handling peerings with peers. Route information flows from left to right in this figure.

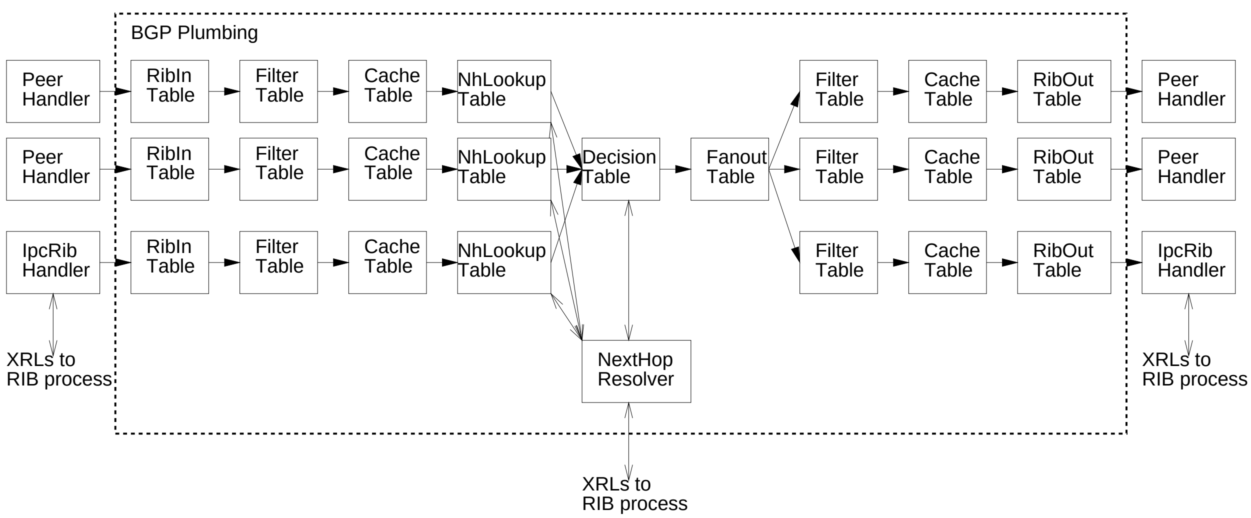


Figure 1: Overview of BGP process

Typically an Update or Withdraw message arrives from a BGP peer, is split up into separate `add_route` or `delete_route` commands by the PeerHandler, and then the update flows through the tables towards the DecisionTable. If the route is better than the best alternative, then it passes through the DecisionTable, and is then fanned out to all the output branches except the one it arrived un. The outgoing PeerHandler then sends the route on to the corresponding BGP peer.

There is one input branch and one corresponding output branch for each BGP peer, plus one branch that handles routes sent to BGP from the XORP RIB, and sends BGP routes to the XORP RIB and hence on to the forwarding engine. The general structure of the RIB branch is identical to that of a peer-related branch, but a special version of the PeerHandler is used.

2 Major BGP Classes

In this section we discuss each of the classes from Figure 1 in turn, before discussing how each BGP peer is handled. Most of these classes are implemented using C++ templates for the address family, so they are capable of handling IPv4 and IPv6 in an identical manner.

2.1 PeerHandler Class

The PeerHandler acts as the interface between the BGP Peer class (which handles BGP peering connections) and all the RouteTables that comprise the BGP plumbing. A single PeerHandler instance receives BGP Update messages coming from the BGP peer and constructs new BGP Update messages to send to that peer.

A BGP Update Message consists of three parts:

- A list of withdrawn route subnets (route prefixes).
- Path Attribute information for announced routes.
- A list of subnets (route prefixes) that are being announced. The Path Attribute information applies to all these subnets.

The PeerHandler splits an incoming update message up, and constructs a series of messages (InternalMessage class) to send to the plumbing.

Each of the withdrawn route subnets is passed to the plumbing using a separate `delete_route` call.

Each of the announced route subnets is passed to the plumbing using a separate `add_route` call, which includes all the Path Attribute information.

On the output side, the PeerHandler receives a series of `add_route`, `delete_route`, or `replace_route` calls. Each batch of calls is for routes that share the same path attribute list. The PeerHandler then constructs an Update Message from each batch, and passes it on to the classes that handle the peering for transmission to the relevant BGP peer router.

In some cases the PeerHandler can receive routes from BGP faster than the connection to the relevant peer can handle them. The PeerHandler can communicate this information back upstream to regulate the flow of changes to a rate that can be accommodated. The actual queuing then happens upstream in the FanoutTable.

Because of the way BGP encodes IPv6 routes, the PeerHandler class handles IPv4 and IPv6 routing information differently.

2.2 RibInTable Class

The RibInTable class is responsible for receiving routes from the PeerHandler and storing them. These are the raw routes, unfiltered and unmodified except for syntactic correctness, as received and decoded from the BGP Peering session.

Because BGP does not indicate in an Update message whether a route is new or merely replaces an existing route, all routes are checked to see if they are already stored in the RibIn. If so, the `add_route` is propagated downstream as a `replace_route`, otherwise it is propagated as an `add_route`.

The RibIn serves several additional purposes:

- It can answer `lookup_route` requests from downstream.
- When a new peer comes up, a route dump is initiated so that the new peer learns all the feasible routes that we know. The RibIn can perform this dump as part of a background task, so as to allow further updates while the dump is taking place.
- When the peer associated with the RibIn goes down, a process to delete all the routes learned from this peer is started. This is done by transferring the RibIn's entire routing table to a new RouteTable called a DeletionTable that is plumbed in directly after the RibIn. The DeletionTable handles the deletion of the routes as a background task, leaving the RibIn ready to cope immediately if the peer comes back up again.
- When the routing information in the XORP RIB changes, the change of IGP metric can change which routes should win the decision process. The RibIn can be told that the routing information associated with the indirect nexthop in a BGP route has changed, and it can initiate a background task that re-sends all the relevant routes downstream as `replace_route` messages, so that the DecisionTable can make its choice again.

The RibIn does not do significant sanity checking on its inputs - it is the responsibility of the receive code in the Peer classes to check that received update messages are syntactically and semantically valid.

The current (Mar 2003) version of XORP stores all routes in the RibIn, irrespective of whether or not they will fail to pass a downstream filter. However, the RibIn has enough information (from the values returned by the `add_route`, `delete_route` and `replace_route` calls it makes downstream) to be able to store only those routes that will not be filtered.

2.3 FilterTable Class

The FilterTable class has one parent (upstream) RouteTable and one child (downstream) RouteTable. It acts as a general purpose filter-bank, passing, modifying, or dropping routing information that travels from parent to child.

A FilterTable can hold many filters. Current filters include:

- **SimpleASFilter:** Drops routes that contain the configured AS in their AS Path.
- **ASPrependFilter:** Prepends the configured AS number to the AS Path of all routes that pass through the filter.
- **NexthopRewriteFilter:** Changes the NextHop attribute of all routes that pass through the filter to the specified value.

- **IBGPLoopFilter:** Drops all routes that we heard through IBGP. This is primarily useful as an outbound filter to an IBGP peer.
- **LocalPrefInsertionFilter:** Inserts the configured value as the BGP Local Preference attribute in all routes that pass through the filter. Typically used on input from an EBGP peer, before route-specific filters.
- **LocalPrefRemovalFilter:** Removes the BGP Local Preference attribute from all routes that pass through the filter. Typically used on output to an EBGP peer.
- **MEDInsertionFilter:** Adds a Multi-exit Descriminator attribute based on the routes IGP metric to each route that passes through the filter. Typically used on output to an EBGP peer. Note that the MED to be inserted will have been added to the route by the DecisionTable, so MEDInsertionFilter cannot be used as an input-branch filter.
- **MEDRemovalFilter:** Removes the Multi-exit Descriminator attribute from all routes that pass through the filter. Typically used just before a MEDInsertionFilter to remove the MED received from the previous AS.

Note that filters are not just for operator configured filtering - they comprise part of the basic BGP processing mechanism.

Typically a FilterTable will receive an InternalMessage from its parent containing a subnet route. All the configured filters will be applied in order to the route. One of three things may happen:

- The route may be dropped by a filter.
- The route may pass through all filters unchanged.
- One or more filters may modify the route. This is done by creating a new copy of the route.

In the last case, the modified route will have the Changed flag set before it is propagated downstream. This flag indicates that no-one upstream is storing a persistent copy of this route, so the downstream tables are responsible for either storing the route or freeing the memory it uses.

Filter implementors should be careful to note that if the route received as input to a filter is already modified, and their filter then drops the route or creates a modified copy of the route, then the old route MUST be freed because no-one else can do so. If the input route is not modified, the filter MUST NOT free the route because it is stored elsewhere.

2.4 CacheTable Class

The CacheTable class has one parent RouteTable and one child RouteTable. Its purpose is to ensure that routes changed by preceding filter-banks are actually stored somewhere. Primarily it is an optimization to prevent the filters from having to be applied every time `lookup_route` is called, but it also simplifies memory management because downstream tables no longer need to be concerned with whether a route needs to be freed or not.

The CacheTable takes as input InternalMessages from its parent, and passes them through downstream to its child. If the route in the message does not have the Changed flag set, then the CacheTable is a no-op. If the route in the message has the Changed flag set, then the CacheTable will store the route (or delete it from storage in the case of `delete_route`). Thus all InputMessages sent downstream have the Changed flag cleared.

A CacheTable in the outgoing branch is flushed (all stored routes deleted) when the peering corresponding to the relevant plumbing branch down. This is because when the peering comes back up, the outgoing branch should restart with no stored state. The incoming branch CacheTable is not explicitly flushed, because the routes will be removed as the DeletionTable gets round to deleting them. Prematurely flushing the input branch CacheTables would potentially result in the DecisionTable seeing inconsistent inputs.

Note that assertion failures in the CacheTable usually indicate that the code upstream is incorrectly propagating changes (for example either a delete with no add, two deletes, or two adds).

2.5 NhLookupTable Class

The BGP decision process implemented in DecisionTable is relatively complex, and takes into account many possible factors including "IGP distance". IGP distance is the IGP routing metric for the route to reach the BGP NextHop (which is often a number of IP hops away in the case of IBGP). Also of interest is whether the BGP NextHop is actually reachable according to the IGP protocols. Because of the multi-process architecture of XORP, BGP does not know the IGP distance or whether the nexthop is reachable. To find out this information, BGP must query the RIB, and this is done by the NextHopResolver class instance. If DecisionTable had to perform this lookup, it would become very complex because it would have to handle suspending the decision process while waiting for results from the RIB. A multi-threaded implementation would solve this problem, but would cause other issues.

To solve these problems we insert an NhLookupTable upstream of the DecisionTable. NhLookupTable queues any updates with NextHop information that the NextHopResolver does not know about, pending the response from the RIB process. Thus by the time an update reaches the DecisionTable, the NextHopResolver already has access to the IGP information related to the BGP NextHop.

A complication comes with `lookup_route`:

- if the lookup matches an `add_route` in the NhLookupTable queue, the NhLookupTable must return "lookup unsuccessful".
- if the lookup matches a `replace_route` entry in the NhLookupTable's queue, the old answer must be given.

In general, the behaviour should be as if the queued updates had not yet been received from the relevant peer. Note that the time for the RIB to respond should normally be very small compared to the usual delays for propagating Update messages between peers.

2.6 DecisionTable Class

The DecisionTable is the core of the BGP process. It takes route changes from the input branches, and decides whether those changes are better or worse than the routes it has already seen.

When DecisionTable receives an `add_route` from one input branch, it queries the other peers input branches using `lookup_route`.

- If none of the other branches returns an answer, then the route is a new one, and can be passed on downstream so long as the BGP NextHop is resolvable.

- If one or more of the other branches returns an answer, one of these answers will have been the previous winner. The new route is compared against the previous winner - if it is better then a `replace_route` message is propagated downstream. If it is worse, then no further action is taken.

When DecisionTable receives a `delete_route` from one input branch, it queries the other peers' input branches in the same way:

- If none of the other branches returns an answer, the the `delete_route` can be passed on downstream so long as the BGP NextHop was previously resolvable.

- If one or more of the other branches returns an answer, one of these answers will be the new winner. The routes are compared, and a `replace_route` will be sent downstream.

The processing for `replace_route` is similar to that for `delete_route` followed by `add_route`, except that only a single replace (or delete in the case where the new nexthop is unreachable and there are no alternatives) will be sent downstream.

2.7 NextHopResolver Class

Unlike most of the previous classes, NextHopResolver is not a RouteTable sub-class. A BGP implementation has a single NextHopResolver instance per address family. The NextHopResolver takes requests to resolve a BGP NextHop address and attempts to resolve the address to that of the immediate neighbor router that would be used to forward packets to the NextHop address.

When it receives an address to resolve, the NextHopResolver first checks its own routing table. If the nexthop address can be resolved there, then the answer can be returned immediately. Alternatively, if its own routing table indicates that the address definitely cannot be resolved, then a negative response can be given immediately. Otherwise it needs to contact the XORP RIB using XRLs to answer the question.

In this way, the NextHopResolver obtains a copy of the relevant subset of the RIBs database related to the NextHops given by BGP. The RIB will also keep track of the subset that it has told BGP about. If this information changes in any way BGP will be informed by the RIB, either directly of the change or that some information is no longer correct and BGP must query again.

The information held by the NextHopResolver is reference-counted so that it can be removed when it is no longer relevant. If the information contained changes, a notification of the change will be passed to the DecisionTable, which will propagate the notification back upstream to the RibIn tables.

2.8 FanoutTable Class

The principle task of the FanoutTable is to distribute route changes that passed the DecisionTable, and therefore are real changes not just possible changes. FanoutTable passes a change to all the output branches except the one where the change originated. In the case of `add_route` or `delete_route`, this is simple but a `replace_route` may contain an old route and a new route that originate from different peers, so it may be propagated as an `add_route` to the peer where the old route originated, as a `delete_route` to the peer where the new route originated, and as a `replace_route` to all the other peers.

The secondary task of the FanoutTable is to serve as a queuing point for changes when the BGP peers are not capable of keeping up with updates at the rate we are propagating them. The advantage of queuing updates in the FanoutTable as opposed to in the RibOut or PeerHandler is that only one copy of the change needs to be kept, no matter how many peers are not keeping up. This is particularly important in the case where the peer from which we heard most of our routes goes down, and a large number of deletions occur in a short period of time. These deletions need to go to all the remaining peers, and it is likely that we can generate them faster than TCP can transfer them to the peer.

Thus there is a single update queue in the FanoutTable, and a separate pointer into this queue is maintained for each outgoing branch (and hence each peer). If a output branch indicates it is busy, the FanoutTable will stop propagating changes to it, and instead queue the changes. Only when a change has been propagated to all the intended peers will it be removed from the queue.

2.9 RibOutTable Class

The purpose of the RibOutTable is to communicate changes to the outgoing PeerHandler and hence on to the relevant BGP peer. The RibOutTable class accumulates changes (add, delete or replace) in a queue, and waits for a flush request. The reason for the queue is that the incoming PeerHandler split up a single incoming Update message into many changes, each with the same Path Attributes. On output, we want to accumulate these changes again, so that we can send them on to our peers in a single Update message. Thus, after the incoming PeerHandler has sent the last change to the RibIn, it sends a flush message through. When this reaches the RibOut, it is the signal to take all the changes that have been queued, and build one or more Update messages from them. Of course the nature of the decision process and filters mean that changes that arrived together do not always result in outgoing changes that share the same Path Attributes. Thus multiple passes over the RibOut queue are required, each accumulating changes that share the same Path Attributes so that they can be sent on in the same Update message.

In principle, the RibOut could also store pointers to the routing information that was passed on to the peer so that Route Refresh (RFC 2918) could be handled efficiently. In our current implementation we do not do this - the RibOut maintains no record of the routes passed to the peer.

2.10 RibIpcHandler Class

The RibIpcHandler class is a subclass of PeerHandler, with basically the same interface as far as communication with the RibIn and RibOut are concerned. However, instead of communicating with BGP peers, the RibIpcHandler communicates routes to and from the XORP RIB. Routes are received from the RIB if the RIB has been configured to redistribute routes to BGP. In addition, all routes we pass to other peers are also communicated to the XORP RIB, and hence on to the forwarding engine, so that we can forward packets based on the routing information.

3 Background Tasks

The XORP BGP implementation, like all XORP processes, is single-threaded. However, certain simple events can cause BGP to perform a great deal of work. For example:

- When a peering goes down, all the routes in the RibIn associated with that peer must be deleted, which either results in Withdraws being sent to all remaining peers, or Updates being sent to indicate an alternative path is now the winner. As there can be many thousands of routes in a RibIn, this process can take some time.
- When a new peering comes up, all the winning routes must be sent to that peer. This can also take some time.

- When the IGP information related to a BGP nexthop changes, all the routes that specify this nexthop must be re-evaluated to see if the change affects the choice of route. In BGP it is fairly common for a very large number of routes to share the same BGP nexthop, so this re-evaluation can take some time.

The XORP BGP process cannot simply process such events to completion - in particular it must keep processing XRL requests from other processes or the IPC mechanism may declare a failure. In any event, it is important that a single slow peer cannot cause route forwarding between other peers to stall. Thus we process the events above as "background tasks".

In a multithreaded architecture, such tasks might be separate threads, but the locking issues soon become very complex. In our single threaded architecture, there are no complex locking issues, but the background nature of such tasks needs to be explicitly coded. We do this by dividing the background task into small enough segments. At completion of such a segment we schedule a zero-second timer to schedule execution of the next segment, and drop back to the main event loop. Execution will then be restarted after pending network events and expired timers have been processed by the main event loop. Care must of course be taken to ensure that when execution returns, the processing of events or other background tasks has not rendered incorrect the state the background task needed to restart. However, as the processing of each background task segment is naturally atomic in a single-threaded architecture, there are fewer possibilities for bad interactions. Even so, the state stored by these background tasks to enable their correct restart involves some rather complex algorithms.

3.1 DeletionTable Class

When a peering goes down, the routing table stored in the RibIn is moved to a DeletionTable that is plumbed in directly after the RibIn, as shown in figure 2. The task of the deletion table is to delete all the routes that

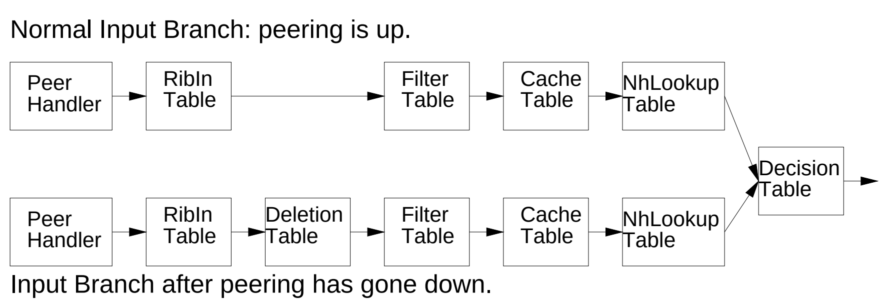


Figure 2: Dynamic insertion of Deletion Table on Peering Failure

were previously stored in the RibIn, but to do so as a background task allowing the BGP process to continue to handle new events.

Deletion is scheduled in series of phases. In a single phase, all the routes that share a single set of Path Attributes are deleted. In this way, if there are alternative routes in a different RibIn that also share a path attribute list (a fairly common occurrence), then the chance of preferred route may be batched in such a way that it might be possible to use a single update message might convey the change to each neighbor. At the end of a phase, the DeletionTable schedules execution of the next deletion phase using a zero-second timer. This allows all pending timer or network events to be handled before deletion resumes.

The DeletionTable must respond to `lookup_route` requests from downstream just as a RibIn table would - even though the deletion table knows the routes it holds will be deleted, it must respond as if they had not yet been deleted until it has had a chance to send the relevant delete_route message downstream. In this way, the DeletionTable provides a consistent view to the downstream tables - if they earlier performed a lookup_route and got a specific answer, then they will still get the same answer unless they have received a delete_route or replace_route informing them of a change.

When the last route is deleted from the DeletionTable, the table unplumbs itself from the BGP plumbing, and deletes itself.

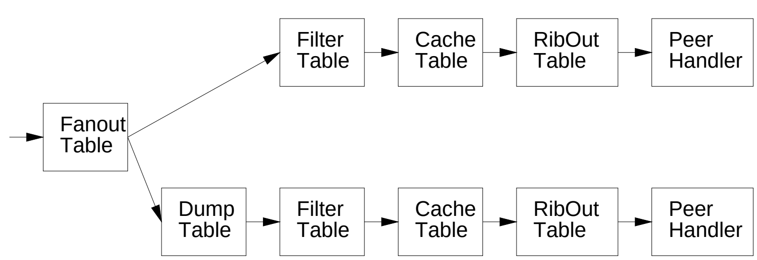
A small complication is added by the possibility that the peering might come back up before the DeletionTable has finished deleting all the old routes. Thus if the DeletionTable receives an add_route from upstream for a route that in present in the DeletionTable, then this route would be passed on downstream as a replace_route, and the route would then immediately be removed from the DeletionTable. add_route, replace_route and delete_route for routes not present in the DeletionTable are simply passed from parent to child without modification.

Should the peering come up and go down again before all the routes in the first DeletionTable have been deleted, a second deletion table would be inserted before the first one. By virtue of the normal functioning of the DeletionTable, if there are two such cascaded DeletionTables, then they will not hold the same route, so this does not add any additional complication.

3.2 DumpTable Class

When a peering comes up, all the currently winning routes from the other peers must be sent to the new peer. This process is managed by an instance of the DumpTable class, which is inserted between the fanout table and the first table on the output branch to the peer that came up (see Figure 3).

Normal Outgoing Branch



Outgoing Branch of Peer that just came up.

Figure 3: Dynamic insertion of DumpTable on a peering coming up.

A DumpTable is perhaps the most complex part of the BGP machinery. While the dump is taking place, it must cope with:

- New routing information being propagated.
- Other peers going down and coming back, possibly repeatedly.

It must do this without propagating inconsistent information downstream, such as a replace_route or a delete_route without sending an add_route first. It must ensure that all the routes what passed decision are dumped to the new peer. And it must cope when the routes just before and just after the most recent route it dumped are deleted, without losing track of where it is in the dump process.

The process is complex enough to merit description here in detail.

Each DumpTable contains a DumpIterator instance which holds all the state related to the current state of that particular route dump. The DumpIterator contains the following state:

- A list of the remaining peers to dump, initialized at the start of the dump. Peers are removed from this list when the dump of the routes received from that peer is complete, or when the peer does down during the dump. Peers are never added to this list during the dump.
- A list of the peers that went down before we'd finished dumping them. Along with each peer is stored enough state to know how far we'd got though the route dump from that peer before it went down.
- The current peer whose routes are being dumped.
- A trie iterator pointing to the next RibIn trie entry to be dumped on the current peer (we call this the Route Iterator)
- The last subnet dumped from the current peer.
- A flag that indicates whether the Route Iterator is currently valid.
- The last GenID seen. The GenID of the RibIn is incremented each time the peering comes up.

At startup the DumpTable initialized the list of remaining peers in the DumpIterator to be the set of peers that are currently up. Then it iterates through this list dumping all the routes from each RibIn in turn.

The DumpTable calls `dump_next_route` on its parent table, passing the DumpIterator as a parameter. The `dump_next_route` request is relayed upstream to the DecisionTable. DecisionTable relays the request to the input branch of the first peer listed in the list of remaining peers, and from there it is relayed back to the relevant RibIn.

To allow routes in the RibIn to be deleted during the route dump without the Route Iterator becoming invalid, we use a special trie and trie iterator in RibIn, where the route in the trie will not actually be deleted until no trie iterator is pointing at it. This is implemented using reference counts in the Trie nodes themselves.

`dump_next_route` in the RibIn checks the Route Iterator to see if it points to the end of the Trie. If the previous call to `dump_next_route` had left the Route Iterator pointing to a node that has subsequently been deleted, this comparison transparently causes the Route Iterator to move on to the next non-deleted node, or to the end of the Trie if there are no subsequent deleted nodes. This updating of the Route Iterator is transparent to the user of the iterator.

The route pointed to by the Route Iterator is then propated downstream from the RibIn to the DumpTable as a `route_dump` call. The DumpTable turns this into an `add_route` call which it propagates downstream to the new peer.

At the end of `dump_next_route`, the RibIn increments the RouteIterator ready for next time.

DumpTable then schedules the next call to `dump_next_route` using a zero-second timer to allow other pending events to be processed.

On returning from the timer, the DumpTable checks to see if any route changes have been queued upstream in the FanoutTable due to output flow control. If so, it processes all these route changes before dumping the next route. This is necessary, or the DumpTable will not be able to tell which changes it needs to propagate downstream because we've already passed their location in the dump process, and which are unnecessary because we will get round to dumping them eventually.

In general, a route change needs to be propagated downstream if:

- It comes from a peer that is not in our remaining peers list.
- It comes from the peer currently being dumped, but its route is before the location of the route in the DumpIterator.
- It comes from a peer that went down, and its subnet is before the subnet we had reached while dumping that peer's RibIn when the peer went down.
- It comes from a peer that went down, and the RibIn GenID later than that peers GenID was when it went down. This would happen because the peering has since come back up, and is now injecting new routes.

When all the routes in the RibIn of a particular peer have been dumped, that peer is removed from the remaining peers list in the DumpIterator, and the next `dump_next_route` will be sent to the RibIn of the next peer in the list.

When there are no peers in the remaining peers list, the dump is complete. The DumpTable then unplumbs itself from the plumbing, and deletes itself.

Note that at any time there may be multiple DumpTables in operation, each dumping to a different peer. All the dump state is held in the DumpIterators, so this does not cause any problem.