Inter-Domain Routing

The Border Gateway Protocol version 4 (BGP) is the standard inter-domain routing protocol used in the Internet today. BGP is a policy based path-vector routing protocol that distributes network reachability information between Autonomous Systems (ASs), see Figure 1. By default, BGP chooses routes with the shortest path to a destination, in terms of the number of AS hops. However, the BGP protocol admits administrator-defined routing policies to control the route selection. Routing policies are used to implement traffic agreements between peering ASs, and the BGP protocol allows each AS to define its routing policies independently from other ASs.

Policy Disputes

Disputing routing policies in BGP routed networks can cause routing divergence. As an example of policy disputes, let us consider a routing configuration that consists of four nodes as shown in Figure 2. In this example, nodes 1-3 try to establish routes to node 0. We apply routing policies such that nodes 1-3 are allowed to choose the direct one-hop route or the two-hop route over their mutual clockwise neighbor, and we let each router prefer the two-hop route to the one-hop route. These policies are shown in Figure 2 where each node's preferred paths are listed next to the node. The paths are ordered by preference such that the most preferred path is listed at the top and the least preferred path is listed at the bottom.

The policies admit any of the four routing states S0-S3 shown in Figure 3. Although routing state S0 is valid, no node prefers it. Instead, node 1 prefers state S1, node 2 prefers S0, and 3 prefers S2. We can satisfy any but one of the three nodes by selecting S0, S1, or S2. We say that node i's routing policy is in dispute with node j's policy, since adopting i's most preferred route (state Si) would prevent 2 to select its most preferred route (state Sj). Likewise, 2's policy is in dispute with 3, and so is 3's with 1. Here, we have a cyclic dispute relation between the policies: 1 is in dispute with 2, which is in dispute with 3, which is in dispute with 1. Due to the cyclic policy disputes and the dynamic properties of the path-vector routing algorithm, the nodes are going to switch persistently between the states shown in Figure 3.

Dispute Digraphs

Dispute digraphs is a notion to describe the static relations between potential routes in a network. Informally, a dispute digraph consists of nodes that represent all potential routes that can be adopted by the nodes in the network, and arcs between the nodes that represent the relations between the routes. Any two routes can be related in two different ways: the adoption of one route may render it possible for the other route to be adopted, or the adoption of one route may prevent the other route from being used. In the former case, we connect the routes with a directed transmission arc from the first route to the second, in the latter case with a directed dispute arc.

An interesting and important property of dispute digraphs is whether they contain cycles. A dispute digraph cycle means that the set of routes in the cycle depend on each other in the process of adopting or preventing routes. Dynamically, this may give rise to either transient or stationary routing oscillations where routes included in cycles are repeatedly selected and abandoned. The relations between routes depend on the applied routing policies. Figure 4 shows the dispute digraph for the routing configuration described above. In the figure, the dashed arcs represent transmission arcs, and the continuous arcs represent dispute arcs. We note that the graph contains a cycle.

The Route-History Algorithm

Griffin and Wilfong have presented a route-history algorithm that dynamically detects cyclic policy disputes when they cause oscillations. The algorithm is executed on each router and generates histories of route selections. The histories are constructed such that they correspond to trails in the network's dispute digraph. The histories are included in the routing information exchanged between the routers. When a cyclic dispute causes oscillations, histories sent between the routers that are involved in the dispute are filled with entries that describe the corresponding dispute-digraph cycle. By detecting repeating history entries, routers are able to distinguish cyclic policy-dispute oscillations and to take countermeasures in order to stop them, e.g., by removing the policies or suppressing the routes that are involved in the dispute. Griffin and Wilfong presented the route-history algorithm in the shape of a simple path vector protocol named SPVP. SPVP, as a policy-based path-vector protocol, is similar to BGP.

Our Work

An important difference between BGP and SPVP, is that BGP applies send-rate constraints on messages. Path-vector routing protocols depend on send-rate constraints of routing information. Without send-rate constraints, the network would be flooded with routing messages and the convergence time would increase.

We have examined the implications of extending SPVP with send-rate constraints and concluded that the route-history algorithm can generate cyclic histories during ordinary convergences when send-rate constraints are applied, leading to routers unnecessarily suppressing (sound) routes.

Currently, we are investigating the possibility to adapt the route-history algorithm to work correctly (i.e., not generate false positives) when send-rate constraints are applied. A possible solution to the problem of false positives may be to put empty histories in messages that replace other pending messages.