Probabilistic Verification of BGP Convergence

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Border Gateway Protocol (BGP) is widely used as the main inter-Autonomous System (AS) Internet routing protocol. An AS selects its preferred routes based on its routing policy and the best routes that have been advertised by its neighboring ASes. Local AS policies play an important role in preferred route selection because the BGP allows policy-based decisions to override distance metrics. Local routing policies are usually defined based on a limited knowledge of other AS policies and network topology and, hence, may be inconsistent. These policies may cause a set of ASes to exchange route information messages indefinitely and not converge to a set of stable routes.

Global BGP Execution Model

- Viewswathan et al., describe the global BGP execution model as an input-output automaton. An AS is the set of all nodes.
- Assumption: node 0 is the single destination for all other nodes.
- Assumption: $Q(S)$ is the set of states of the global automation describing path assignments.
- Let $\pi$ be a mapping function that assigns each node $v$ to a permitted path $\pi(v)$.
- For every node $v$, the path assignment initially maps the empty path to $\pi(v) = \emptyset$.
- Inputs to the automaton are events of the form: $\langle \text{advertise}, u \rangle$, for some $u \in V^+ \setminus \{0\}$, where $V$ is the set of all nodes.
- The transition matrix $T(S)$ of such an automaton is of dimensions $|Q(S)| \times |Q(S)|$ and $T(S)_{ij} = \langle \pi \rangle$ if $\langle \pi \rangle$.
- Let $p = (p_1, p_2, \ldots, p_n)$ be an activation probability vector with $\sum p_i = 1$, where each $p_i$ represents the probability that node $i$ receives an event $\text{advertise}$. Node $i$ recomputes its routes after receiving the event.
- $T(S)$ may evolve to a stochastic transition matrix $T'(S)$ by casting operator $P$ on every element of $T(S)$. Let $\gamma$ be a subset of power set of $V \setminus \{0\}$. $P_\gamma$ is defined as: $P_\gamma(\pi) = \sum_{\gamma \subseteq \gamma} P_{\gamma}(\pi)$.

Safety

- Any instance of global BGP execution is safe with respect to an initial state $\gamma$ if and only if for an activation probability vector $P$ there is no cyclic state.
- PCTL: $P_\gamma(GF \pi \rightarrow GF \pi) \forall \gamma \in Q(S)$.
- CTL*: $A(GF \pi \rightarrow GF \pi) \forall \gamma \in Q(S)$.

Convergence Time

- We define a state reward function $r(\pi)$ as: $r(\pi) = 1, \forall \pi \in Q(S)$.
- Let $\bar{\pi}$ denote a unique absorbing state. The number of transitions made until $\bar{\pi}$ is reached may be expressed as: $R_{\gamma}(\bar{\pi})$.

Example

- We used example by Viewswathan et al., and PRISM for model checking.
- Network configuration is deterministically unsafe but probabilistically safe.

References