DFINITY

Implications of Routing Coherence and Consistency on Network Optimization

Yvonne-Anne Pignolet (DFINITY), Stefan Schmid (University of Vienna) ,
Gilles Tredan (LAAS-CNRS)

IFIP Networking 2020

Invitation: A Road Trip in Networks

Road map 1927: Arizona and New Mexico

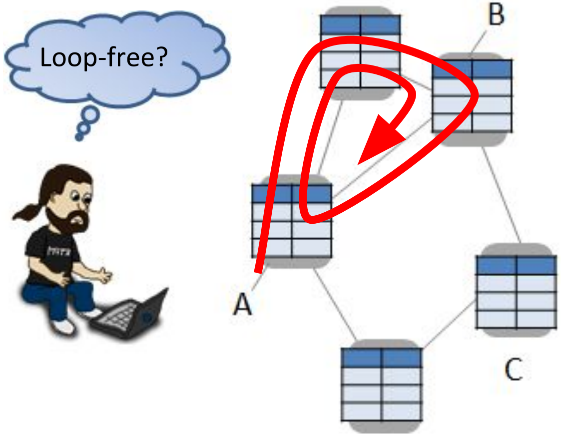
Routing and Traffic Engineering (TE)

- Evergreen topic in networking

- Especially TE technologies evolved
  - Traditionally: weight-based shortest paths (e.g., OSPF, ECMP)
  - More recently: MPLS, SDN, Segment Routing
  - Introduces **great opportunities** for optimization
  - Typical goal: avoid congestion

Network Policies: Constraints on Routes

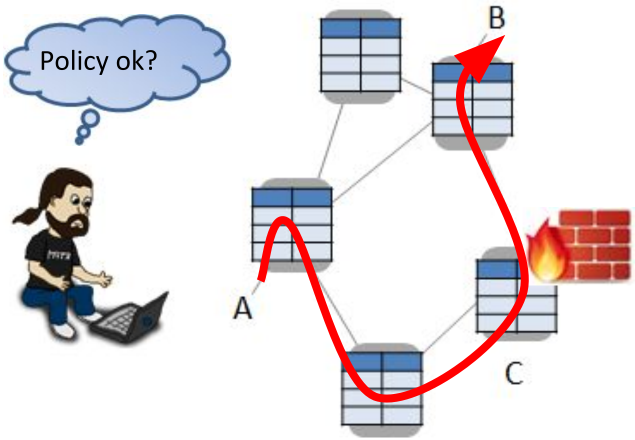
- Routes typically need to fulfill certain **policies**



E.g.: Loop-freedom: Are the routes loop-free?

Network Policies: Constraints on Routes

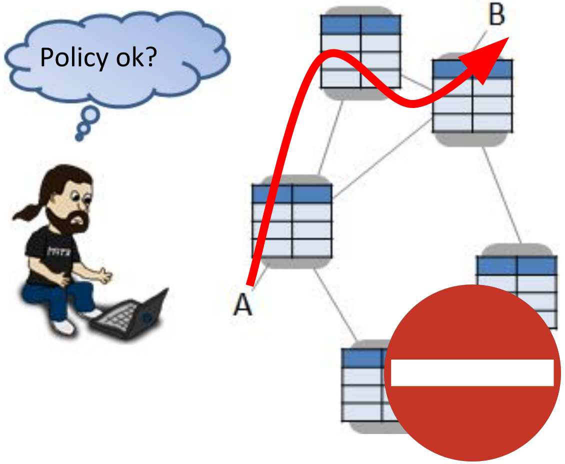
- Routes typically need to fulfill certain **policies**



E.g.: Waypoints: Is it ensured that traffic from A to B is always routed via a node C (e.g., a firewall)?

Network Policies: Constraints on Routes

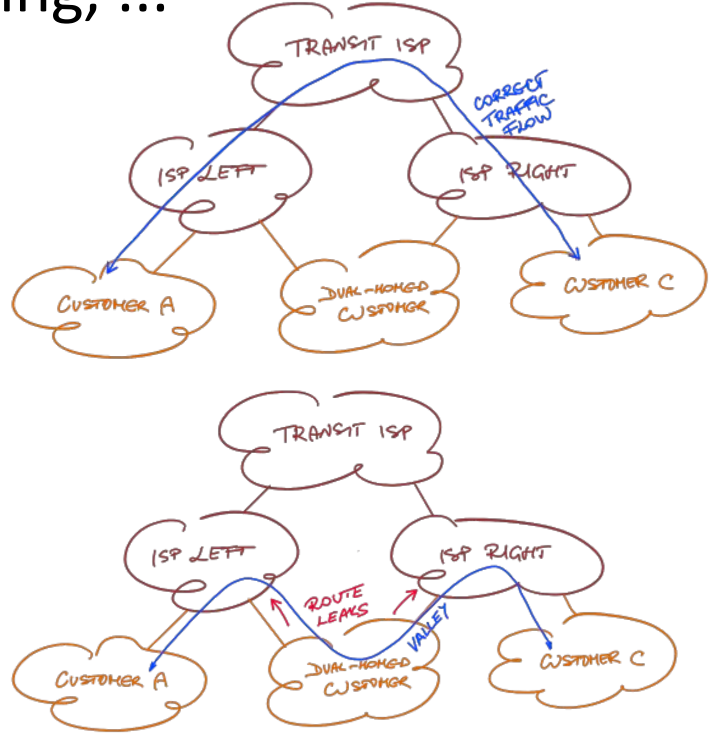
- Routes typically need to fulfill certain **policies**



E.g.: Blacklists: Is it ensured that traffic from A to B never goes via C?

Many More

- E.g., valley-free, shortest paths routing, ...



Consistency Properties

Shared characteristic of previous examples:
properties of individual routes!

=> **consistency properties**

- Often specified with regular expressions

  e.g., (c2p)*(p2p)?(p2c)* for valley-free routing

- Or routing algebras

  e.g., $(\mathbb{R}+,\infty,+,=<)$ for shortest paths routing

But there is another dimension to routing...

Coherence Properties

Some properties hold for a set of routes
(not individual routes)
=> **coherence properties**

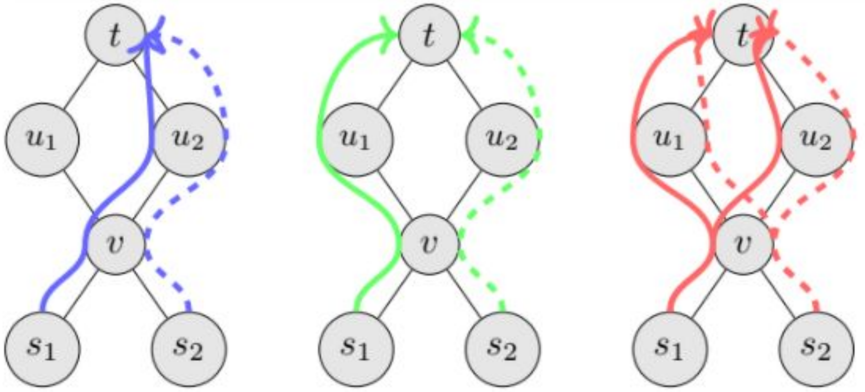
Examples

- Symmetric: A -> B, B -> A
- Confluent: same dst routes form a tree

Useful for load balancing, routing table space, CPU

Coherence Illustration

Properties of **sets** of routes = “how routes relate to each other”



>

same dst routes form a tree

!

exactly one route per src-dst

*

all routes set are valid

Impact:

- Load Balancing:
  Is u_2 congested ?

- Monitoring:
  Is u_1 up ?

Different answers depending on coherence...

Motivation for This Paper

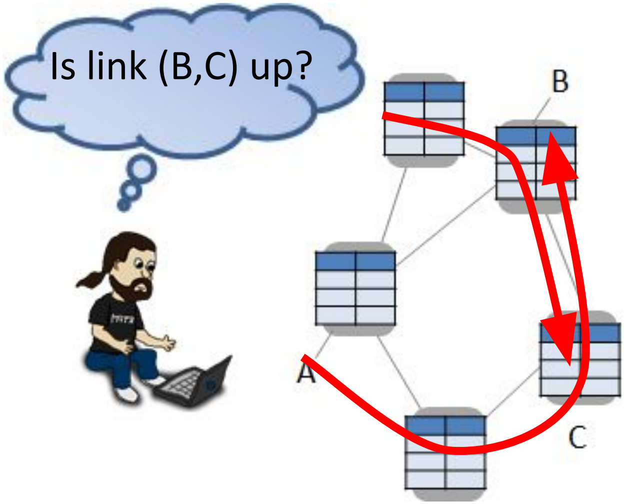
- Consistency and coherence requirements influence:
  - available path diversity (search space)...
  - … and hence achievable objective function
  - … and hardness of underlying optimization problems
- However:
  - Effects hardly understood today
  - Algorithm designers often just think about graphs
- We need to account for the routing model influence !

Roadmap

- How did we end up working on this?
- Routing models
- Impact on quality and complexity
- Empirical findings

Network Tomography

Goal: obtain detailed picture of network from **E2E measurements**



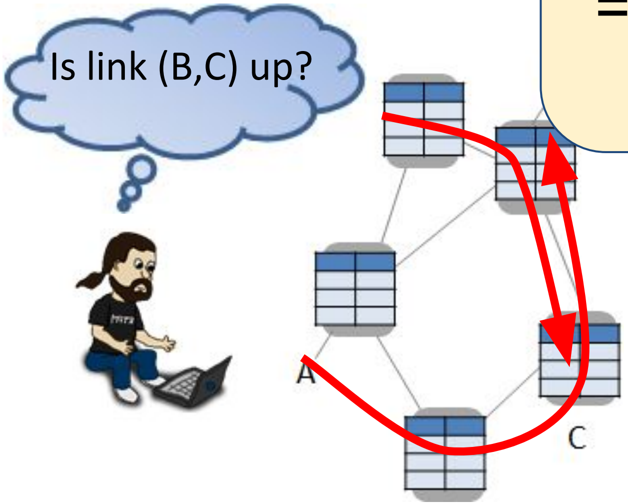
=> **Infer** topology and link status

Optimization problem:
deploy minimum equipment to monitor all edges

Network Tomography

Goal: obtain detail[...]ents

[...]s



Network graph input is not enough to solve this problem

=> Introduce **routing models** and investigate their **impact**

Optimization problem:
deploy minimum equipment to monitor all edges

Routing Algorithms

Input G alone is ambiguous (even with shortest path consistency):

Given a message m **from** s **to** t **(code for node** v**)**

$C = \arg\min_{i \in V(v)}(d(i,t))$ /*find relay candidates*/
if $|C| > 1$ /* ... than one relay candidate */ **then**
ne...

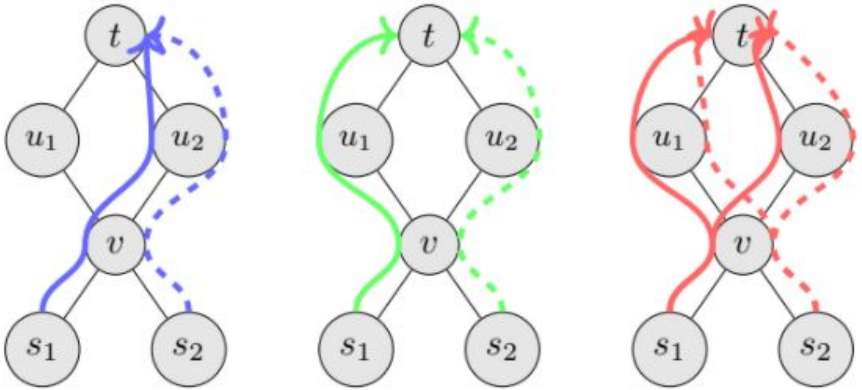
Select consistent routes

$argmin_{i \in C}(i)$

$argmin_{i \in C}(|i - s|)$

$random(i \in C)$

forward packet to $next\_hop$
else
/* algorithm continues */



>

same dst routes form a tree

!

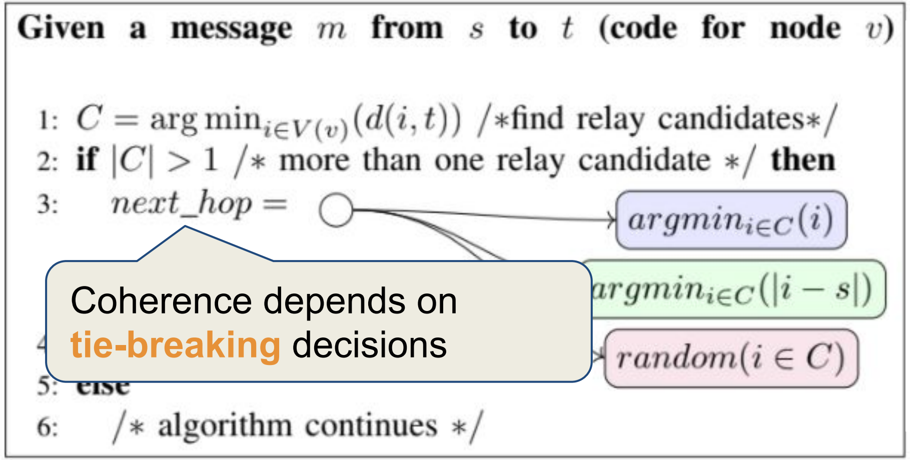
exactly one route per src-dst

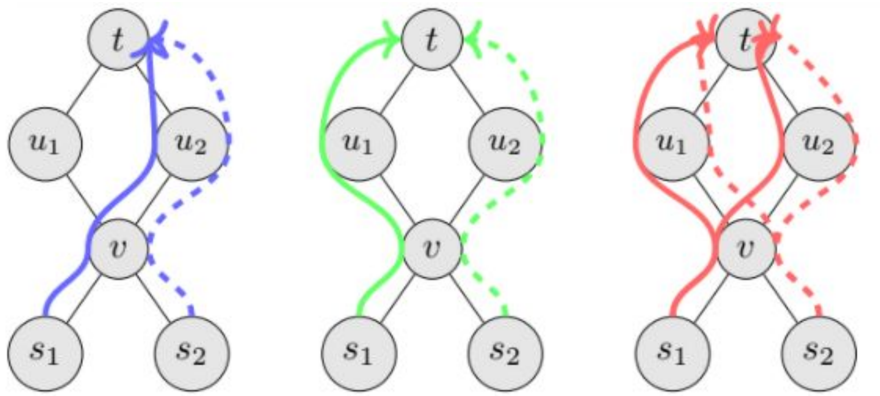
*

all routes set are valid

Routing Algorithms

Input G alone is ambiguous (even with shortest path consistency):

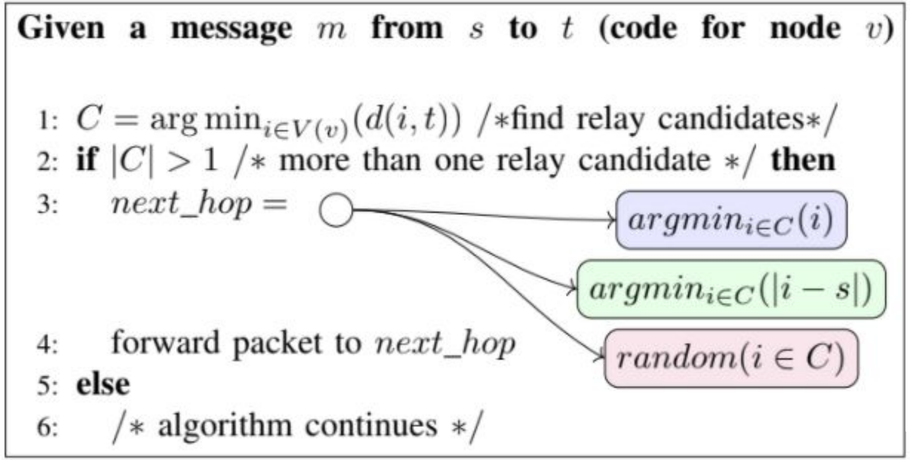


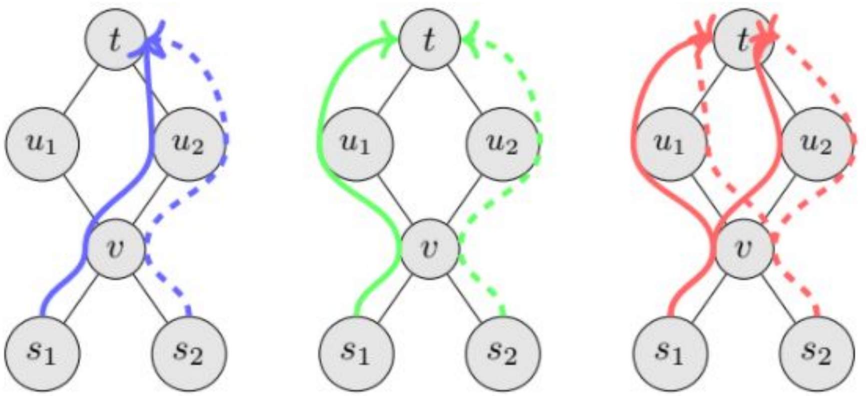


>	!	*
same dst routes form a tree	exactly one route per src-dst	all routes set are valid

Routing Algorithms

Input G alone is ambiguous (even with shortest path consistency):



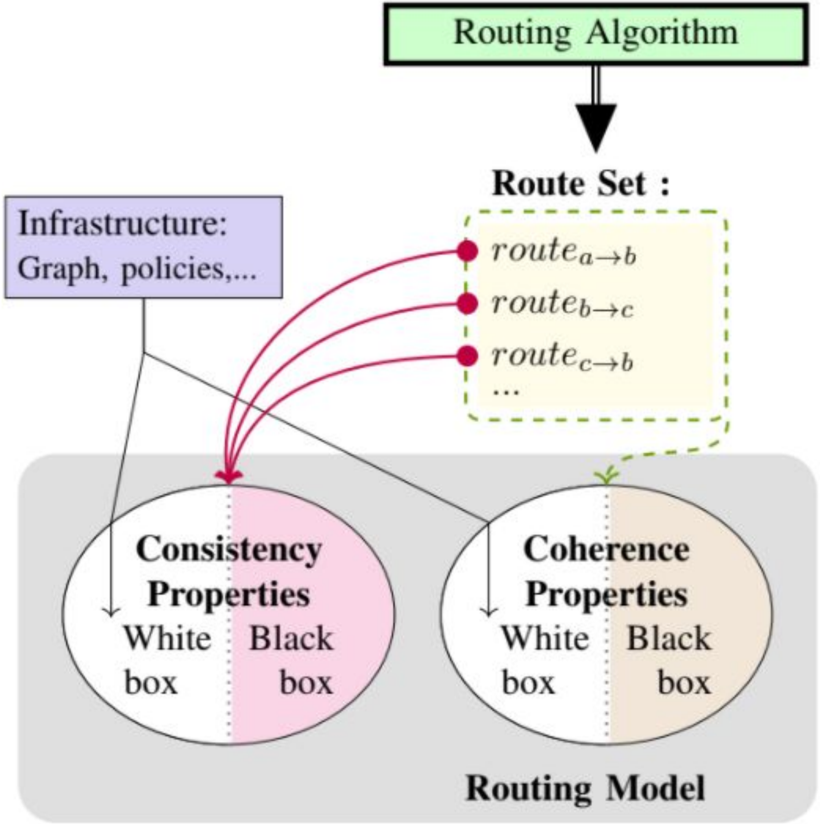


> ! *

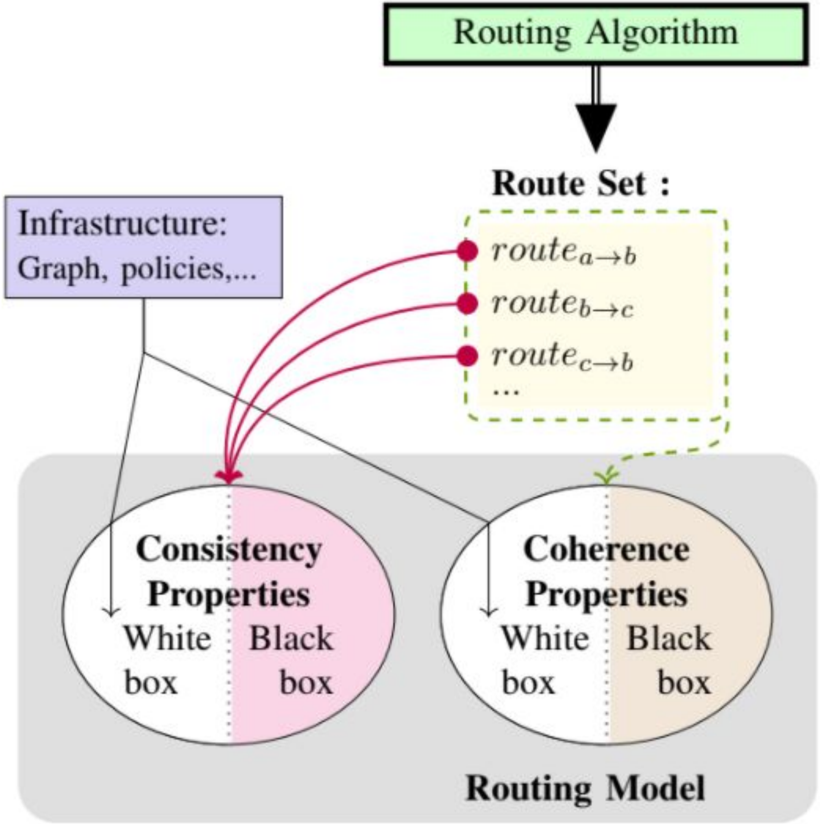
Tie-breaking is often overlooked in protocol design despite its impact

Routing Model

Routing Model



Routing Model

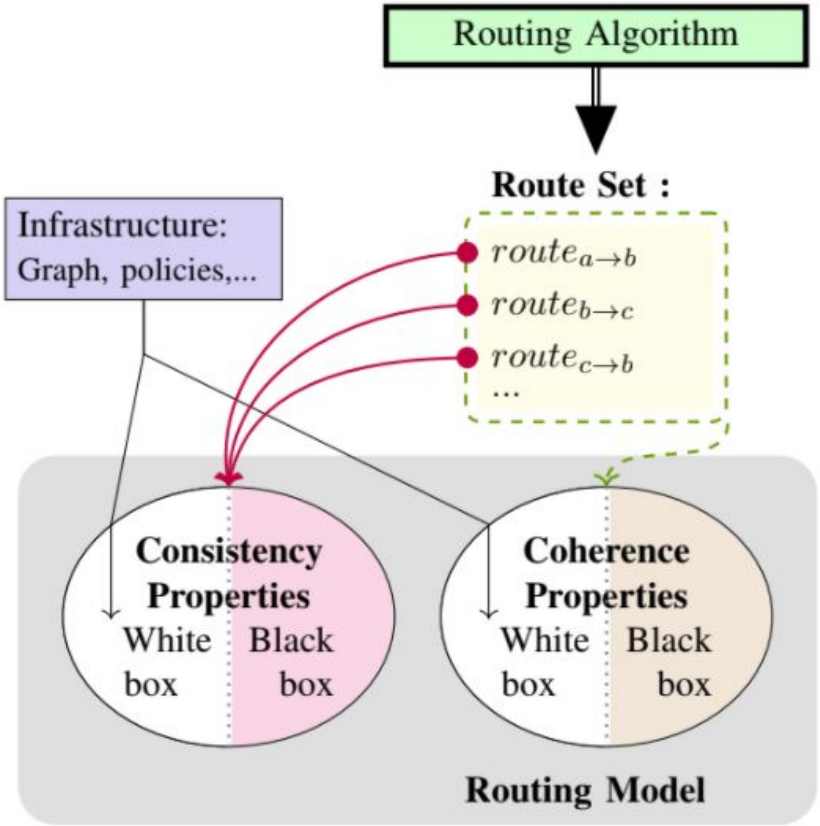


Consistency: per route

- Shortest path
- Way points
- Valley-freedom
- ….

Routing Model

Consistency: per route
- Shortest path
- Way points
- Valley-freedom
- ….



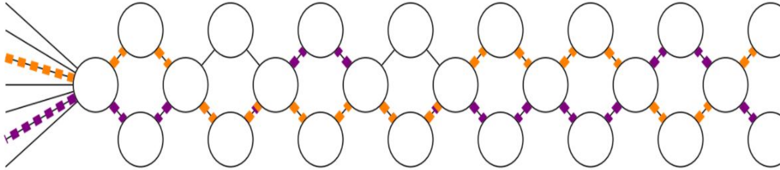
Coherence: per route set
- Canonical properties of route sets
- Structure the space from most constrained model to most permissive model e.g., <, !, *

Impact on Complexity and Quality

Examples

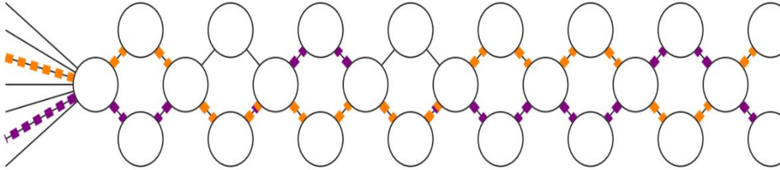
- Coherence
  - Tomography:
    - !, > : NP-hard in general
    - !: NP-hard on cactus graphs, possibly O(1) deployment

      >: polynomial on cactus graphs and O(n) deployment



Impact on Complexity and Quality

Examples



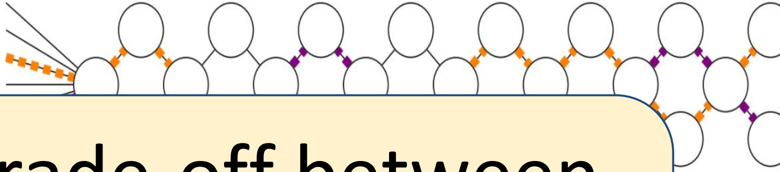
- Coherence
  - Tomography:
    - !, > : NP-hard in general
    - !: NP-hard on cactus graphs, possibly O(1) deployment
      >: polynomial on cactus graphs and O(n) deployment

- Consistency
  - Traffic engineering:
    - shortest capacity-respecting paths in O(poly(n))
    - NP-hard if path must pass a given waypoint
    - congestion with sp up to Ω(n^2) larger than achievable

Impact on Complexity and Quality

Examples

- Coherence
  - Tomography:
    - !, >: NP-hard in general
    - !: NP-hard on cactus graphs,
      >: polynomial on cactus grap



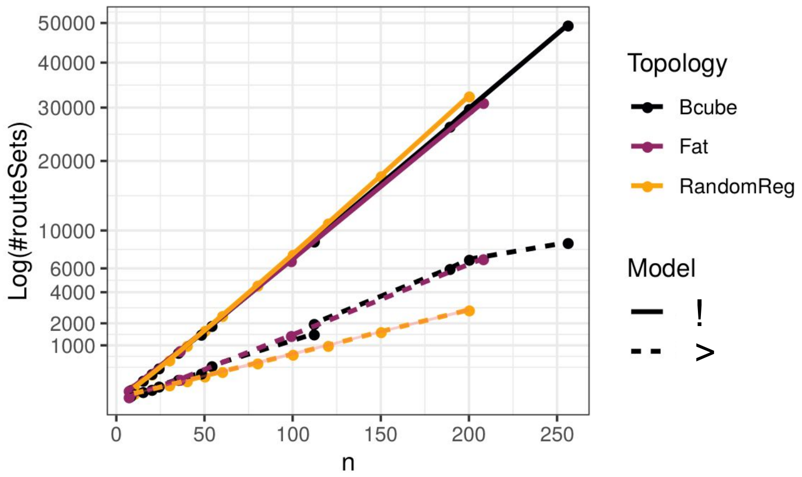
Trade-off between search space size and quality

- Consistency
  - Traffic engineering:
    - shortest capacity-respecting s-t-path in O(poly(n)),
    - NP-hard if path must pass a given waypoint
    - congestion with sp up to $\Omega(n^2)$ larger than achievable

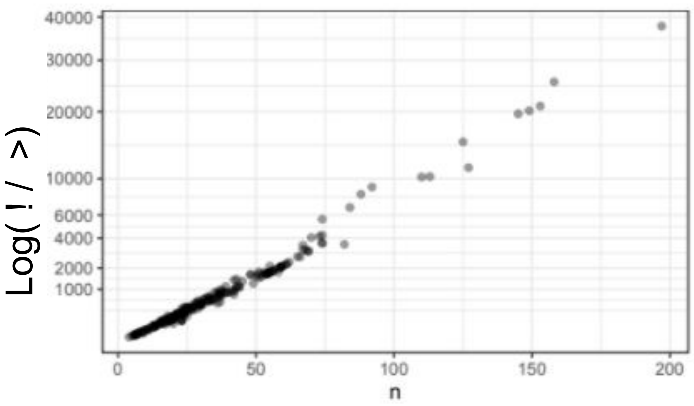
Empirical Analysis

Research question: How big is the search space in practice?

LAN/ datacenter topologies (synthetic)



WAN/ topology zoo topologies (real)

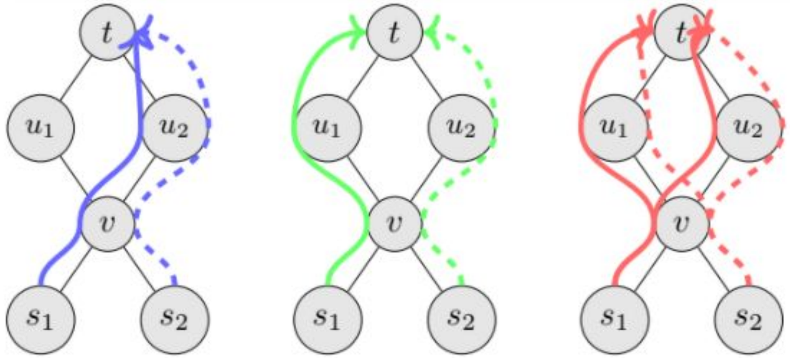


Takeaways

Coherence relation between routes is often overlooked

Tie breaking is crucial

=> Routing model



Not only consistency, but also coherence impact

- Quality
- Complexity

=> exploit it!

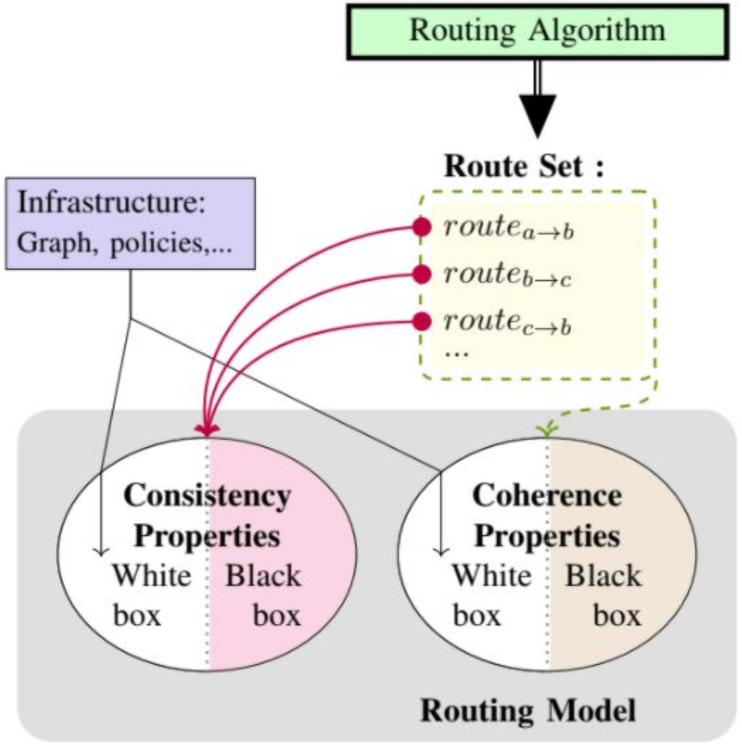
Related work: Erlebach09, Chekuri07, Pignolet18

yvonneanne@dfinity.org
stefan_schmid@univie.ac.at
gtredan@laas.fr

OSPF

Theorem 3. *(i) Given a loop-free contained scheme, we can find OSPF weights in $O(poly(n))$ if they exist. (ii) There are loop-free contained schemes for which no OSPF weights exist.*

Routing Models



Consistency: per route

- Shortest path
- Way points
- Valley-freedom
- ....

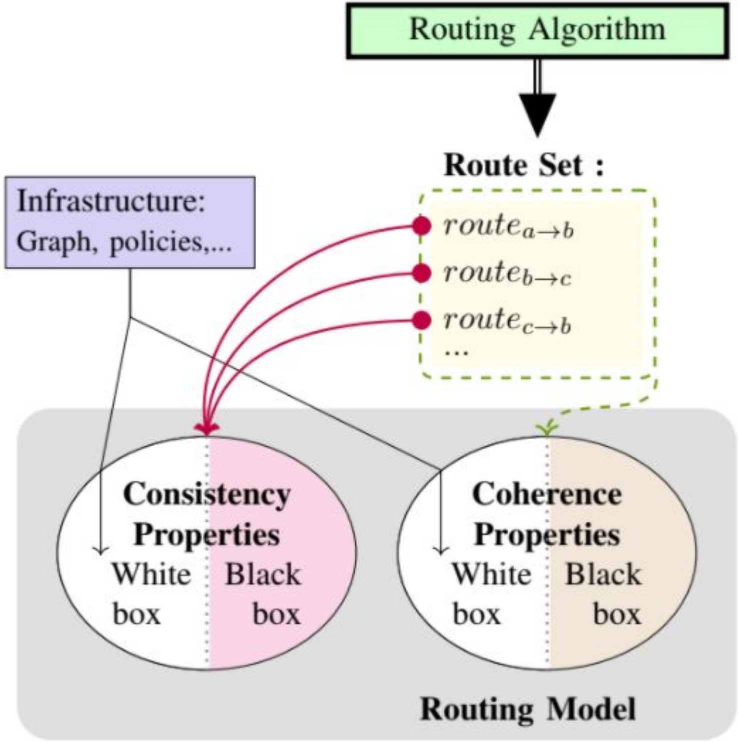
  Described with regular languages or algebraic methods

Coherence: per route set

- Multi: any subset is valid
- Any: exactly one route per src-dst
- Confluent: same dst routes form a tree
- Contained: two routes share at most one subroute
- Forest: union of all routes is a forest
- Symmetric: same route in both directions

=> load balancing, routing table space, CPU

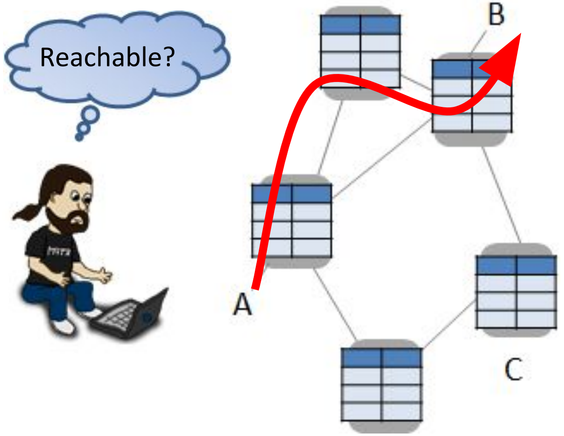
Routing Models



White box vs black box

Network Policies: Constraints on Routes

- Routes typically need to fulfill certain **policies**

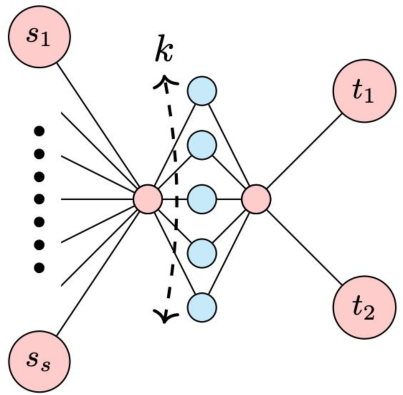


E.g.: Reachability: Can traffic from A reach B?

Routing Model Impacts Quality

Examples

- Coherence impacts quality:
  - Tomography:
    - !: O(√ k) monitoring equipment
    - > , ⊆ : Omega(k) equipment
  - Traffic Engineering:
    - > congestion up to Ω(|V|) higher than for !



- Consistency impacts quality:
  - Traffic engineering: congestion with shortest path routing up to Ω(n^ 2) larger than achievable