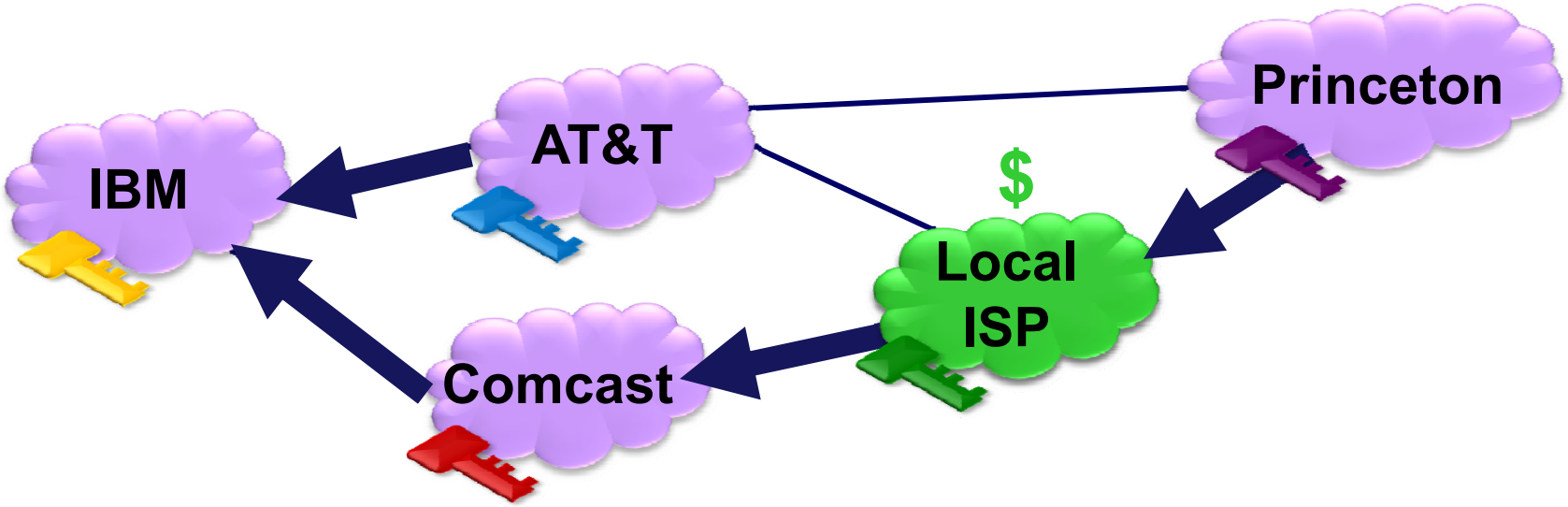
Rationality and Traffic Attraction

Incentives for Honest Path Announcement in BGP



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Princeton University

SIGCOMM 2008

Incentives and Security

We use game theory to understand the which secure protocols should be deployed in the Internet.

We ask: Does traffic on the Internet actually follow the paths announced in **BGP**?

Approach: Assume that nodes are economic entities

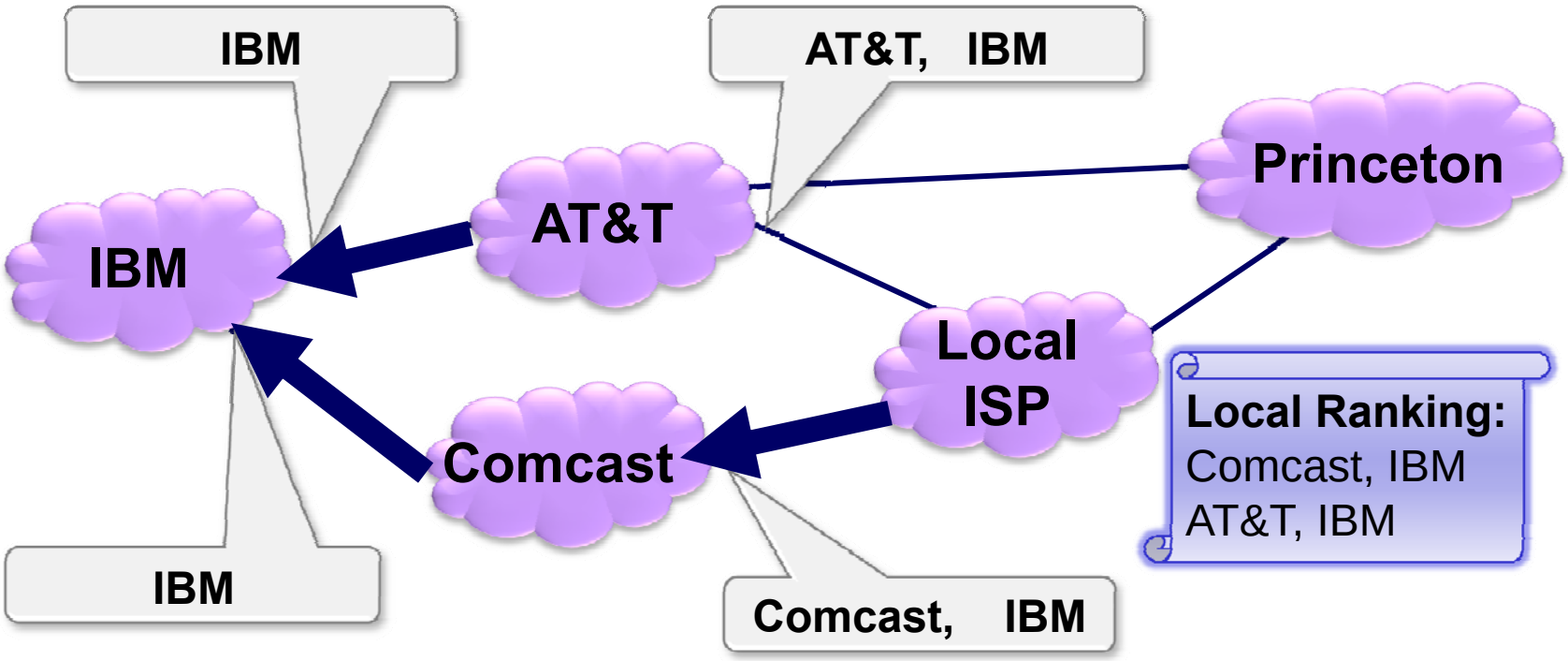
- They are **rational** -- try to maximize utility.

Our Results: Mostly **bad news**.

- We find that **cryptographically authenticating routing messages** is not sufficient.
- … unless we also make **unrealistic assumptions about routing policies.**
- Results are mostly descriptive, not prescriptive

BGP: The Interdomain Routing Protocol (1)

The Border Gateway Protocol (BGP) is the routing protocol that sets up paths between Autonomous Systems (ASes).



Forwarding: Node use **single** outgoing link for all traffic to destination.

Rankings: Static and local; usually based on economic relationships.

BGP: The Interdomain Routing Protocol (2)

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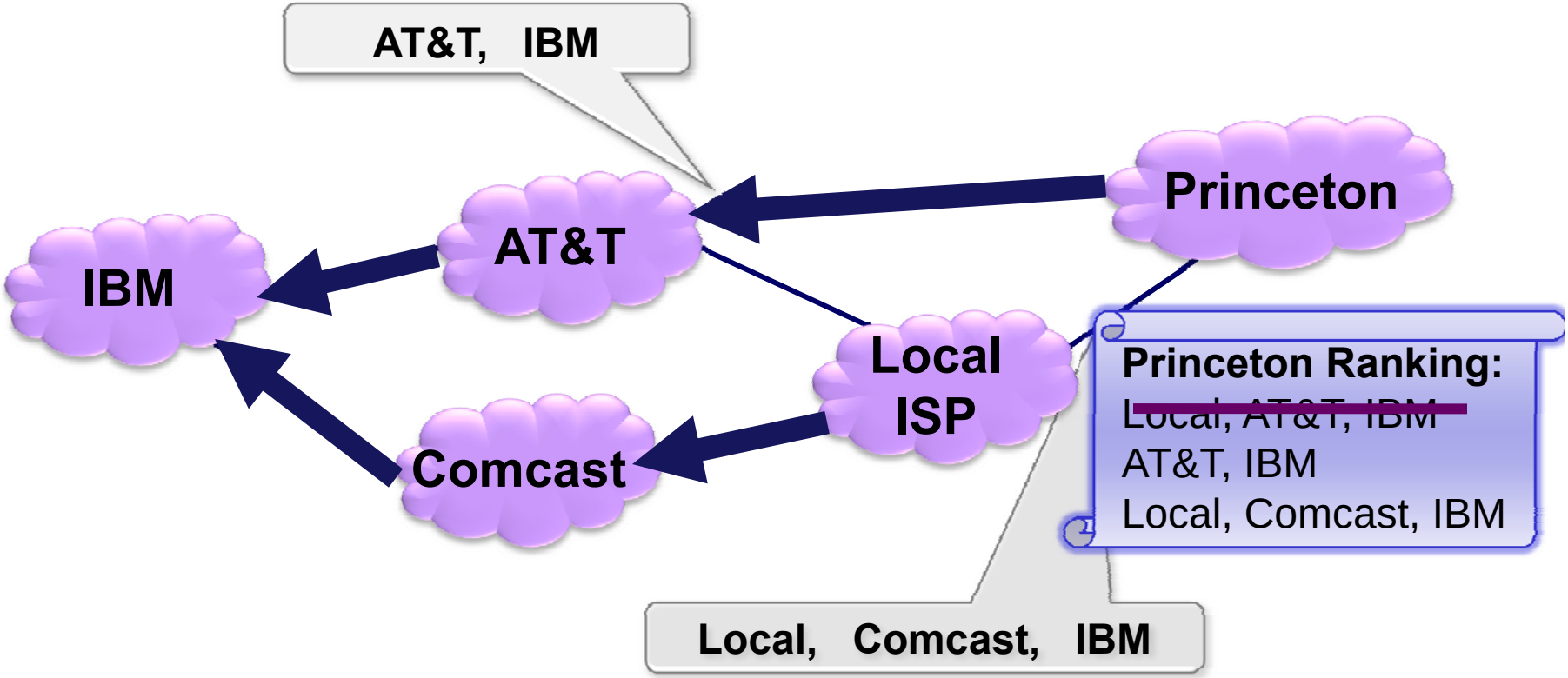

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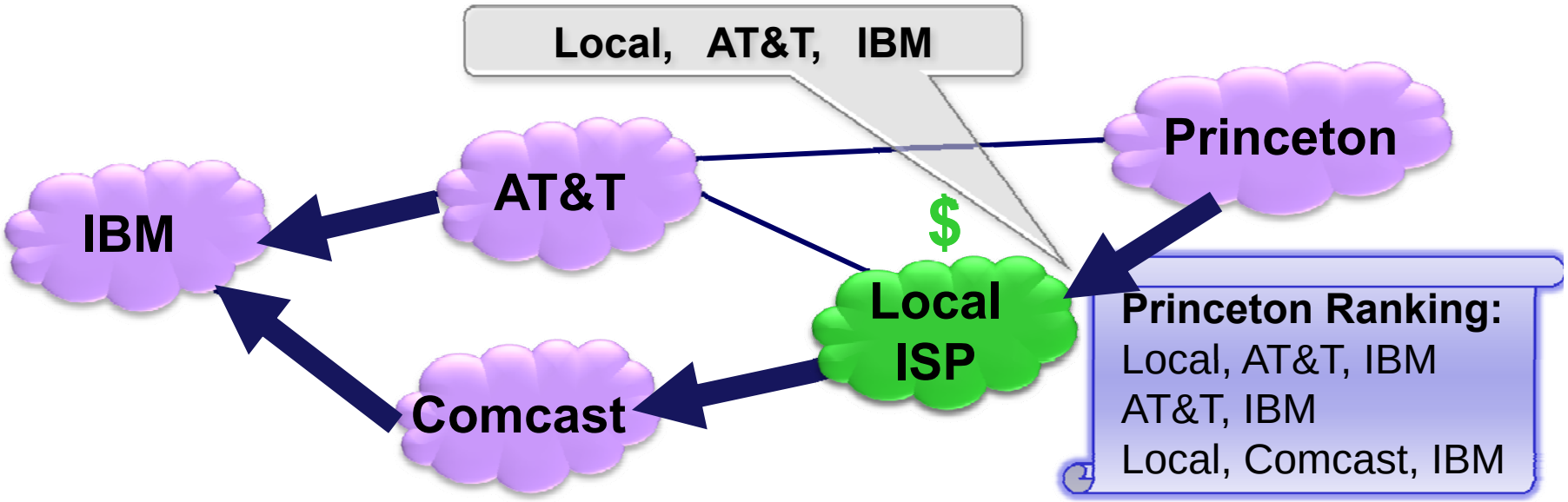
Rankings: Static and local; usually based on economic relationships.

Today's Security Goal: Matching the Data Plane

Goal: BGP announcements match AS-paths packets take in data plane.



This way, ASes can use BGP messages:

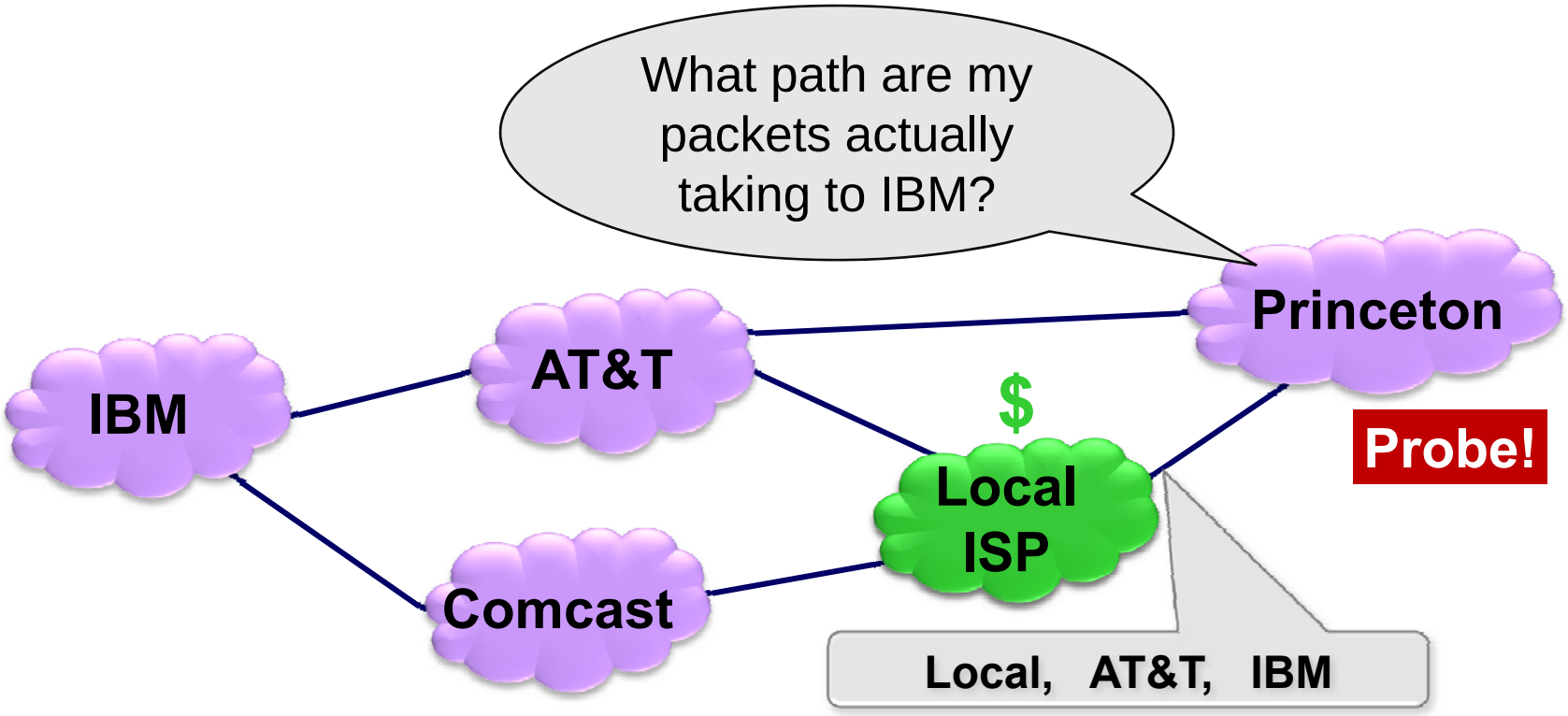
1. To avoid ASes perceived as adversarial / unreliable
2. To choose high performance paths
3. As part of an accountability framework

Data Plane Approaches

Secure Data-Plane Protocols:

- Packet Passports **[LYWA-06]** Packet Obituaries **[AMISS-07]**
  Truth in advertising **[WBAGS-07]** Failure Localization **[BGX-08]**

✗ **Secure AS-path tracing protocols incur overheads proportional to the amount of traffic sent in the data plane.**

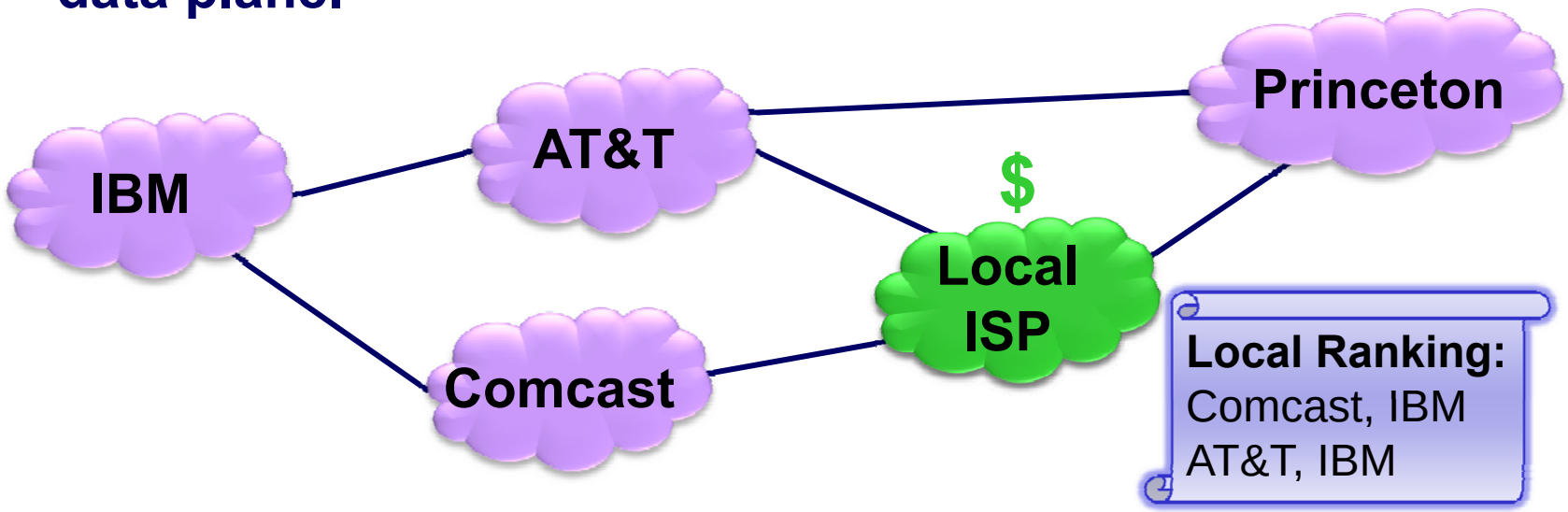


Routing Protocol Approaches to Match Data Plane

Routing Protocols + Game Theory:

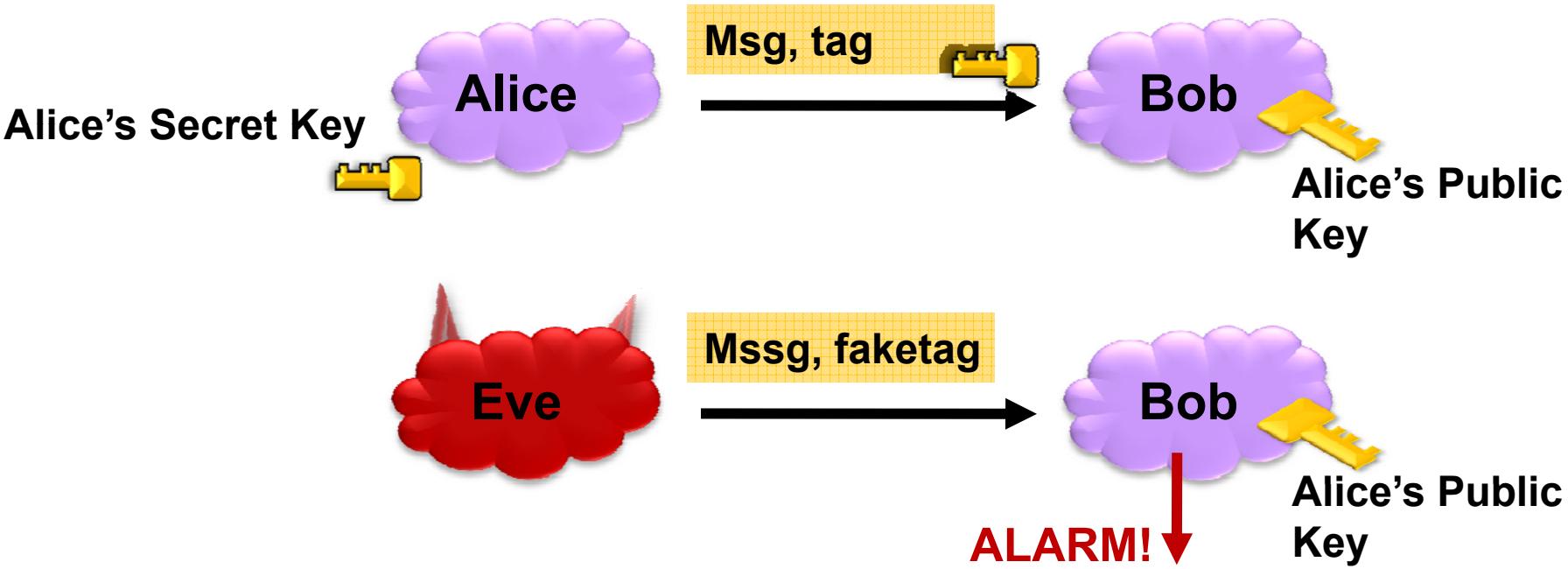
- [NR-01] [FPS-01] [FPSS-05] [PS-04] [FKMS-05]
  Shortest-path policy / Next-hop policy [FRS-06] [FSS-07]
  Secure BGP [LSZ-08]

✓ **Corollary: If _____, rational ASes have no incentive to unilaterally deviate from announcing paths that match data plane.**



Quick background: Public-key Signatures

Anyone who knows Alice's public key can verify that yreceived the correct message from Alice.



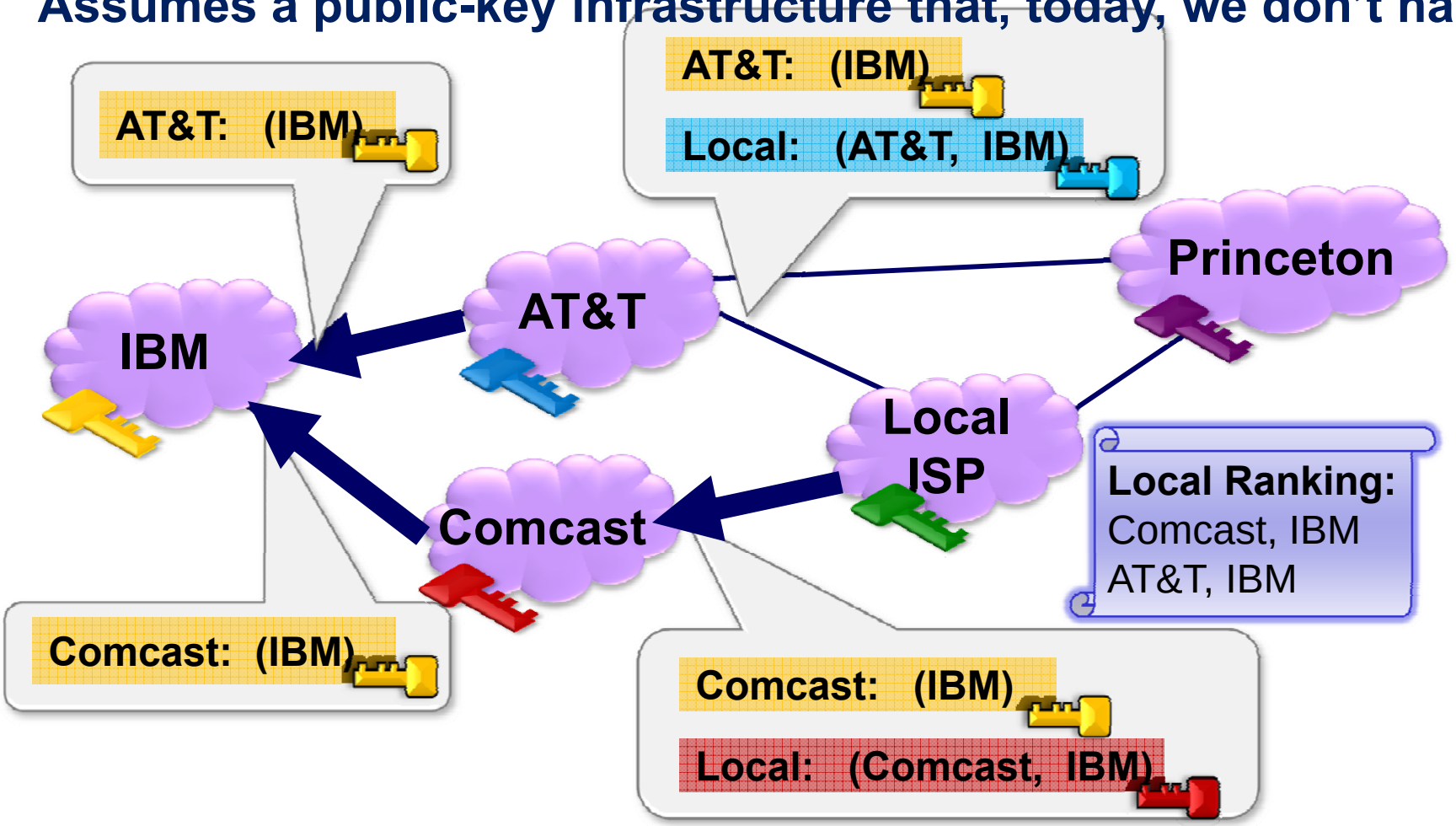
This looks great, what's the catch?

We need an infrastructure to certify the public keys.

Secure BGP (1)

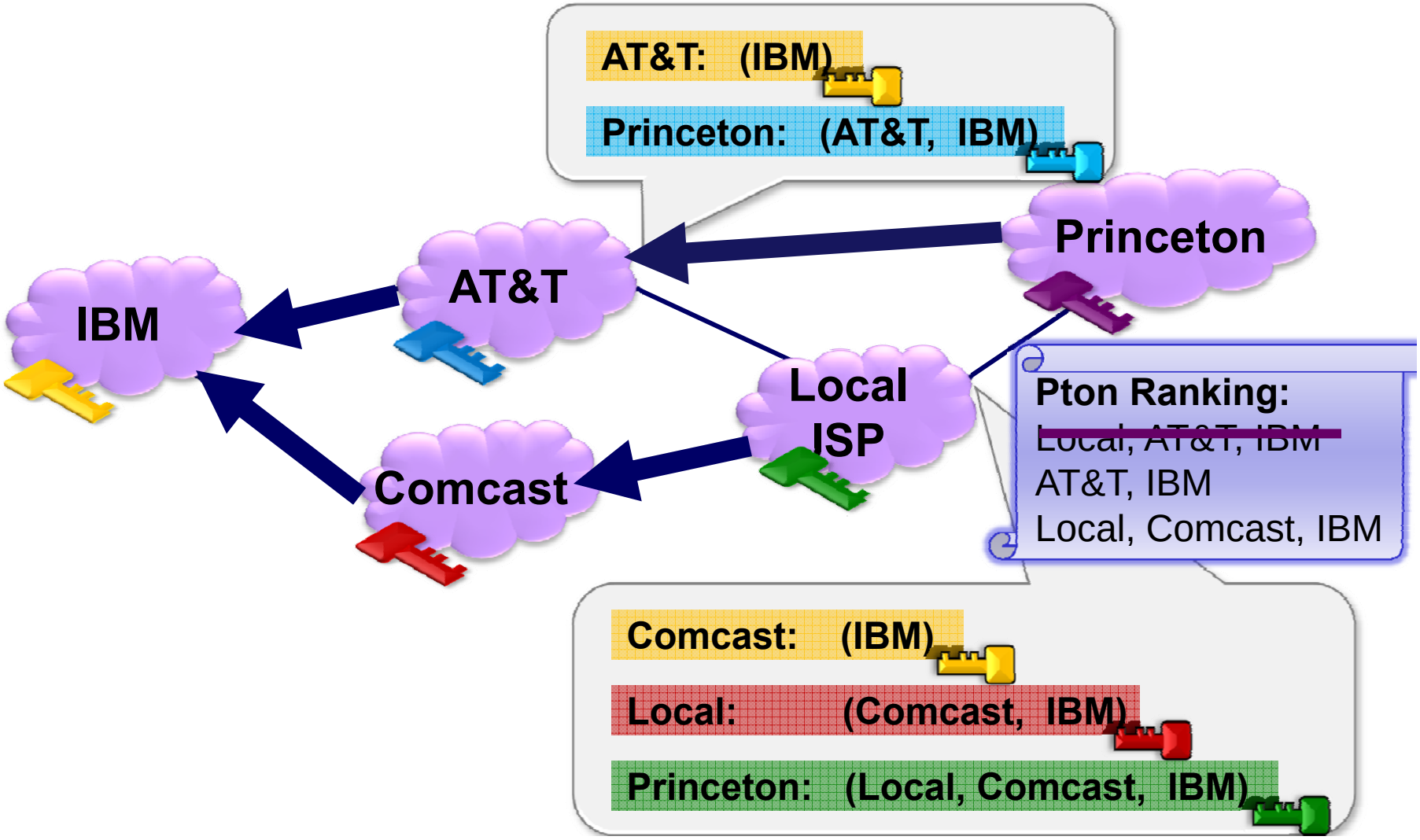
If AS **a** announced path **abP** then **b** announced **bP** to **a**

Assumes a public-key infrastructure that, today, we don't have.



Secure BGP (2)

If AS **a** announced path **abP** then **b** announced **bP** to **a**

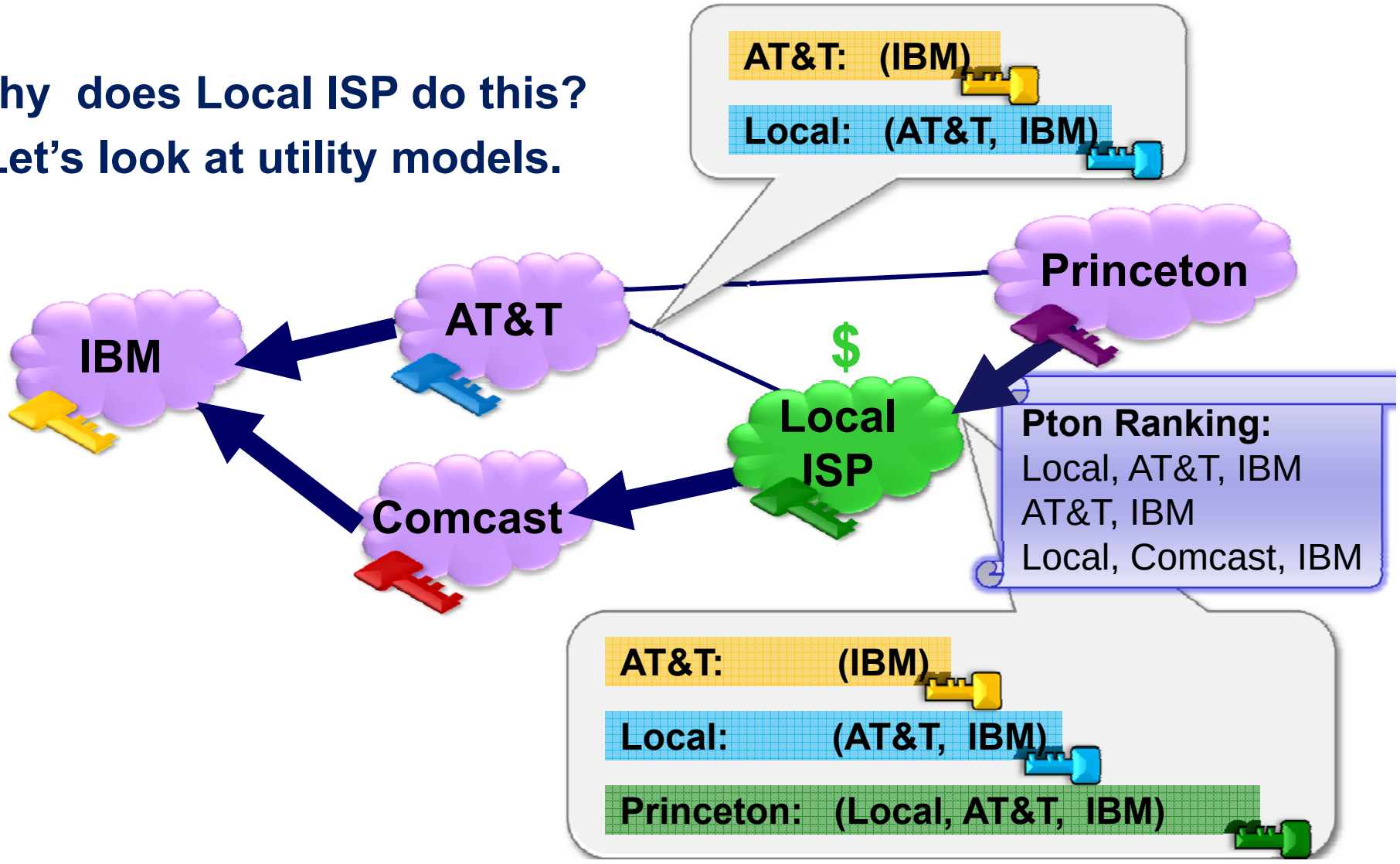


Secure BGP : Matching the Data Plane ???

If AS **a** announced path **abP** then **b** announced **bP** to **a**

Why does Local ISP do this?

Let's look at utility models.

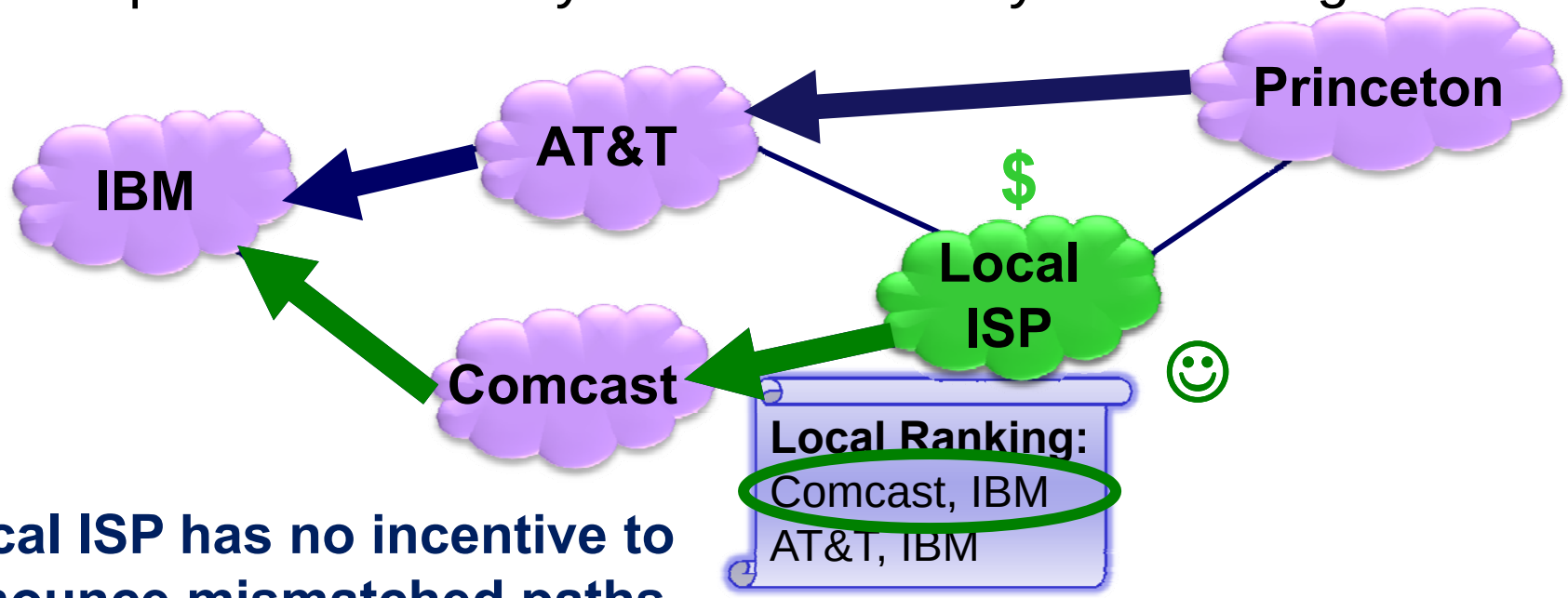


Modeling Utility

Our model of utility:

Utility of **AS** = Utility of outgoing (data-plane) path + Utility of attracted incoming traffic

In all prior work: Utility is determined by the ranking function



Local ISP has no incentive to announce mismatched paths.

Modeling Utility with Traffic Attraction

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Utility of **AS** = Utility of outgoing (data-plane) path + Utility of attracted incoming traffic

Traffic-volume attractions:

- **AS** only cares **who** originates traffic
- Models incentive to snoop / tamper
- … or increase incoming traffic volumes

Customer attractions:

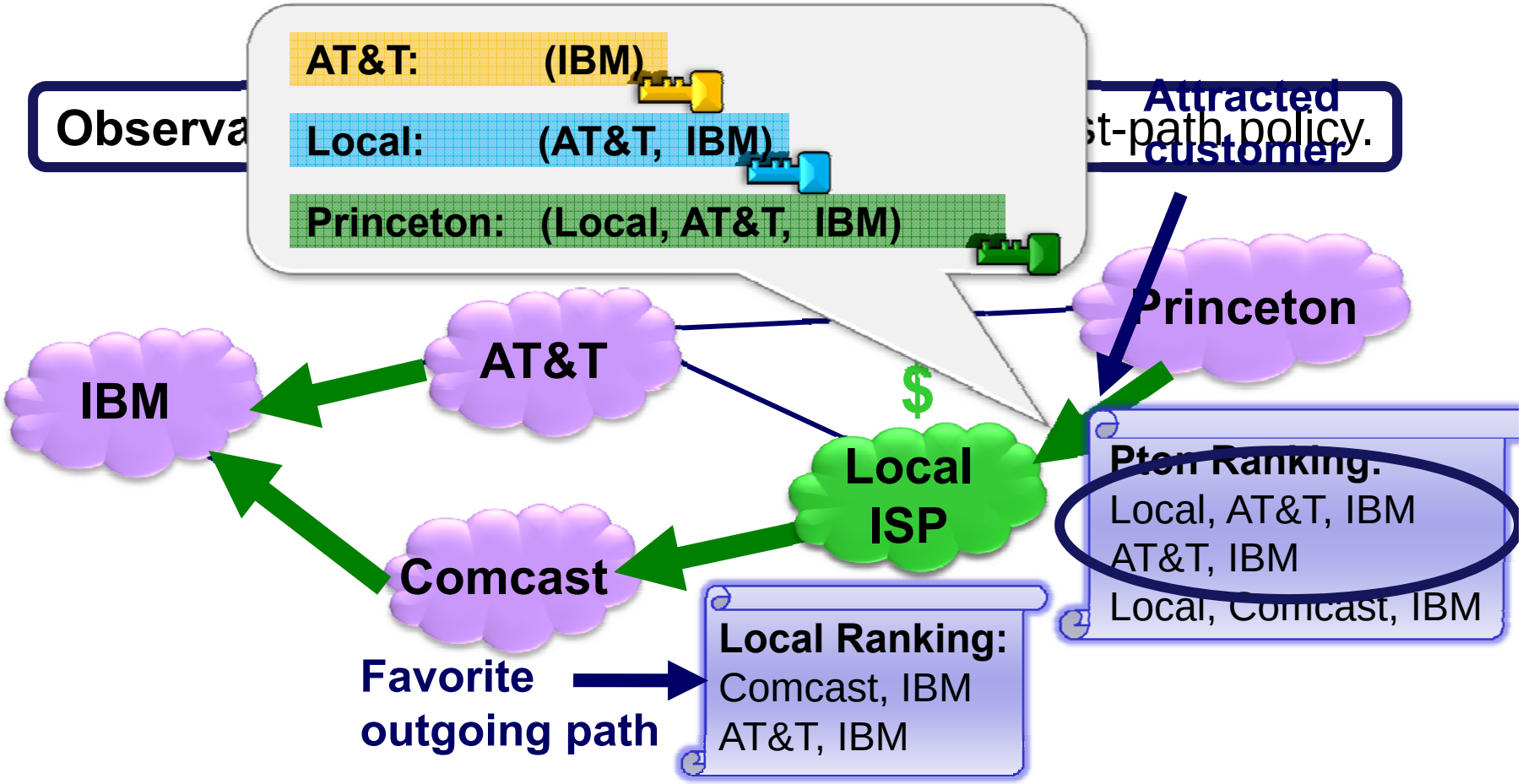
- **AS** wants to attract traffic from customers **via direct link**.
- Models bilateral economic relationships.

Generic attractions:

- **AS** wants to attract traffic from specific ASes via a specific path

Result: Secure BGP is not Sufficient!

With **traffic-volume** OR **customer** attractions, there can be an incentive to announce mismatched paths, **even with Secure BGP**.



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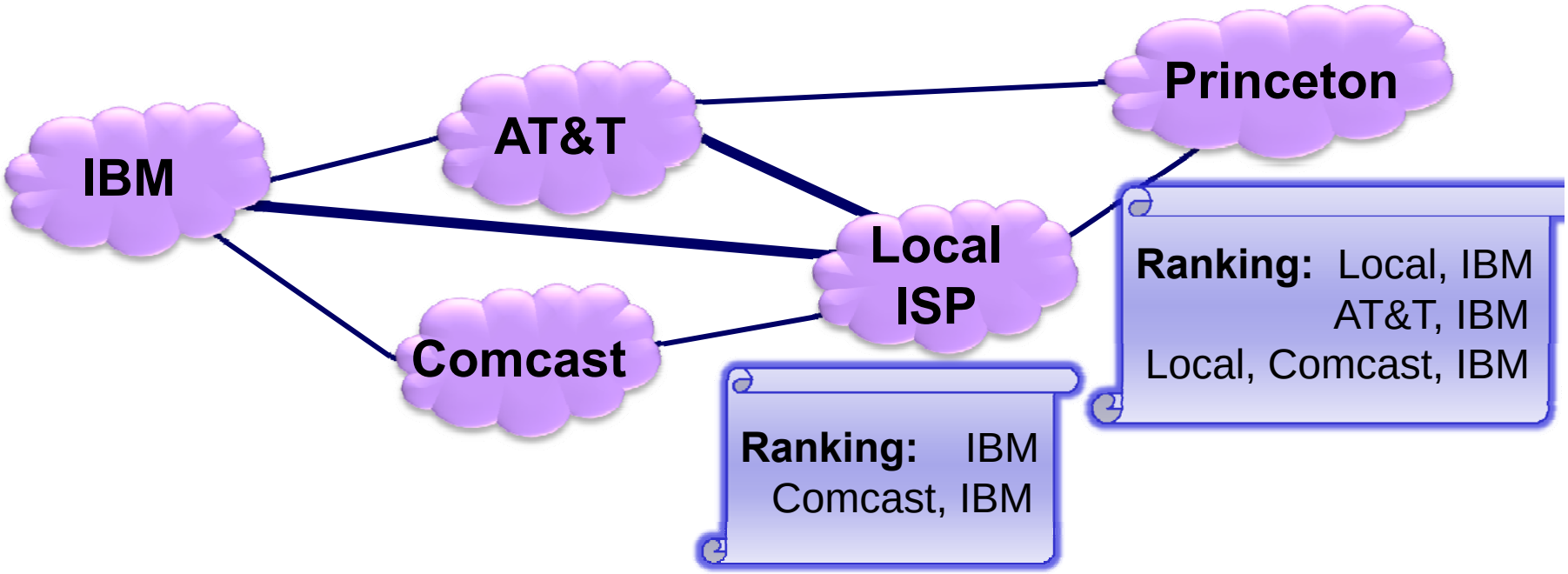

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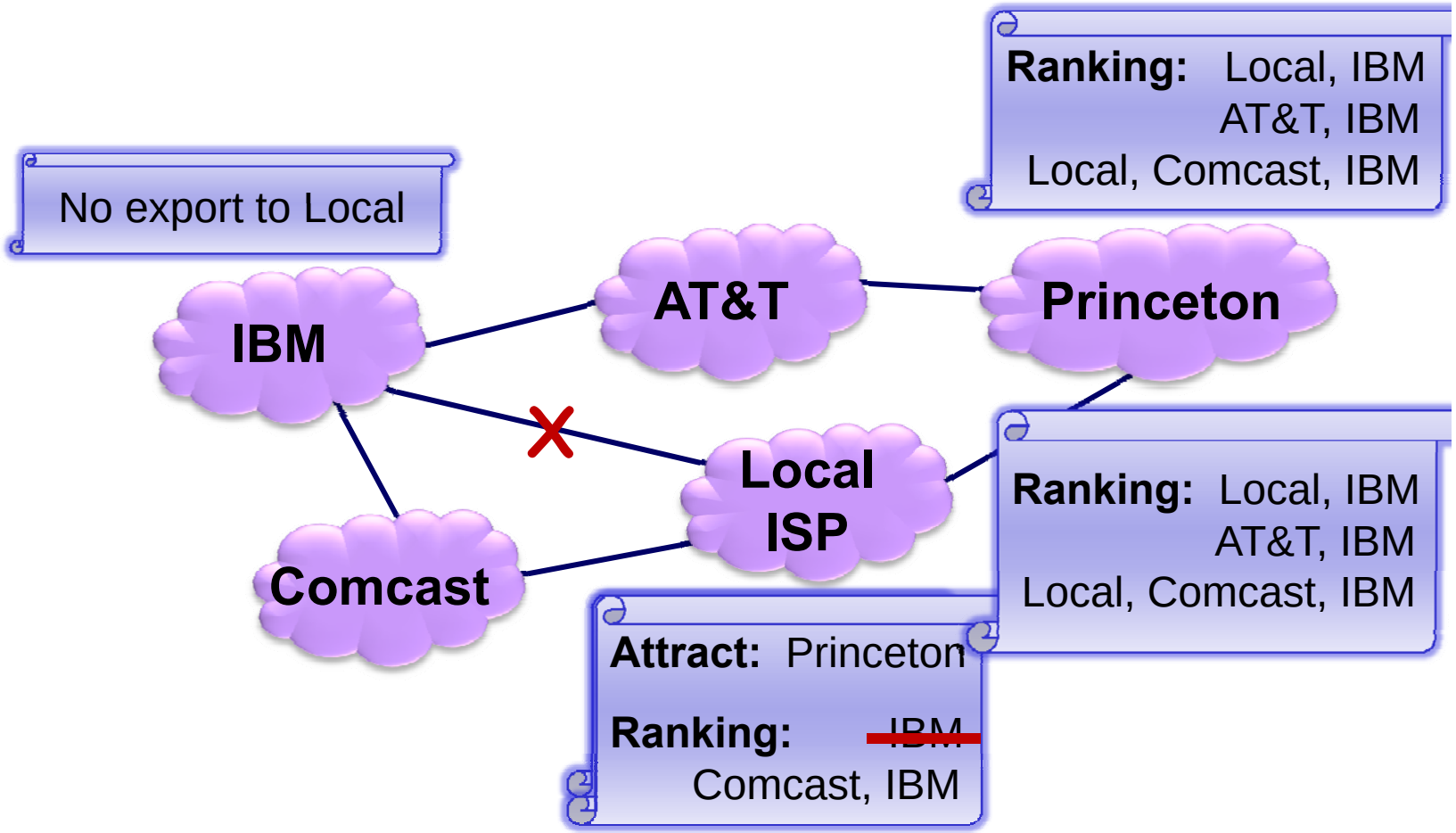

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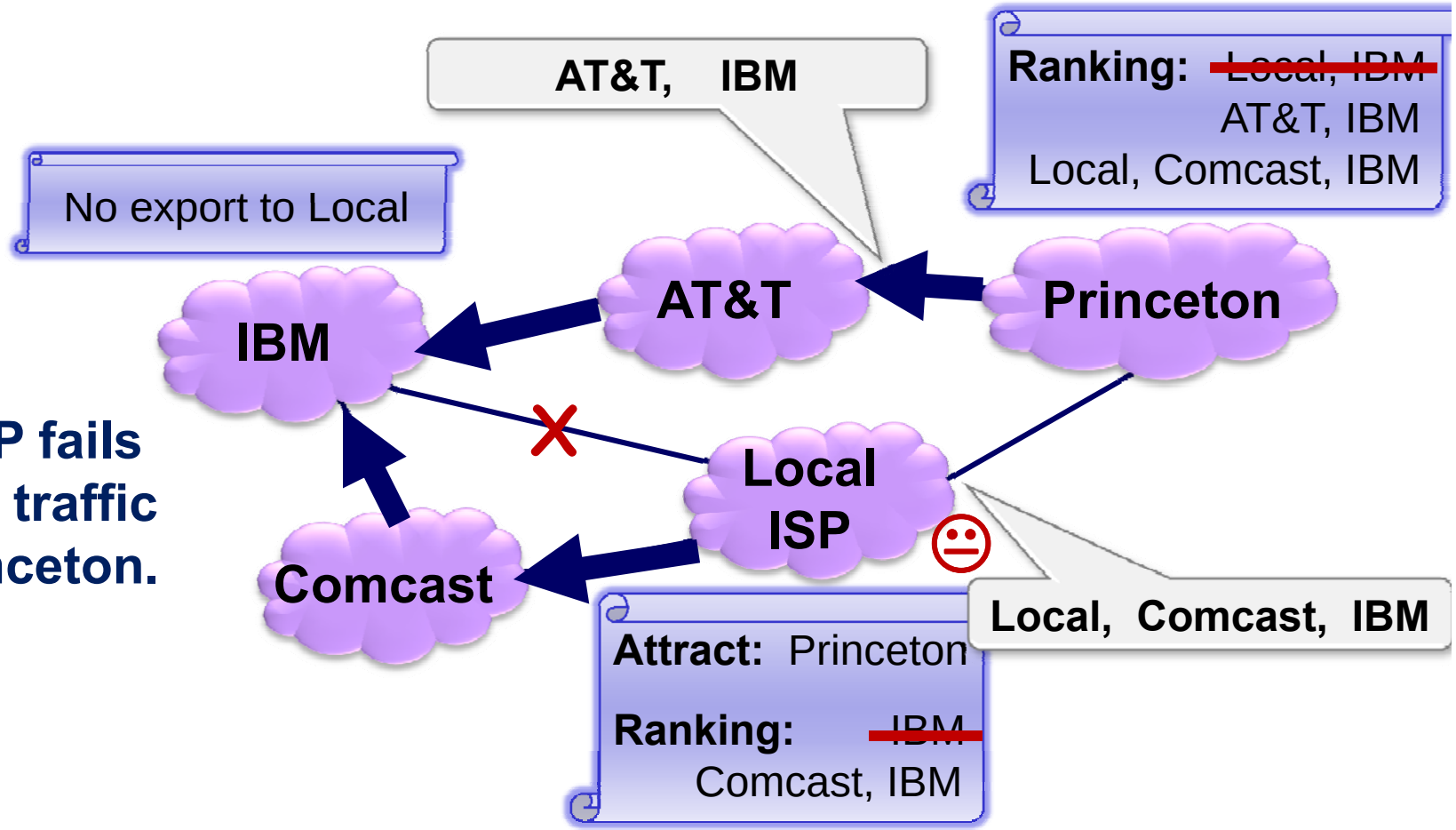

Local ISP fails to attract traffic from Princeton.

Result: Shortest-Path Policy is not Sufficient! (3)

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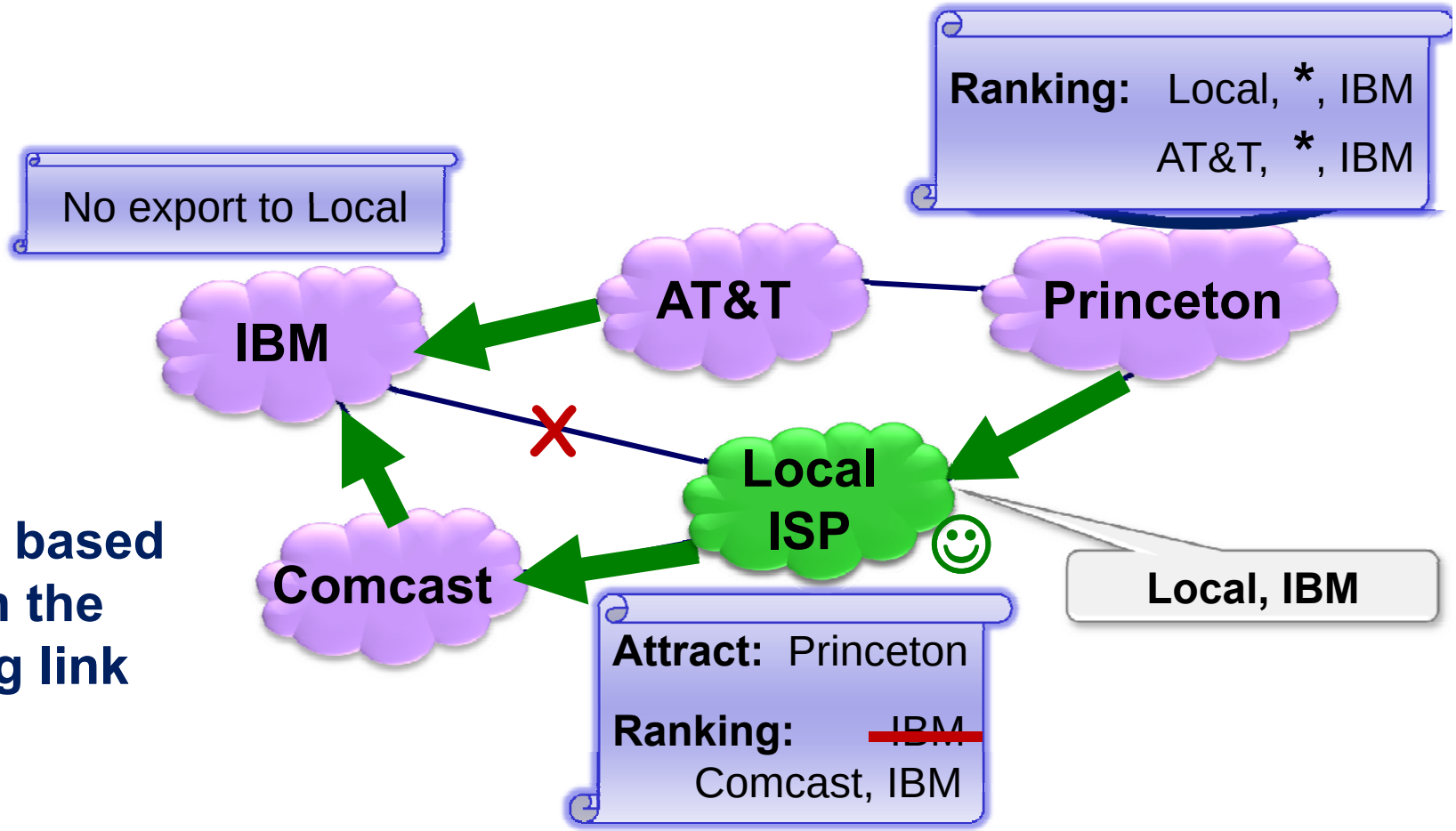

Rankings based only on the outgoing link

Observation: Princeton does not use a next-hop policy.

Secure BGP (1a)

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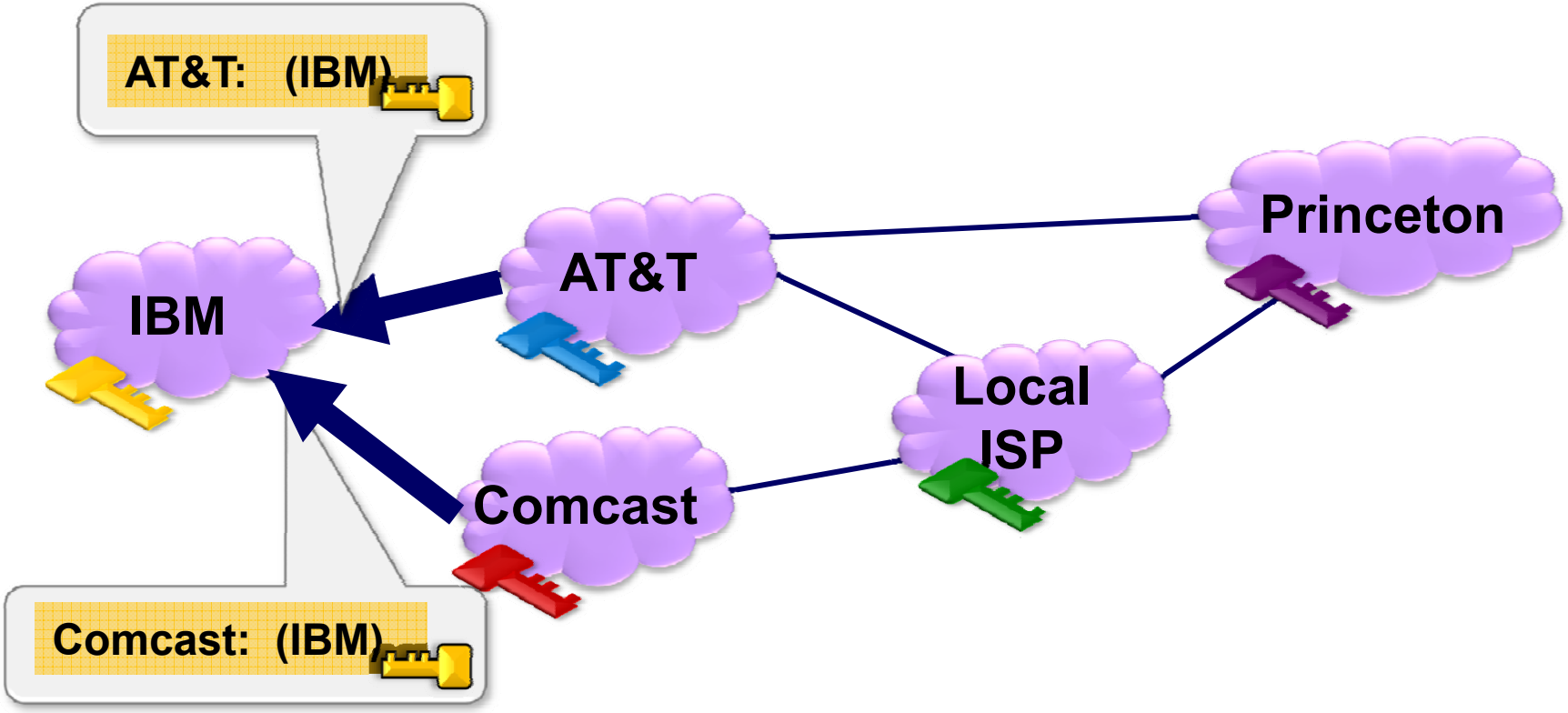
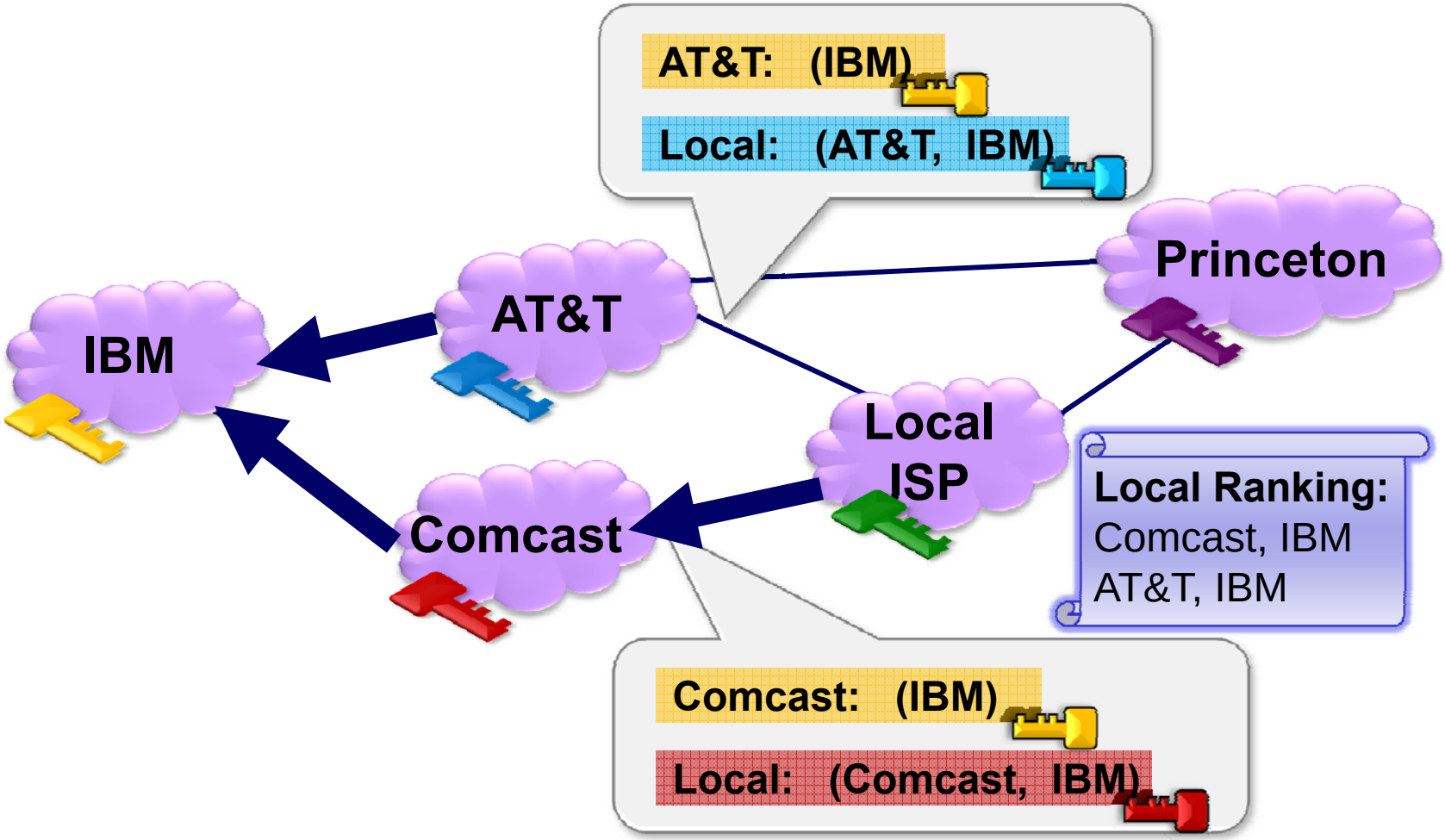


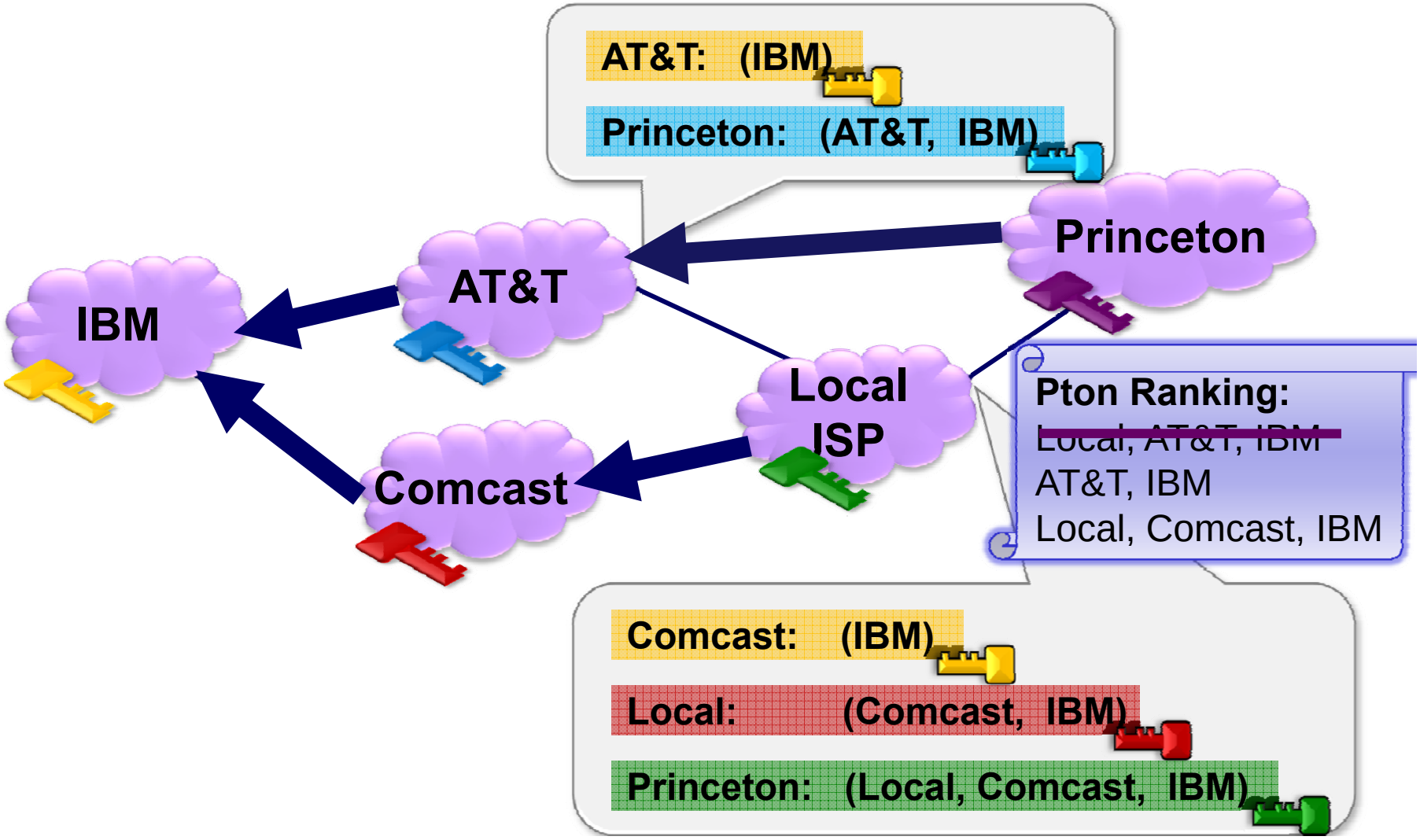
Secure BGP (1b)

If **a** announced path **abP** then **b** announced **bP** to **a**



Secure BGP (2)

If **a** announced path **abP** then **b** announced **bP** to **a**



Secure BGP : Matching the Data Plane ???

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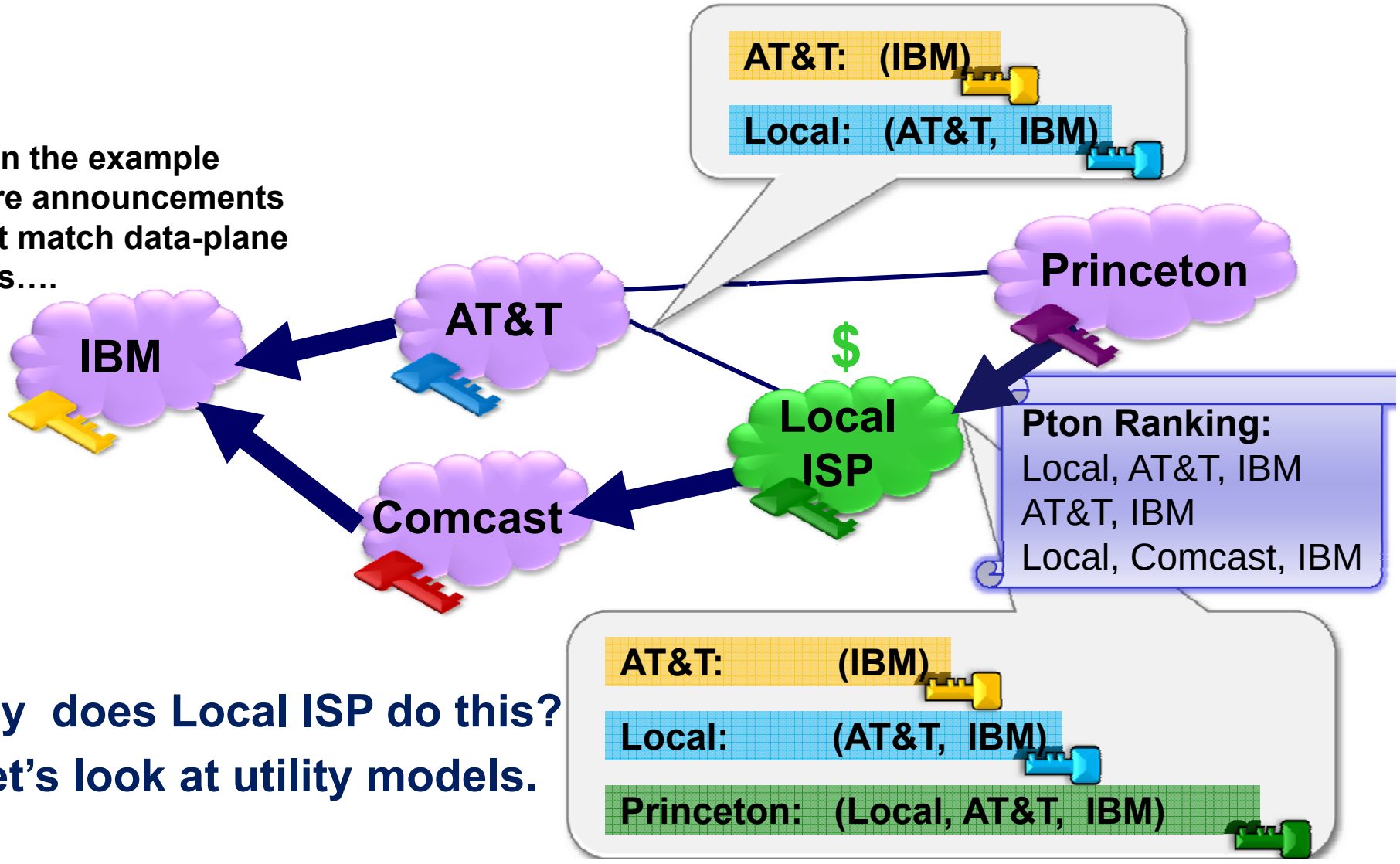
Again the example where announcements don't match data-plane paths….



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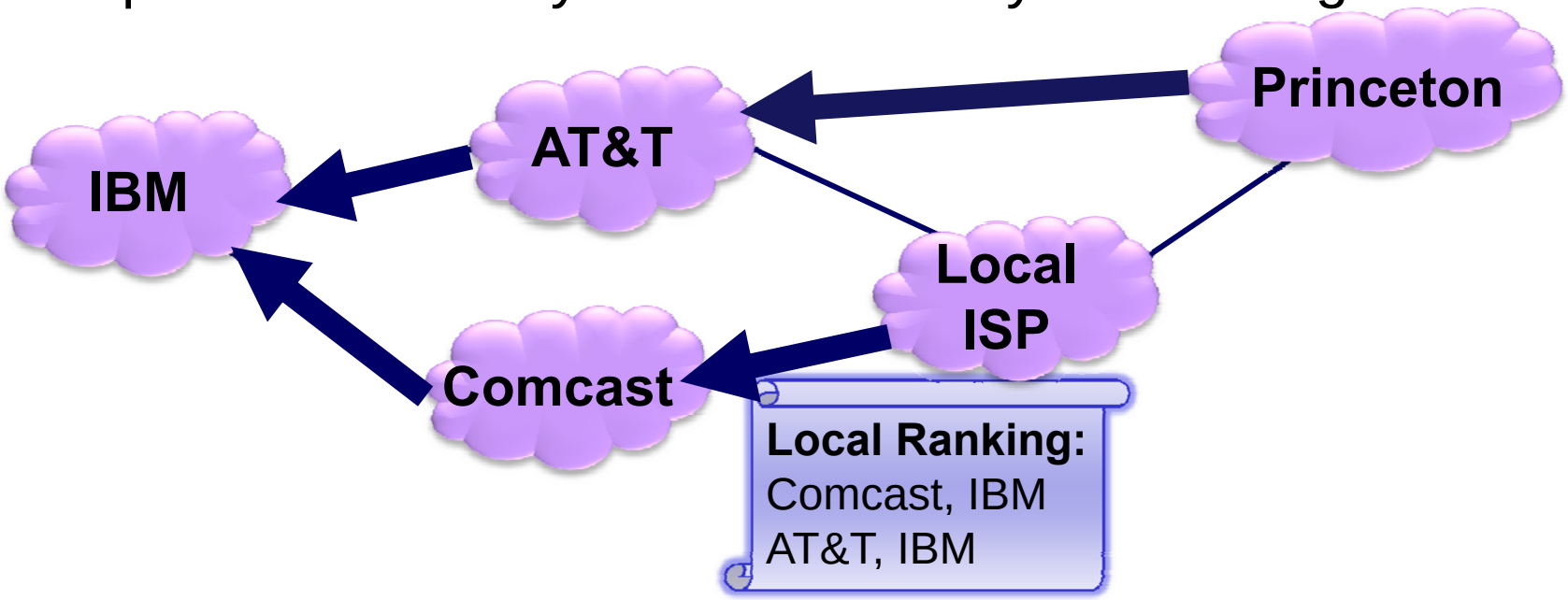

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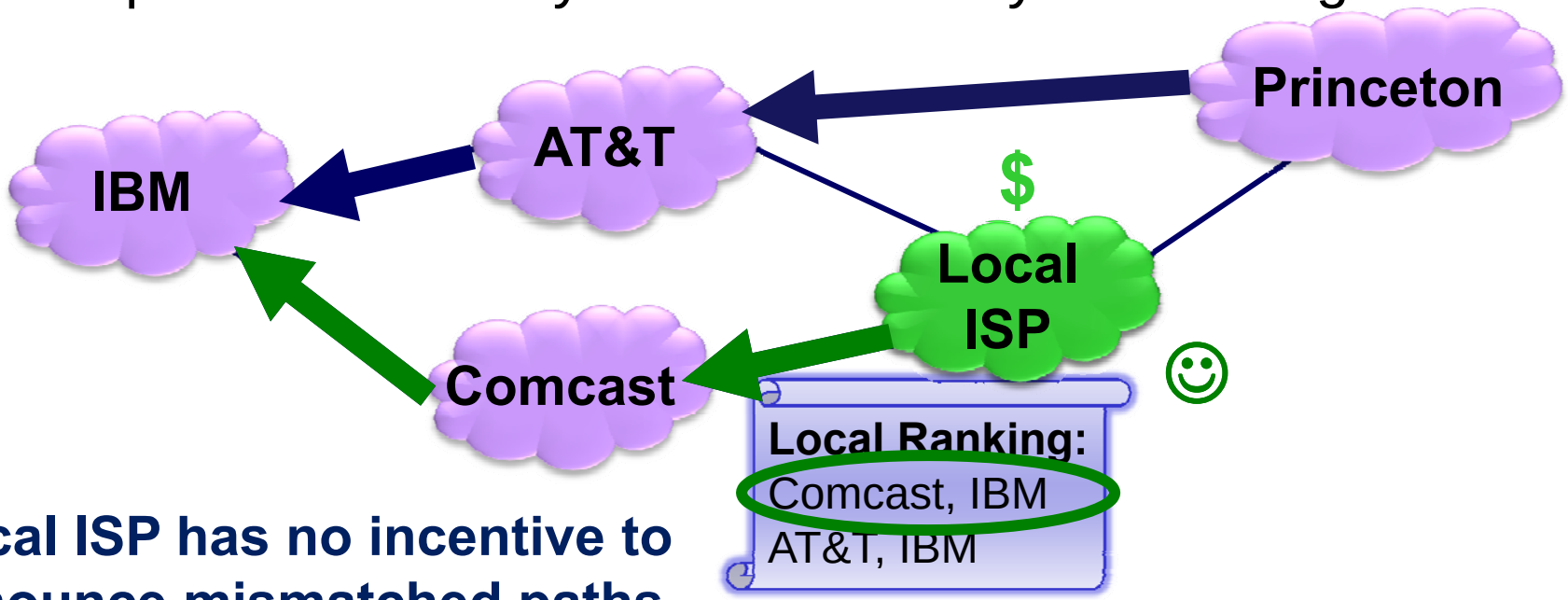

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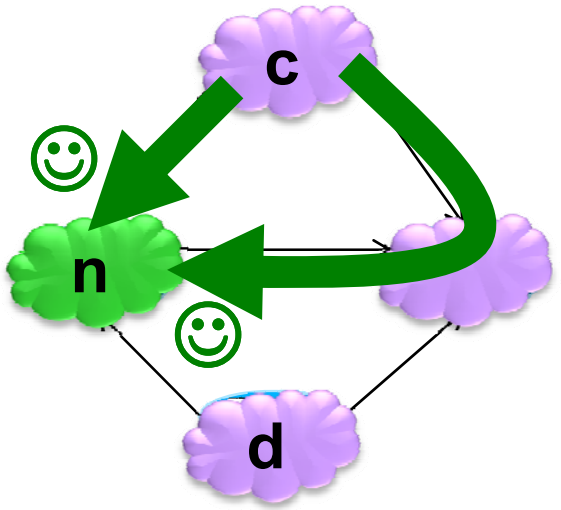

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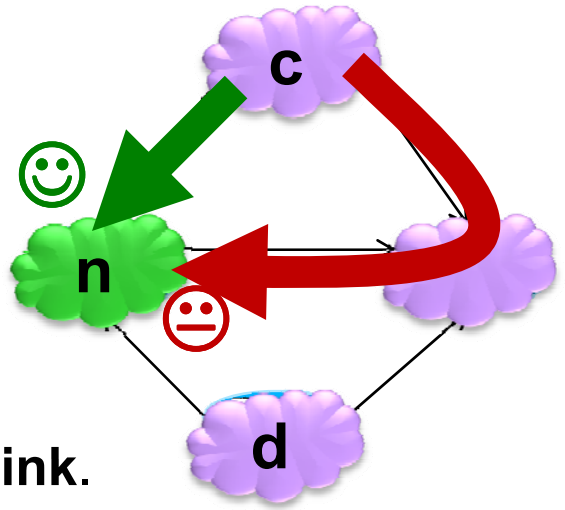

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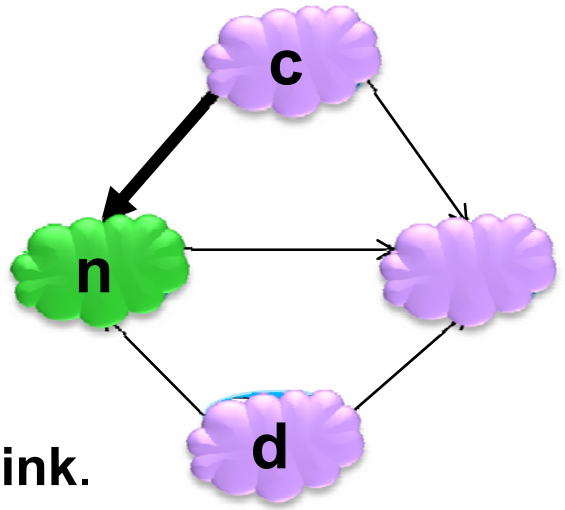

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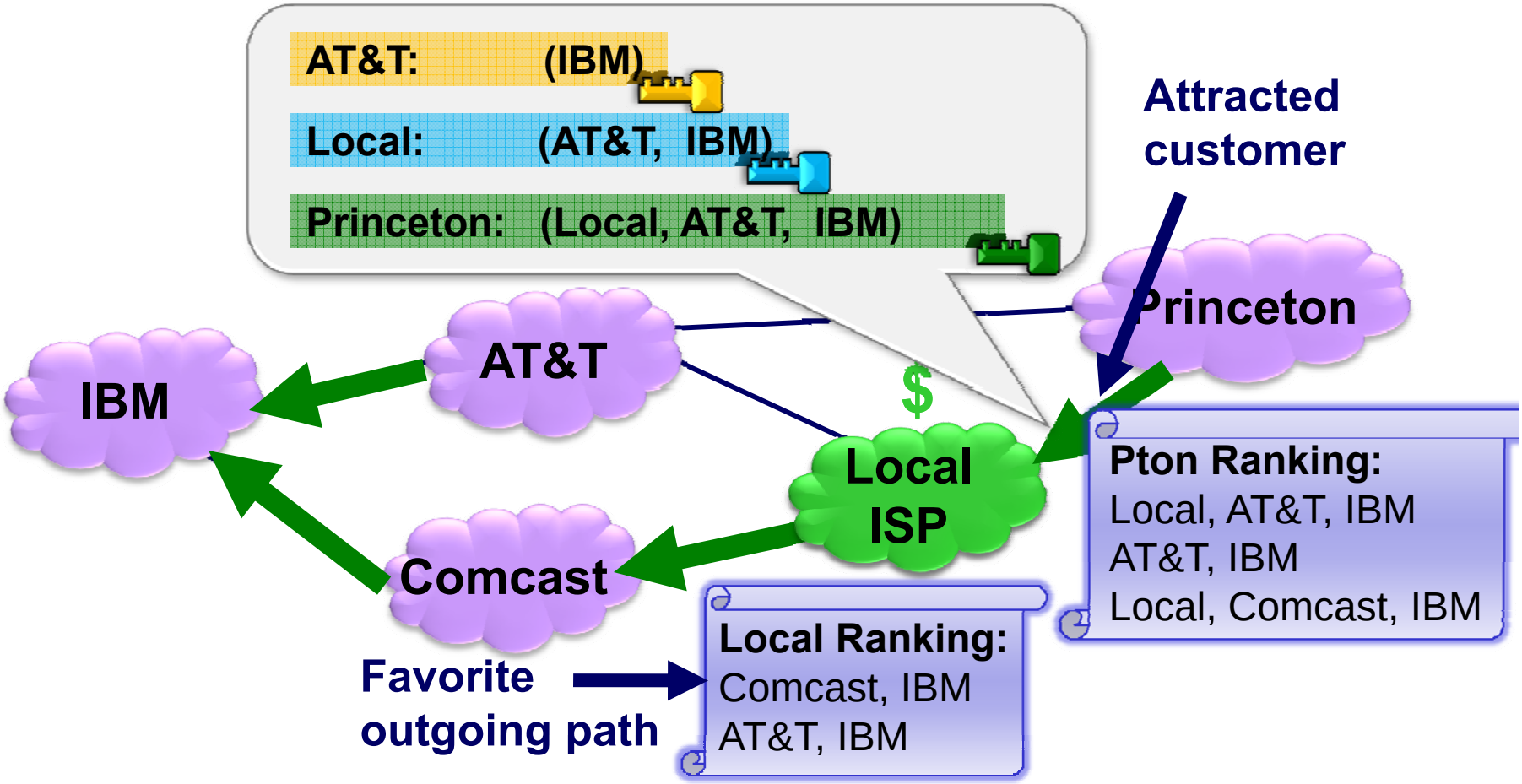

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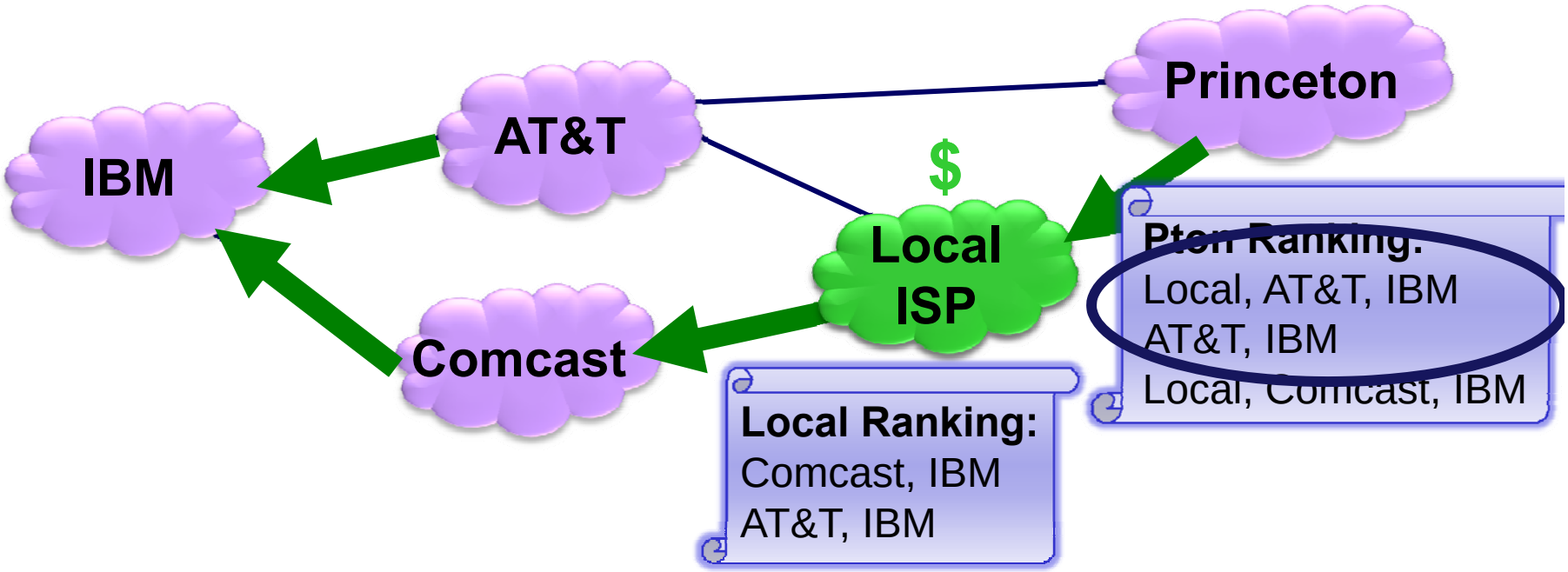

Observation: Princeton does not use a shortest-path policy.

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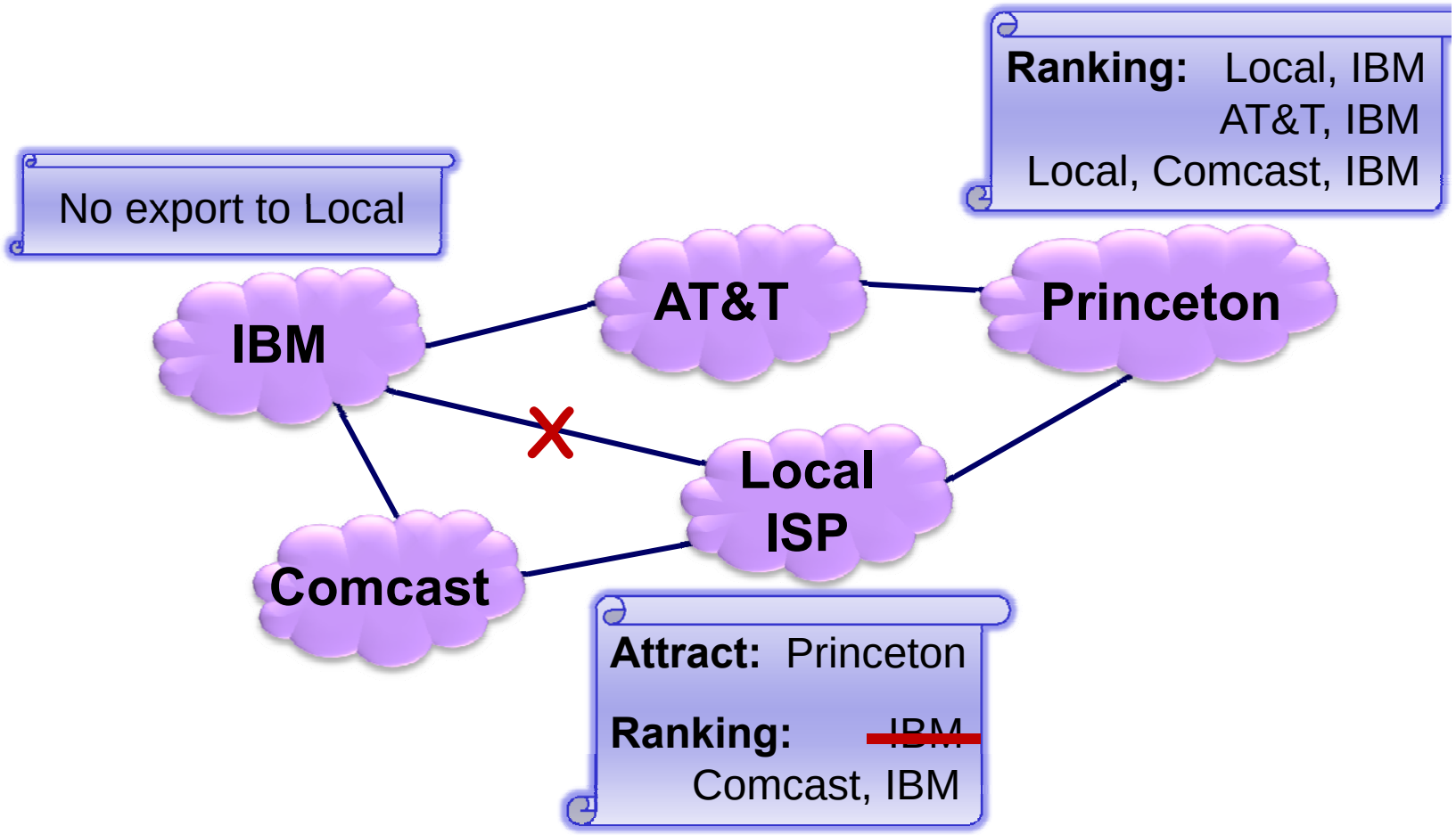

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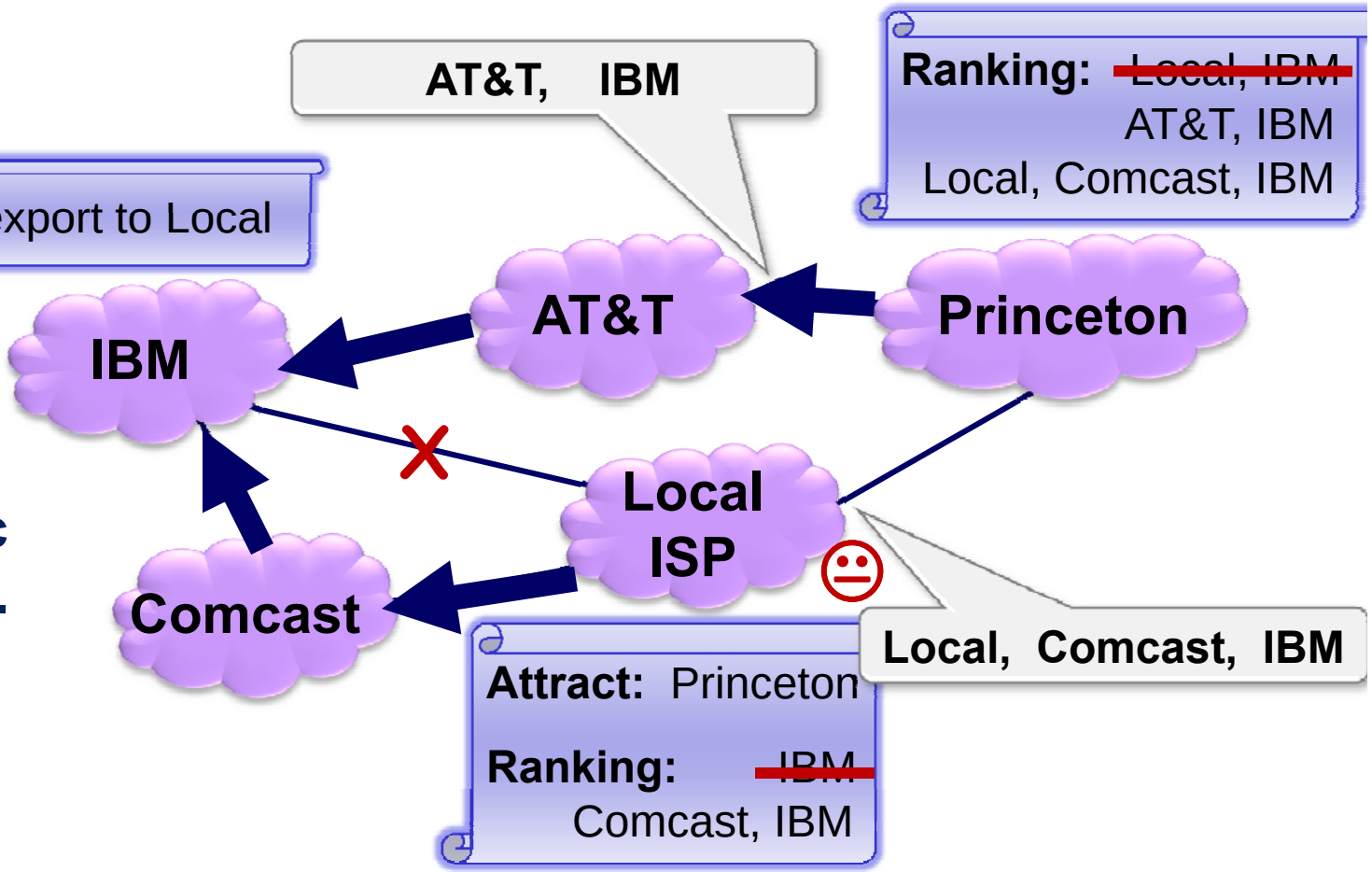

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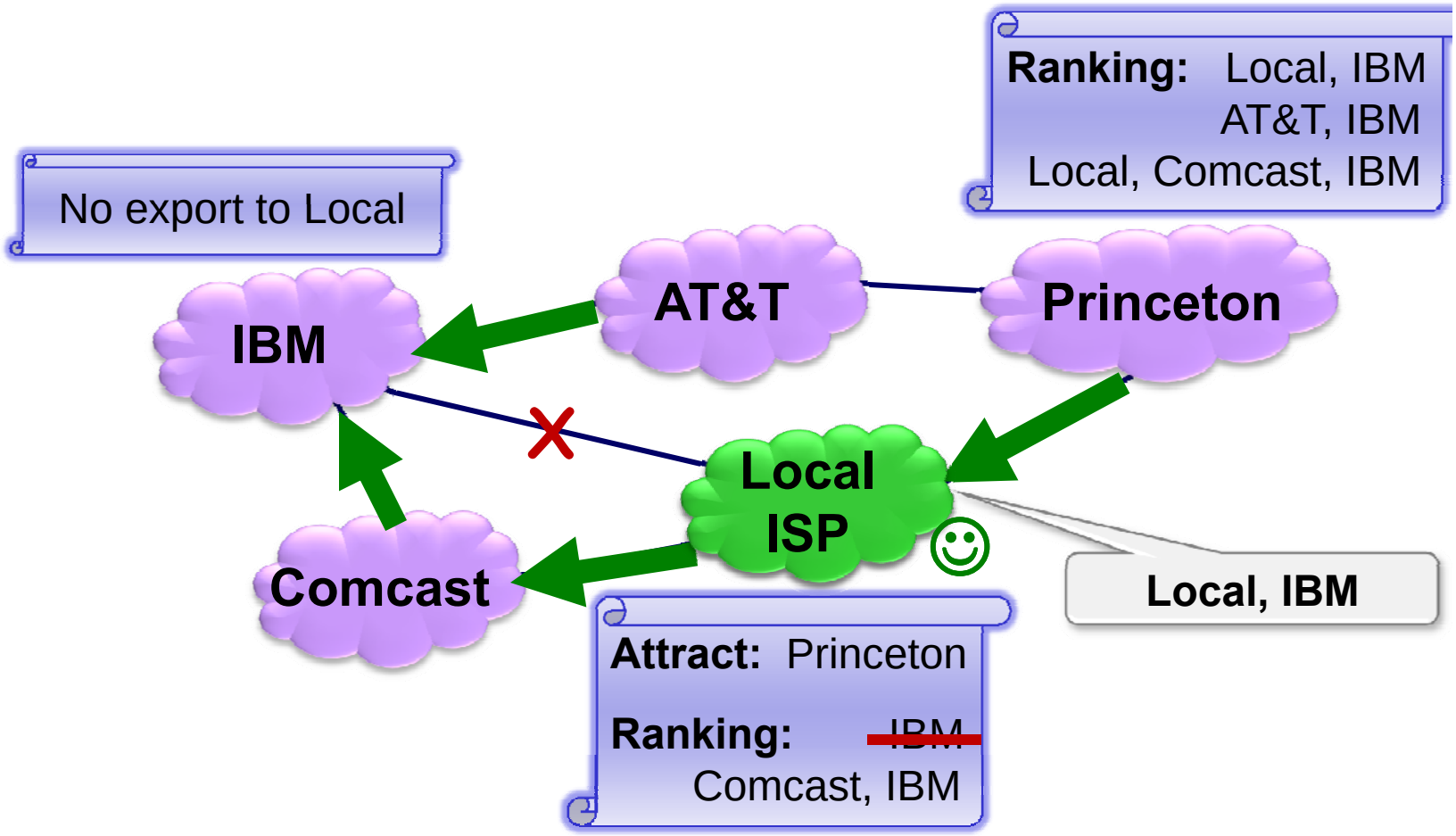

Result: Shortest-Path Policy is not Sufficient! (4)

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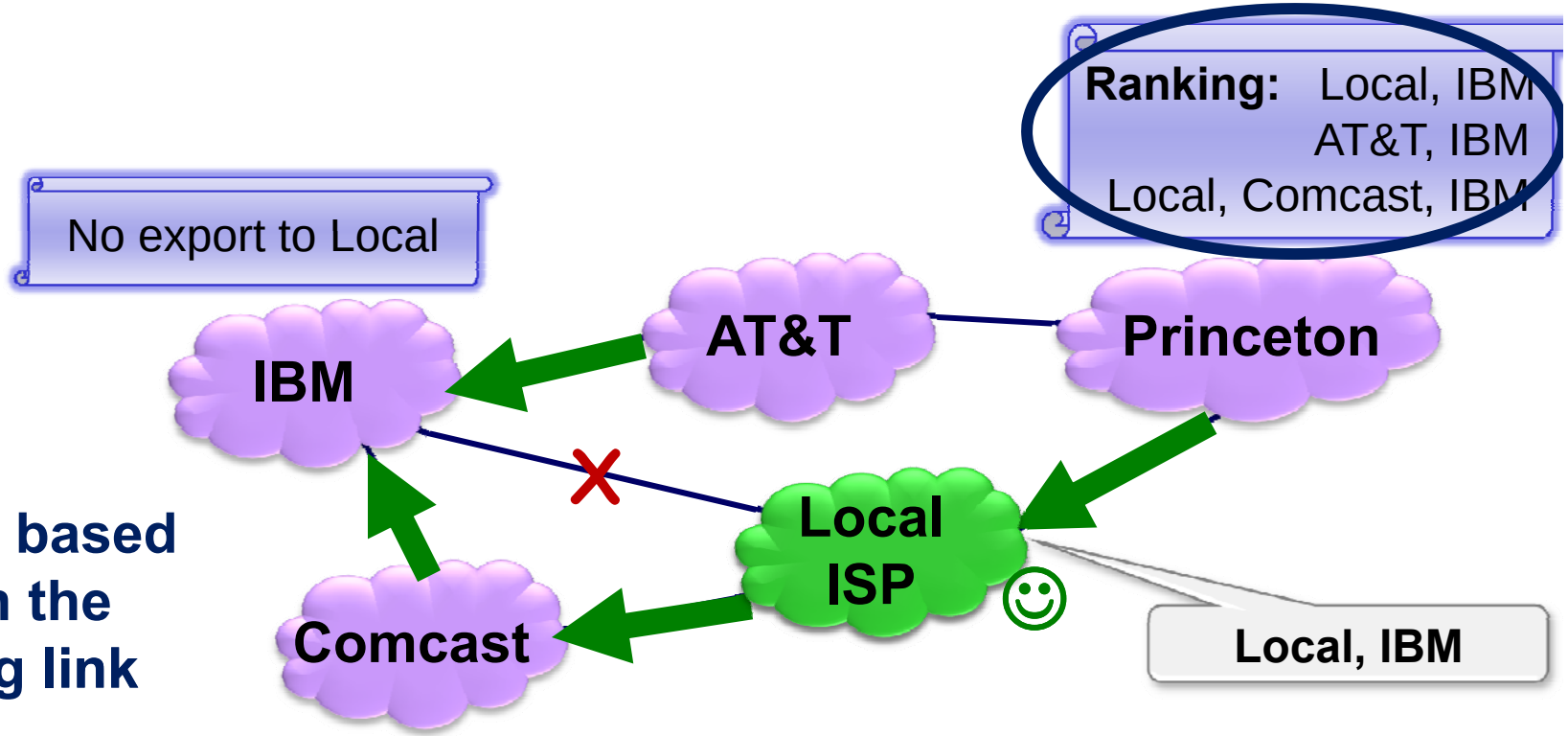


Rankings based only on the outgoing link

Observation: Manipulation not possible with Secure BGP.

Observation: Princeton does not use a next-hop policy.

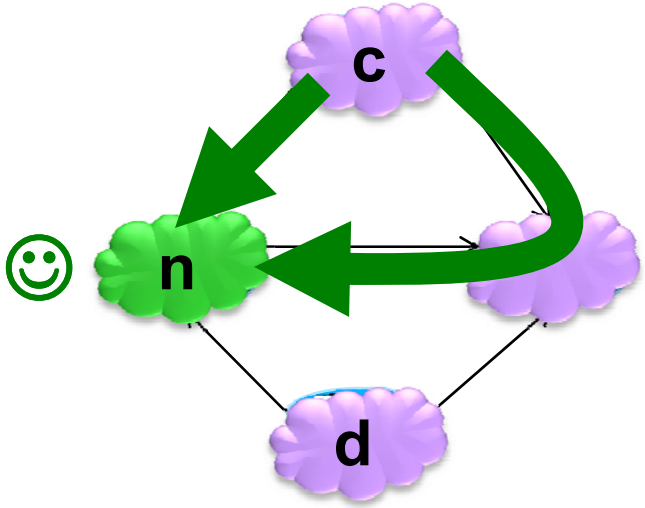
Theorem: Traffic Volume Attractions

When all attractions are **traffic volume**, nodes have no **incentive** to **unilaterally** announce mismatched paths if all nodes in the network use either:

1. **Secure BGP**, and
2. **Policy consistency**;

OR

1. **Next-hop policies;**



and there is no dispute wheel in the network

and there is consistent export (in the first case) or all-or-nothing export (in the second case).

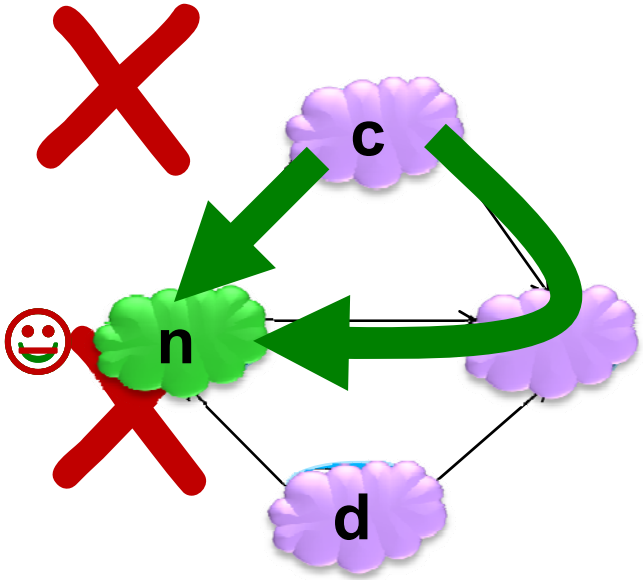
The exact statement of this result is in the paper

What about Customer Attractions? (1)

Are these sufficient if we have customer attractions?

1. **Secure BGP**, and
2. **Policy consistency**;

1. **Next-hop policies;**

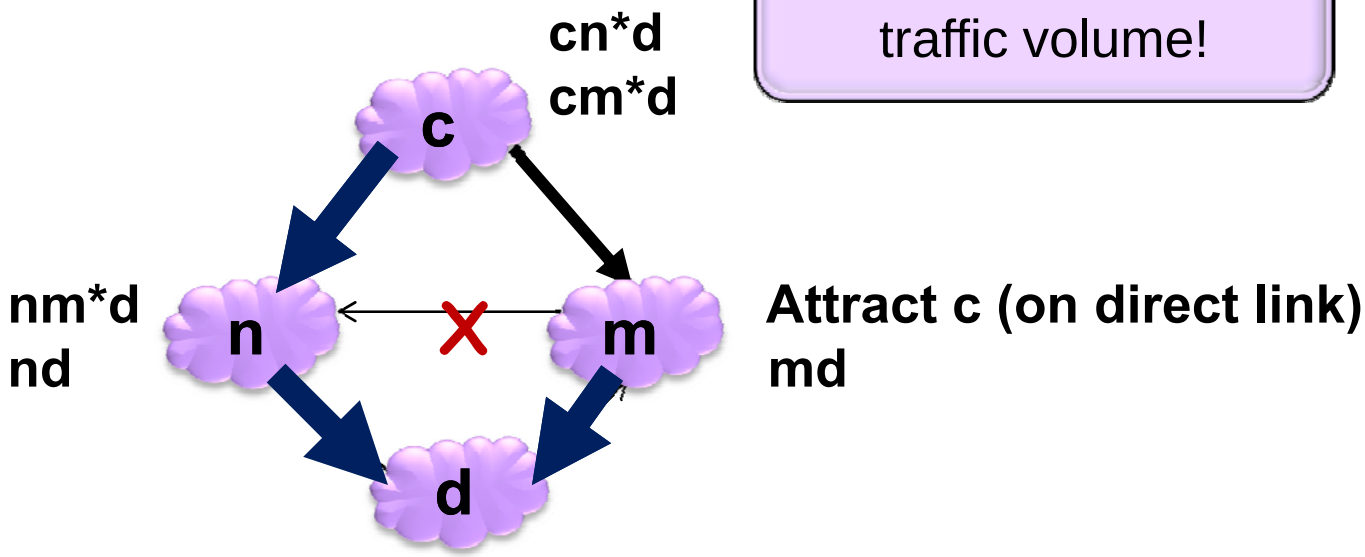


Customer attractions:
Attract customers **via direct link**.

Customer Traffic Attraction (1a)

With **customer** attractions, there can be an incentive to announce false paths, **even if all nodes use next-hop policy.**

This was sufficient for traffic volume!



Observation: All nodes use next-hop policy.

Customer Traffic Attraction (1b)

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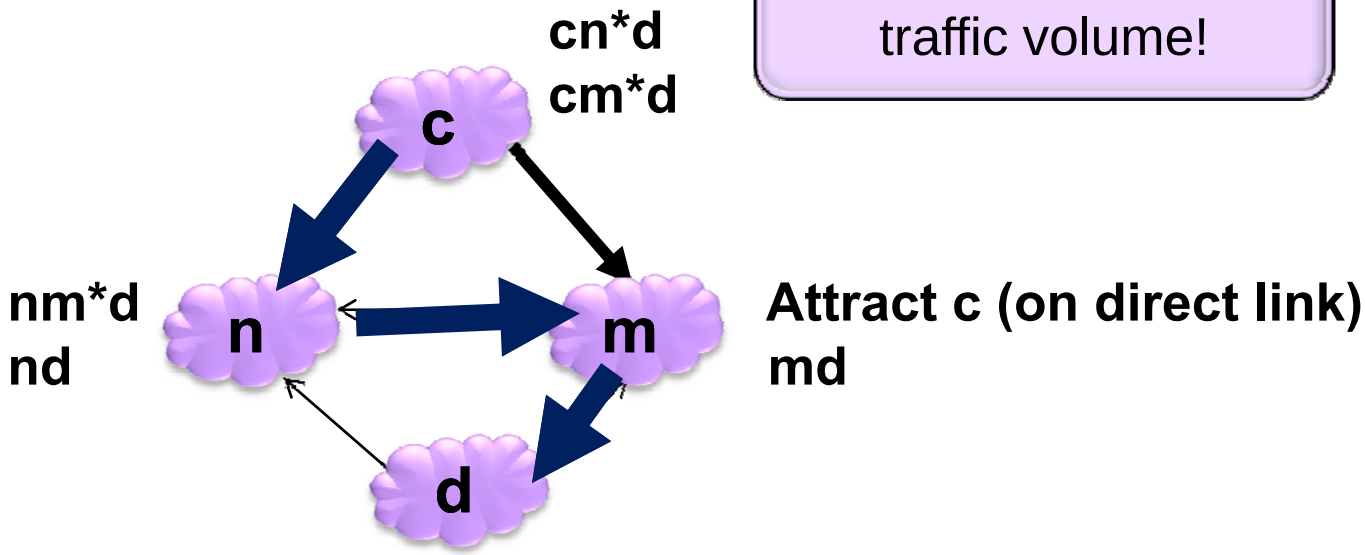

Observation: All nodes use next-hop policy.

Customer Traffic Attraction (2)

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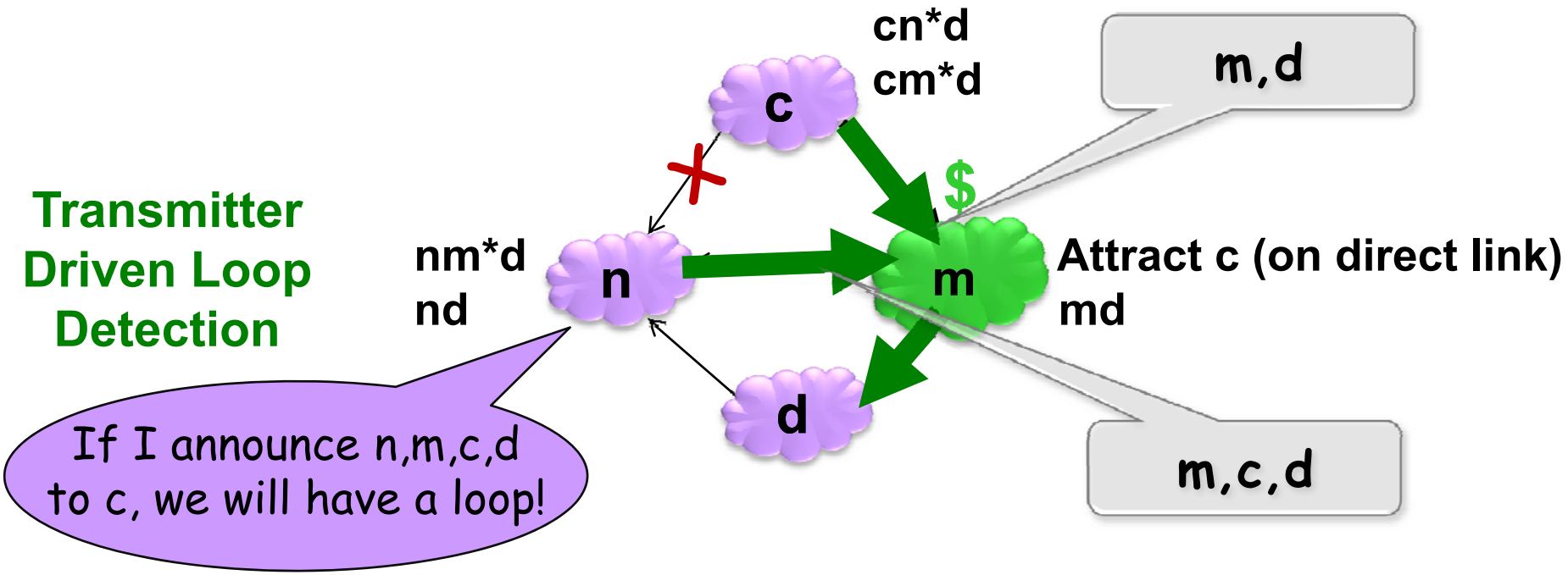
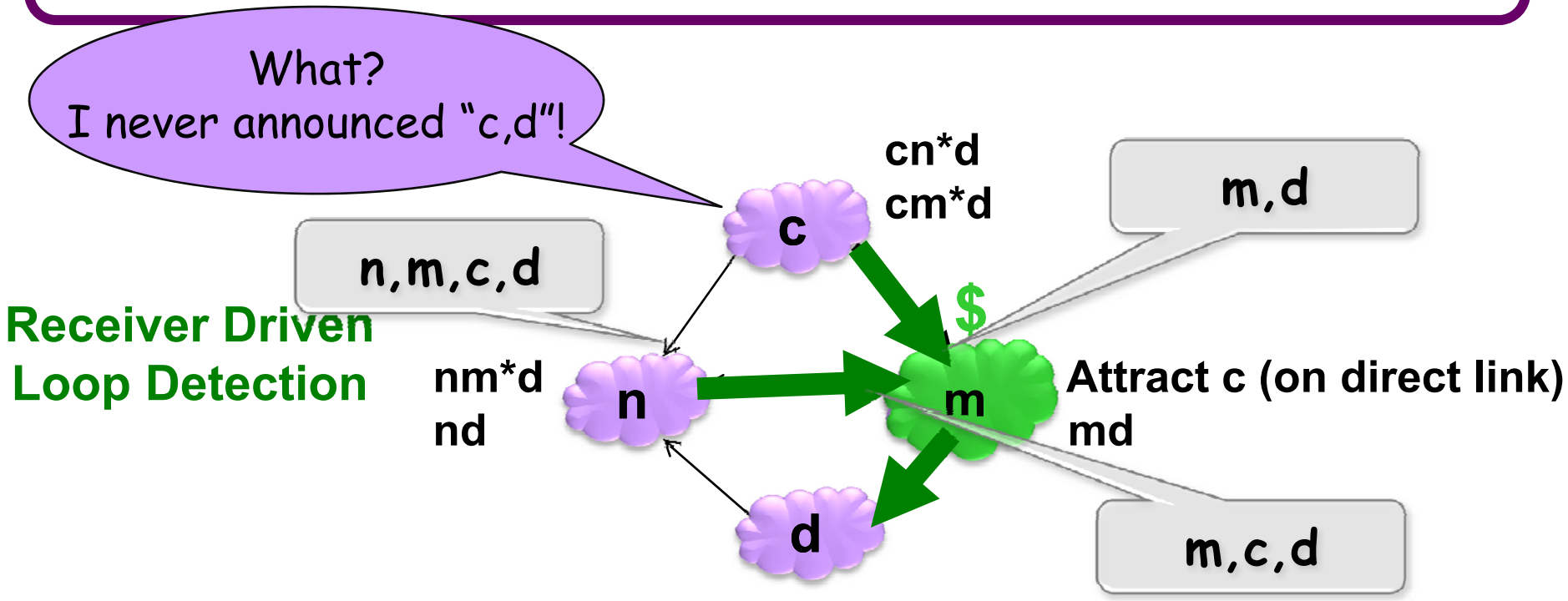


Observation: All nodes use next-hop policy.

Customer Attractions: Introducing Loop Verification

With **customer** attractions, there can be an incentive to announce false paths, **even if all nodes use next-hop policy.**



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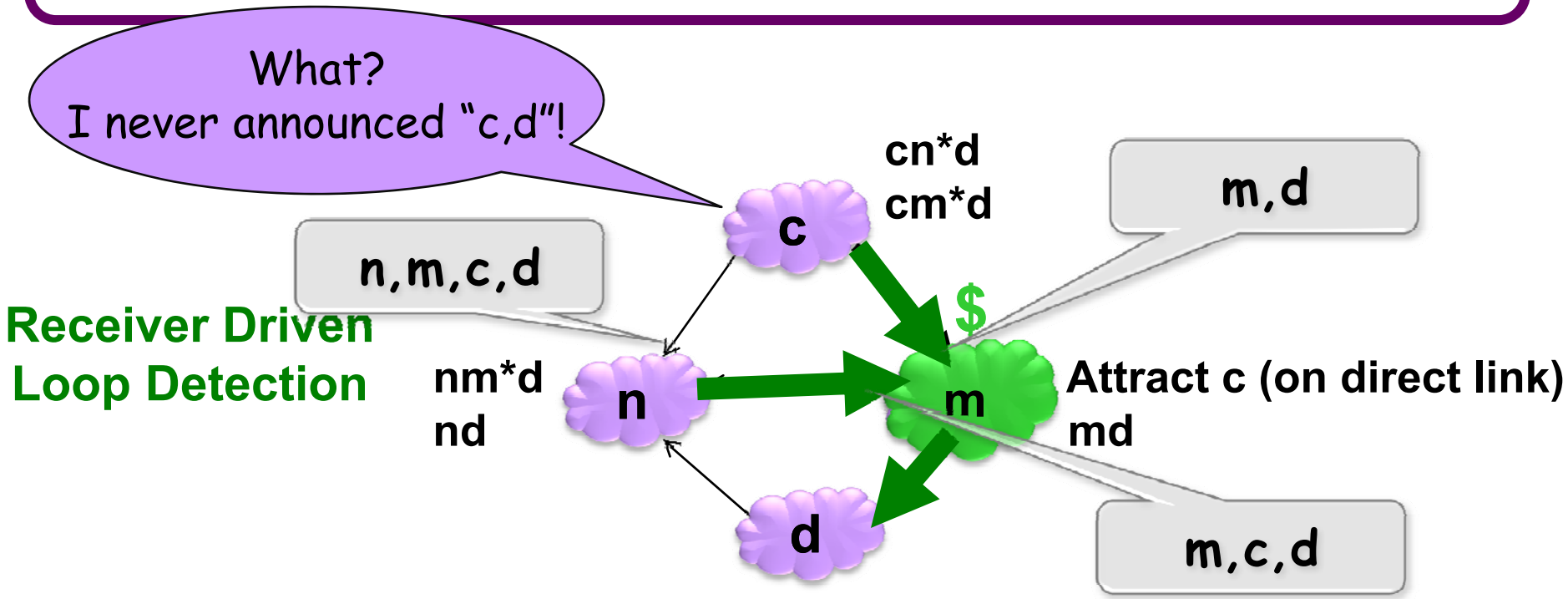


Loop Verification:

If **c** receives announcement **QcR** but **c** did not announce path **R** then the lying node on path **Q** is punished with zero utility.

Models "fear of getting caught'. Also implied by Secure BGP.

Somewhat More Formally …

With **generic traffic attraction**, there exists an honest strategy that obtains the best possible stable outcome for each node (*i.e.* that each node has no incentive to **unilaterally** mismatch paths), if every node uses

1. **Loop verification,** and
2. **Next-hop policies,** and
3. **All or nothing export.**

and there is no dispute wheel in the network

Removing any condition gives a counterexample 

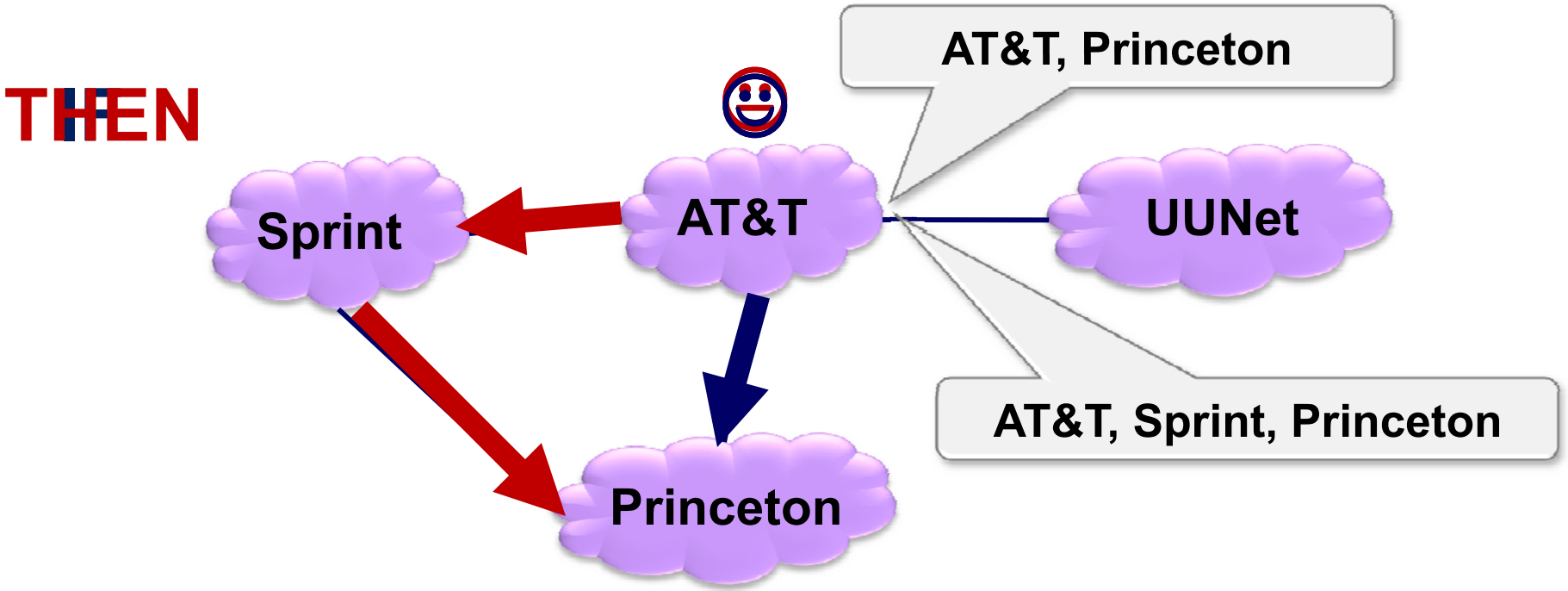
The exact statement of this result is in the paper

All-or-Nothing Export

For each neighbor, either export all paths or export none.

Path-based egress filtering is not allowed!

(Incompatible with practice.)



AT&T makes money because it delivers traffic to a customer.

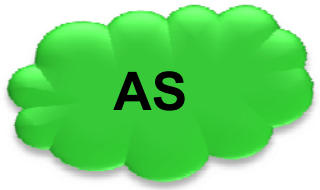
AT&T loses money because it transits traffic between its peers.

Conclusions

What conditions ensure BGP messages match data-plane paths?

- **Secure BGP** is not sufficient
- …if it is rational for ASes to want to **attract traffic.**
- Generally, we need **next-hop policy** as well as
- … other conditions (no dispute wheel, no egress filtering).

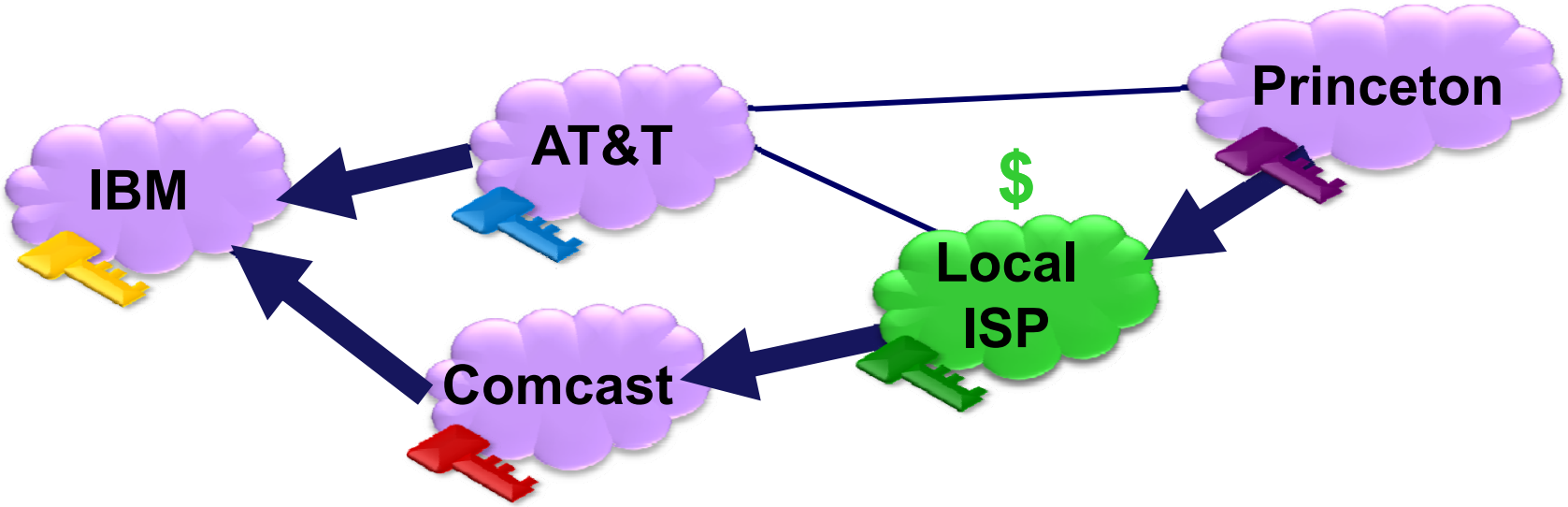
Also, notice how strongly results depend on utility model.



What should we do?

- Use expensive **data-plane protocols**?
- **Forget about** matching BGP messages to data plane?
- Allow ASes to send traffic on **more than one outgoing link**?

Thanks!



Full version with all proofs and counterexamples available:

www.princeton.edu/~goldbe/

Formalizing the Model

Acts on data plane

Acts on control plane

Utility

Satisfaction of node **n** with a data-plane routing outcome **T**

$$u_n(T) = v_n(T) + \alpha_n(T)$$

$v_n(T)$ is the **valuation function**

Satisfaction of ***n*** is with his **outgoing path** in ***T***

$\alpha_n(T)$ is the **attraction function**

Satisfaction of ***n*** with **incoming traffic in T**

compile

Ranking

Ranking of **outgoing paths**

Used by **n** in BGP decision process

$$r_n(T)$$

Export

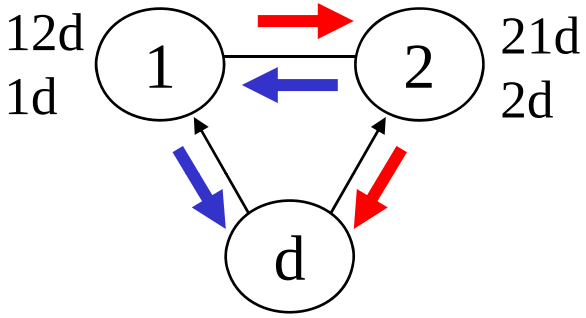
The set of neighbours to which **n** is willing to announce path **P**

$$e_n(T)$$

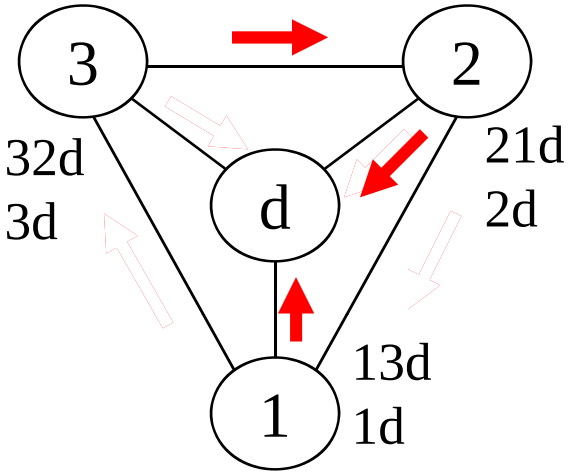
Formal model

Stability: No Dispute Wheel

A dispute wheel is a cycle of nodes with rankings that prefer paths through neighbours over direct paths



Disagree: 2 stable outcomes



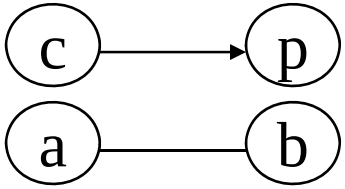
Bad Gadget: no stable outcomes

Without traffic attraction [GSW01]: The network has a unique stable outcome when there is no **dispute wheel** in the rankings.

The Gao-Rexford Conditions

Adjacent nodes have a **customer-provider relationship:**

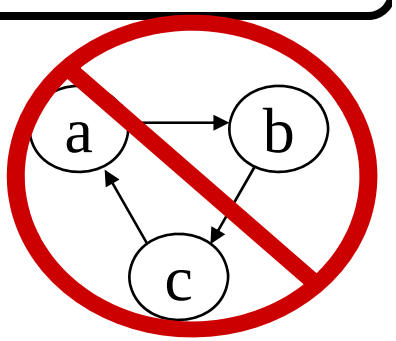
or a **peer-peer relationship:**



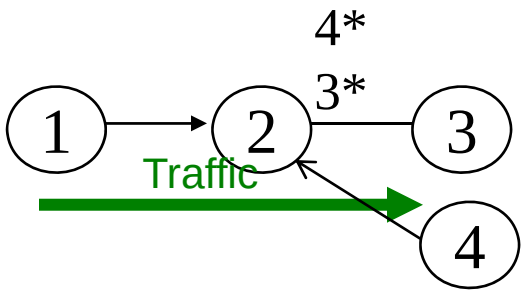
Customer pays provider for service

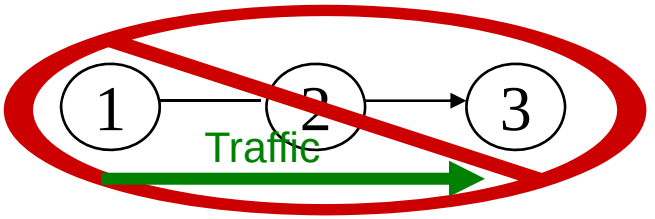
Transit each other's traffic for free.

Topology: No customer-provider cycles in the network.



Transit: Transit traffic only for your customers.





Preferences: Prefer customer routes to peers & providers.

Attractions: Only want to attract traffic from your customers.