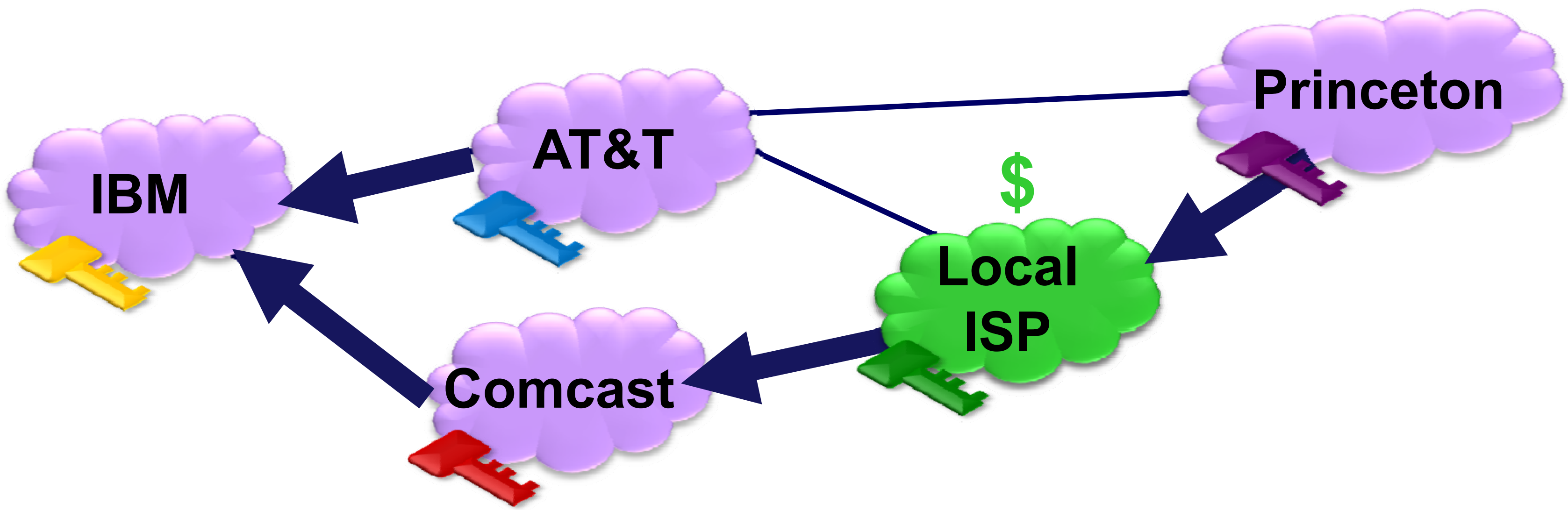
Rationality and Traffic Attraction

Incentives for Honest Path Announcement in BGP



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SIGCOMM 2008

Incentives and Security

We use game theory to understand 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.

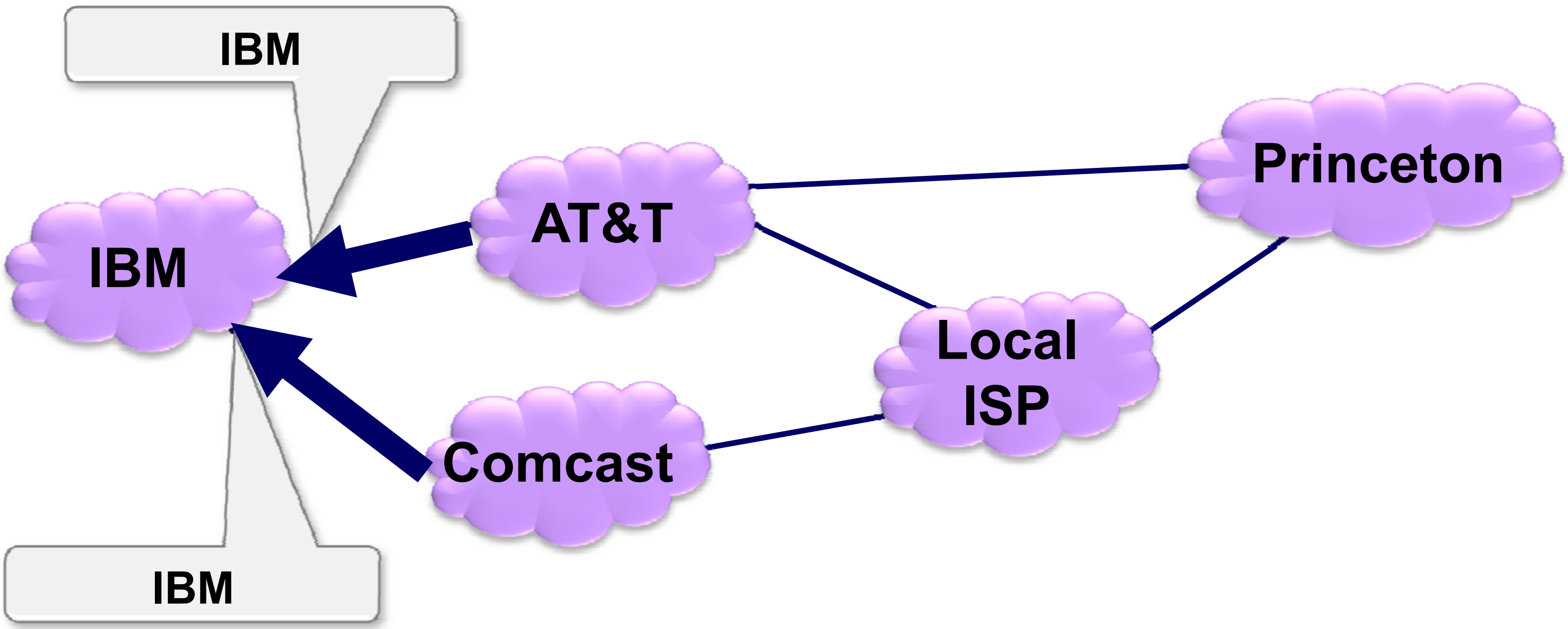
Our Results: Mostly **bad news**.

- 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 (1a)

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

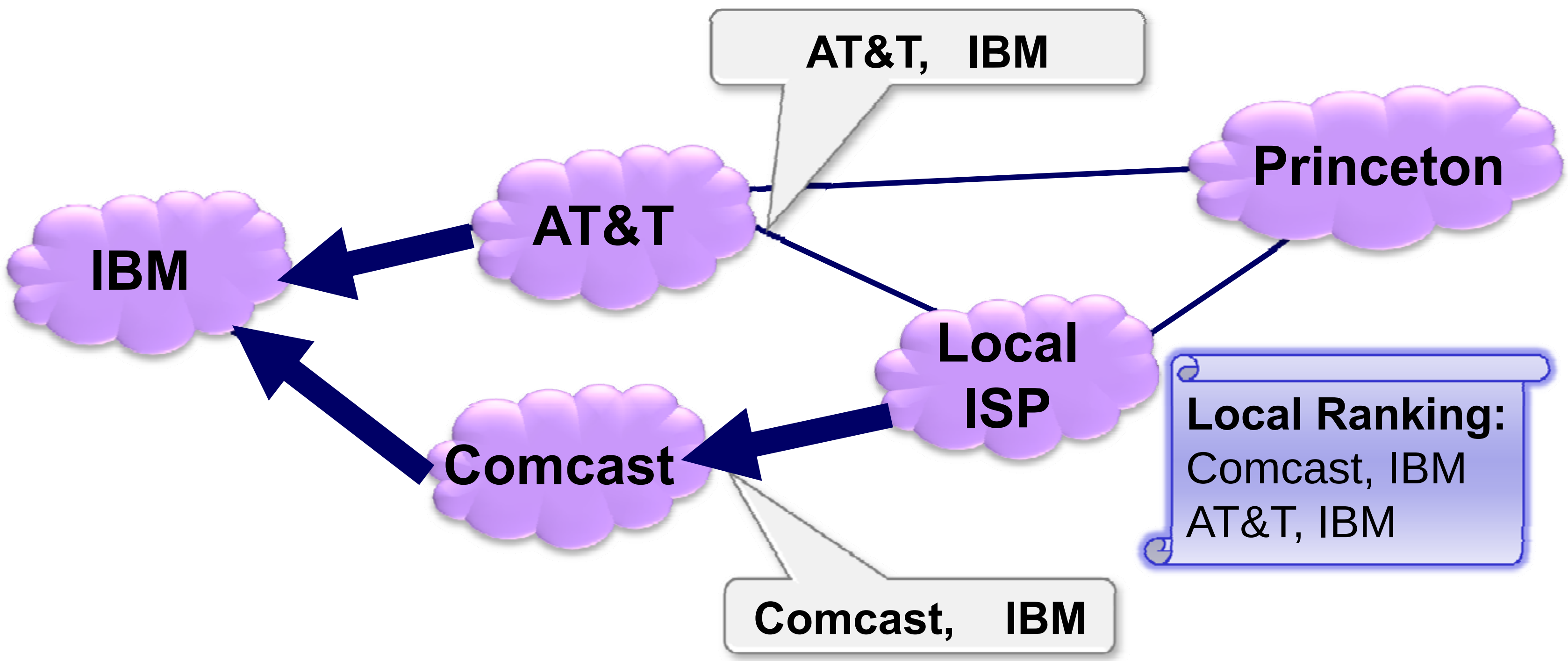


Forwarding: Node use **single** outgoing link for all traffic to destination.

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

BGP: The Interdomain Routing Protocol (1b)

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



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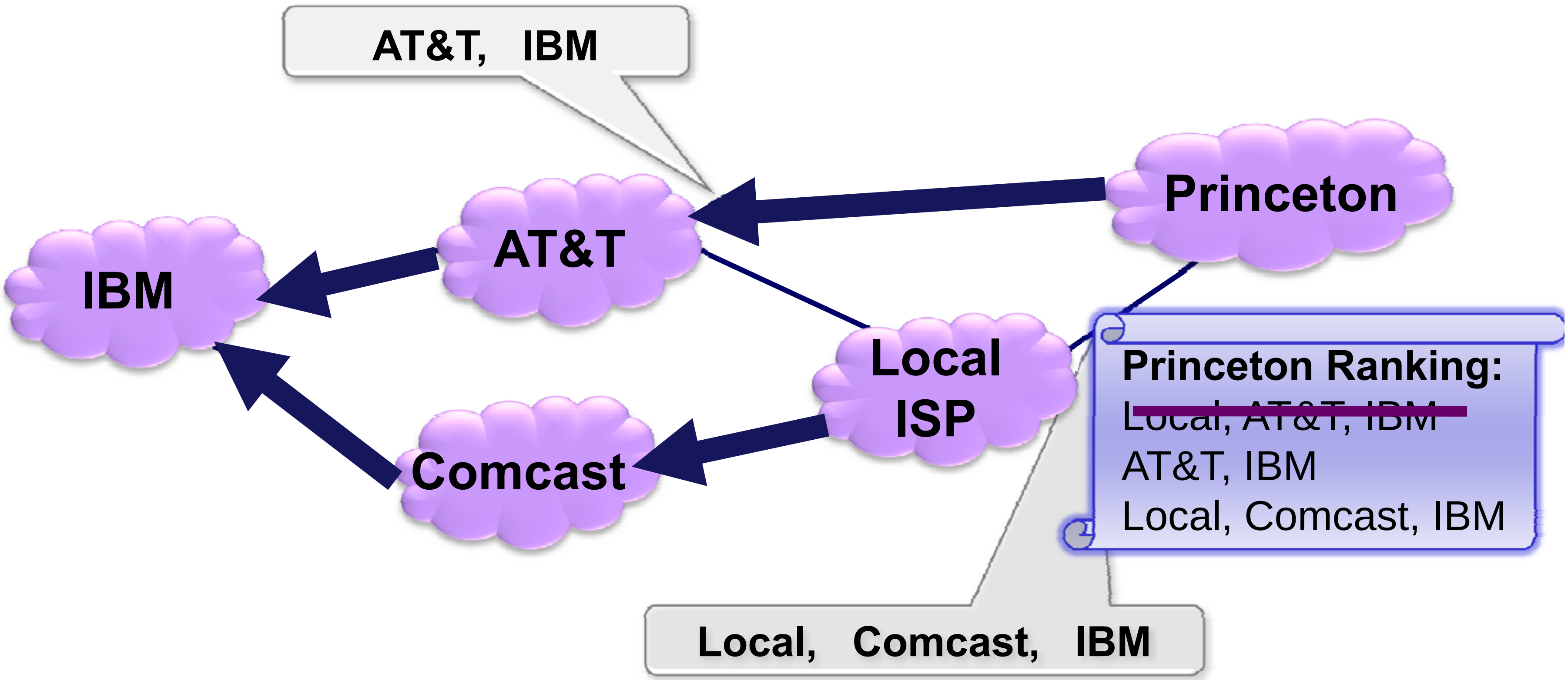
BGP: The Interdomain Routing Protocol (2)

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.

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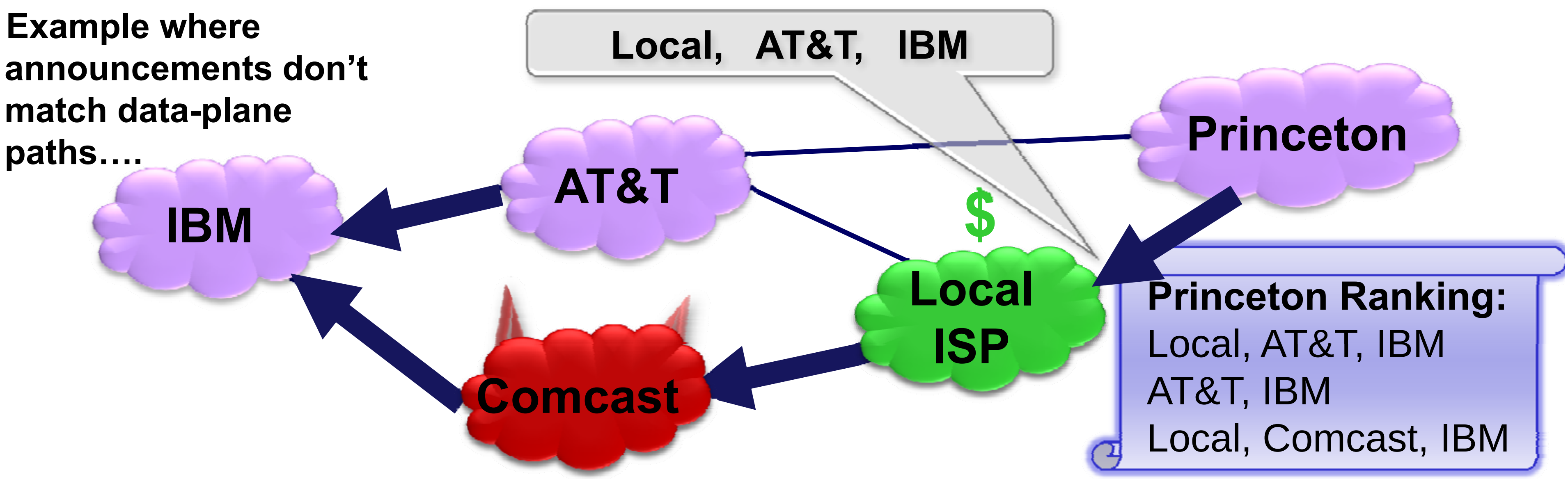
Matching the Data Plane

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



This way, ASes can use BGP messages:

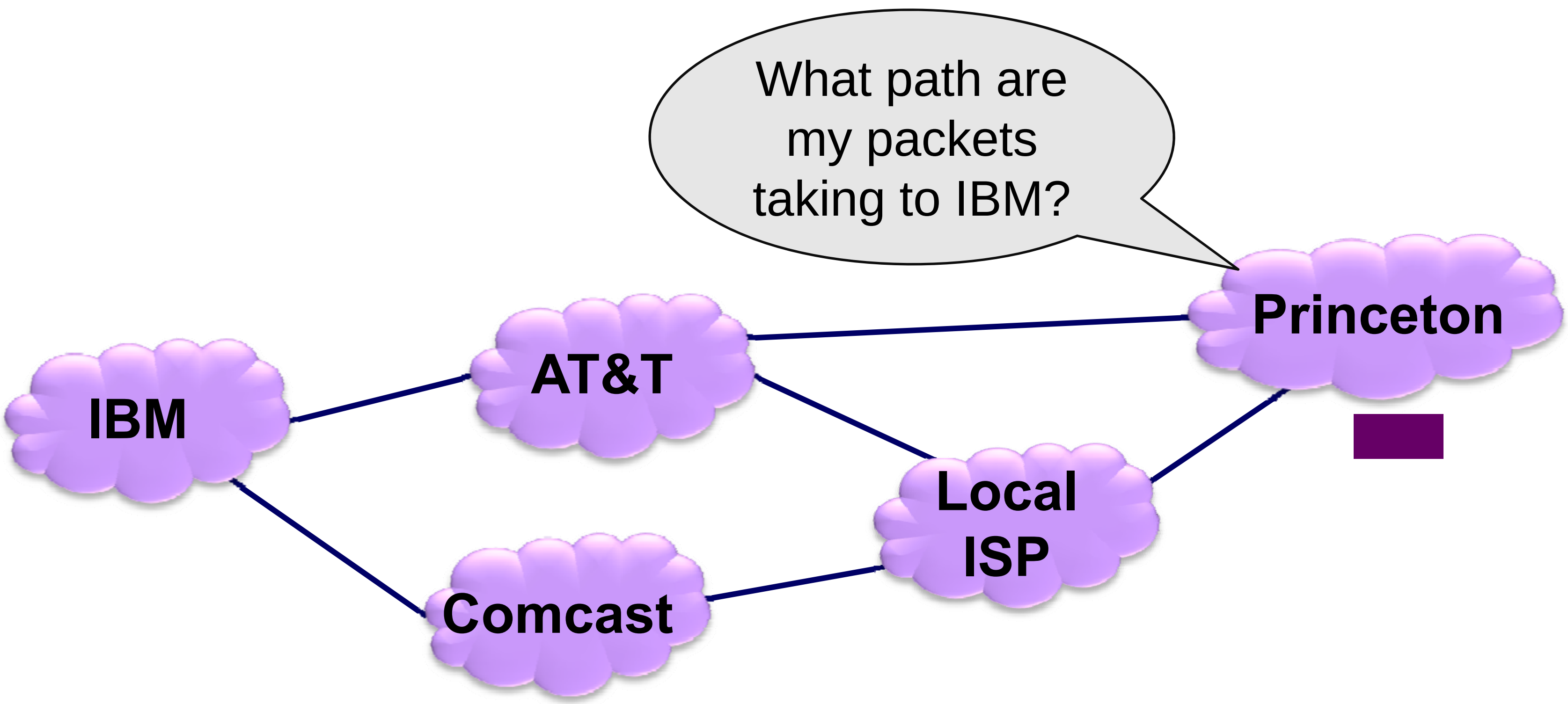
1. To avoid ASes perceived as adversarial / unreliable
2. To choose high performance paths
3. As part of an accountability framework

Data Plane Approaches for Matching BGP Messages

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 high overheads**

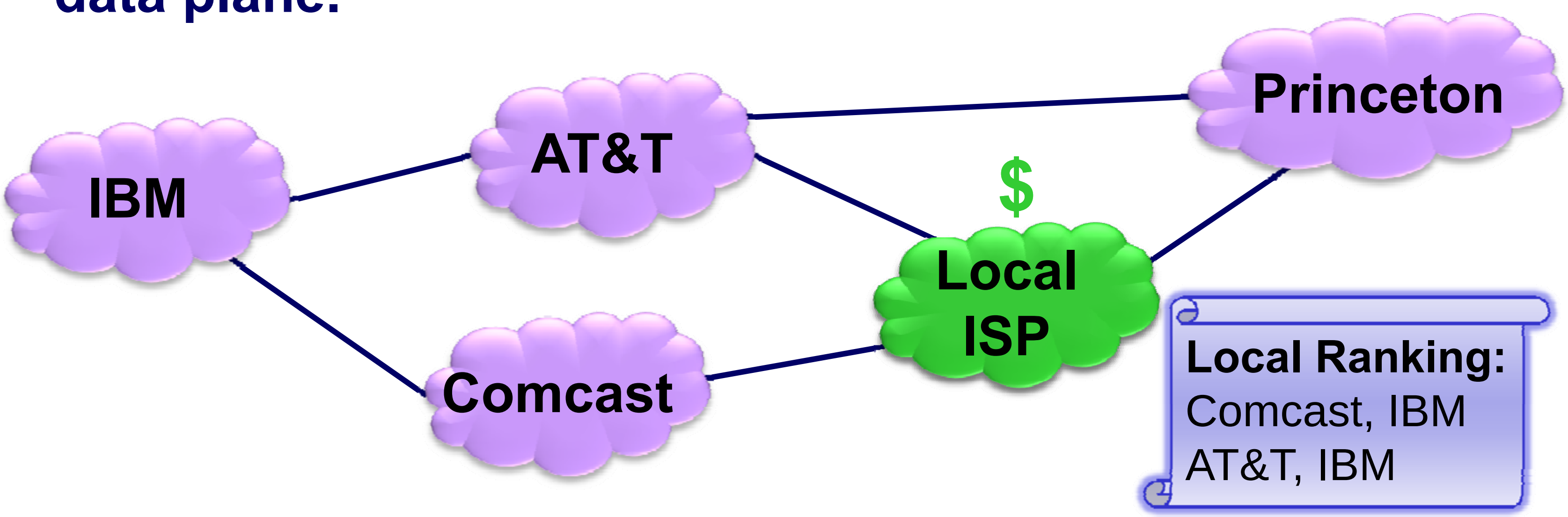


Routing Protocol Approaches to Match Data Plane

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]

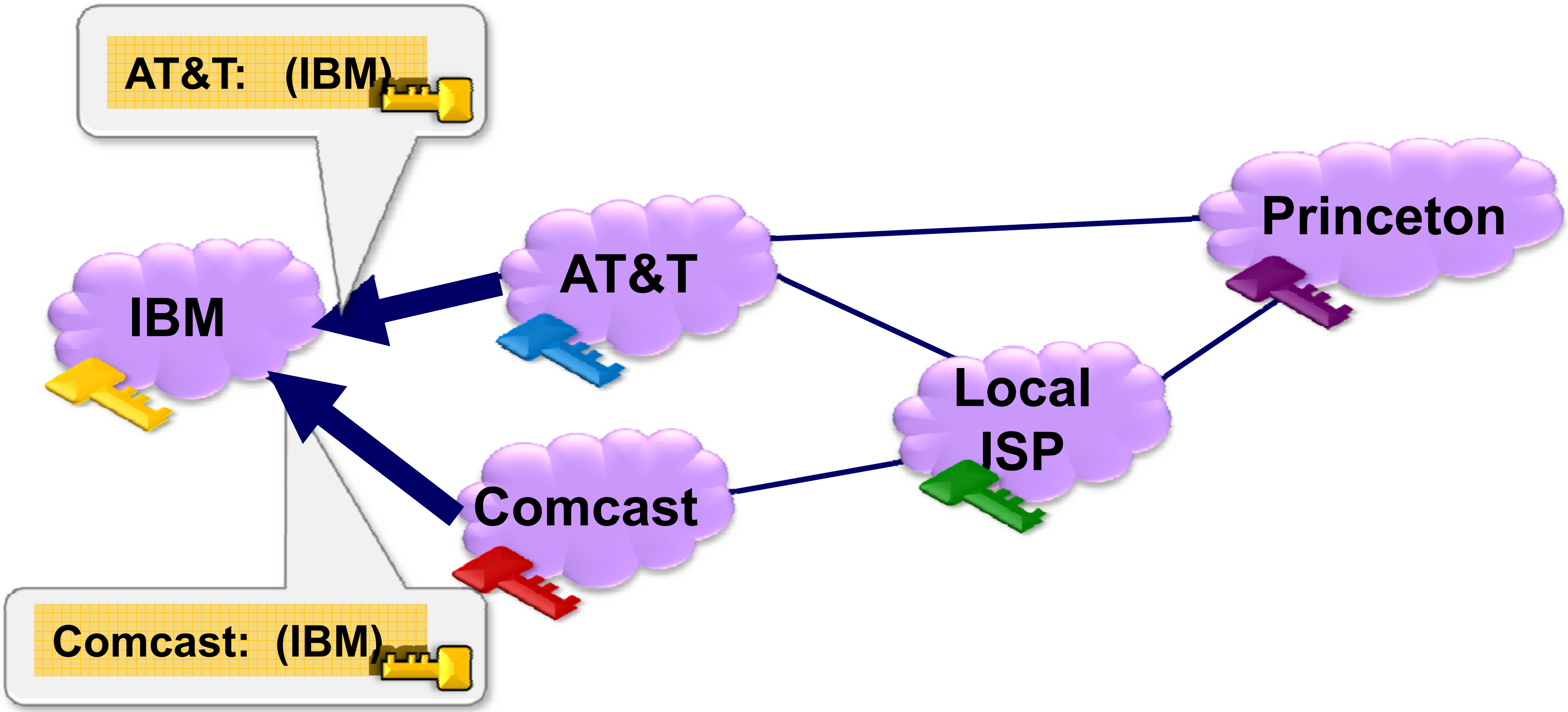
✓ **Corollary: If ______, rational ASes have no incentive to unilaterally deviate from announcing paths that match data plane.**



Secure BGP (1a)

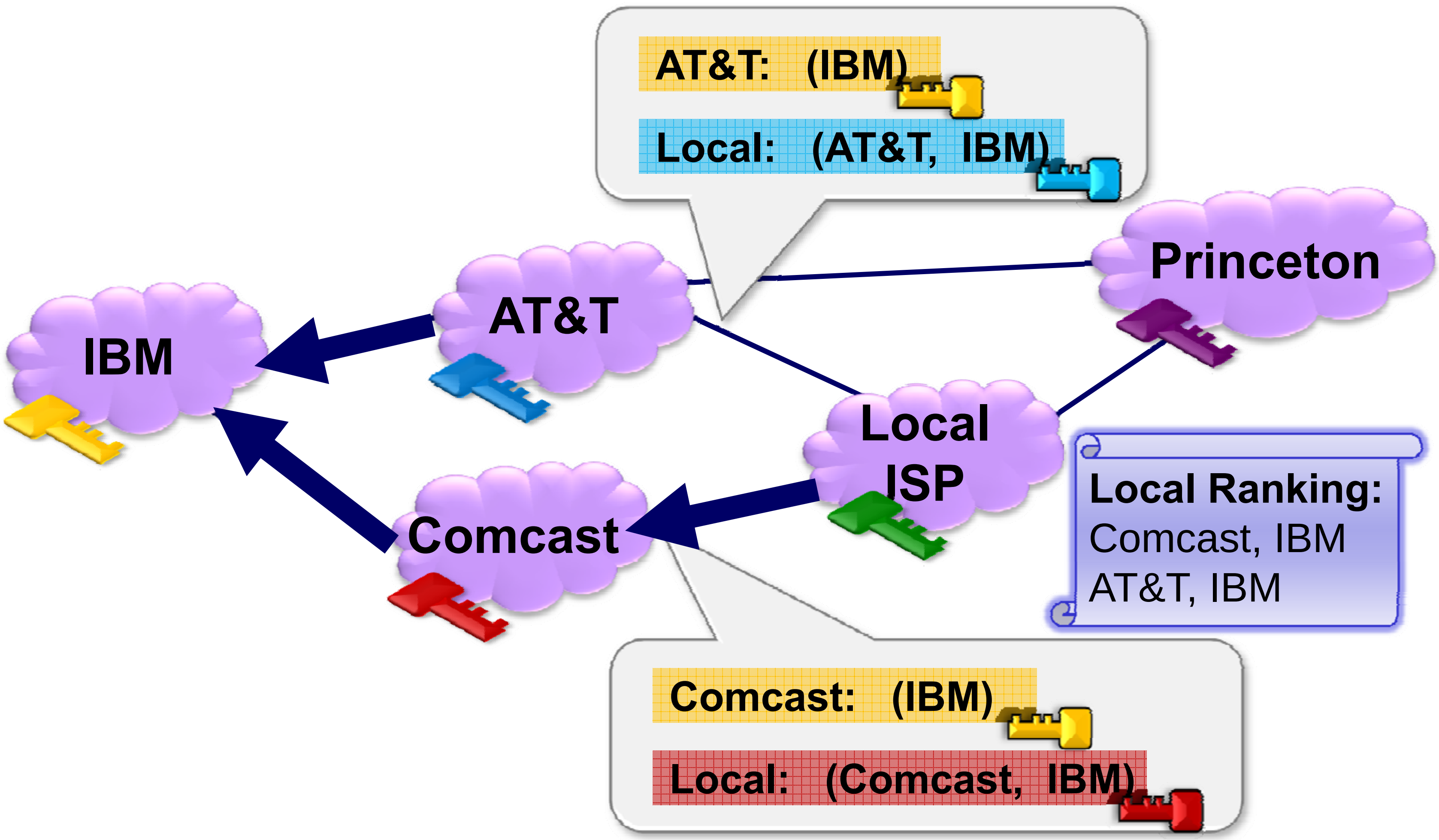
If **a** announced path **abP** then **b** announced **bP** to **a**

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



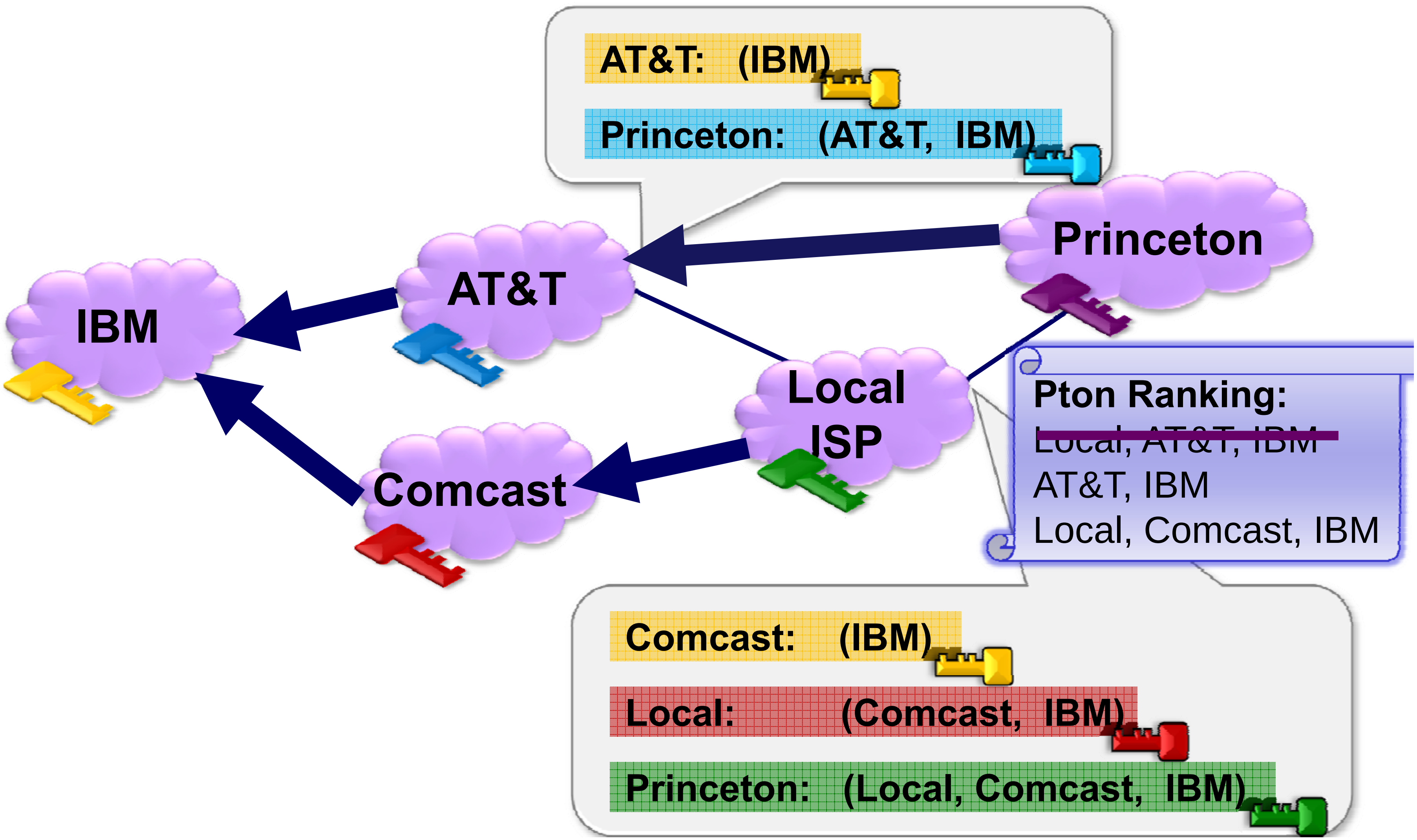
Secure BGP (1b)

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



Secure BGP (2)

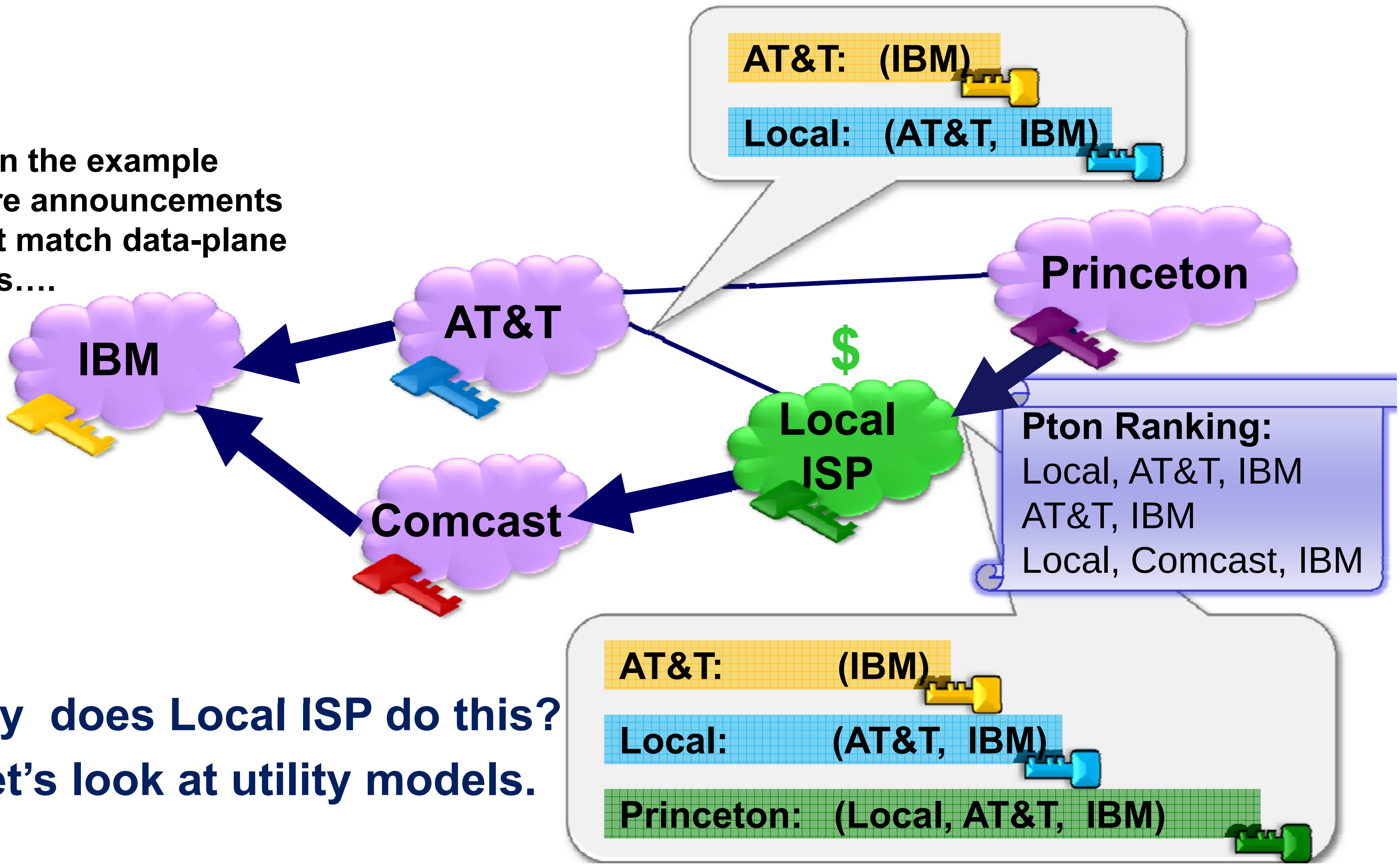
If **a** announced path **abP** then **b** announced **bP** to **a**



Secure BGP : Matching the Data Plane ???

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

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



Why does Local ISP do this?

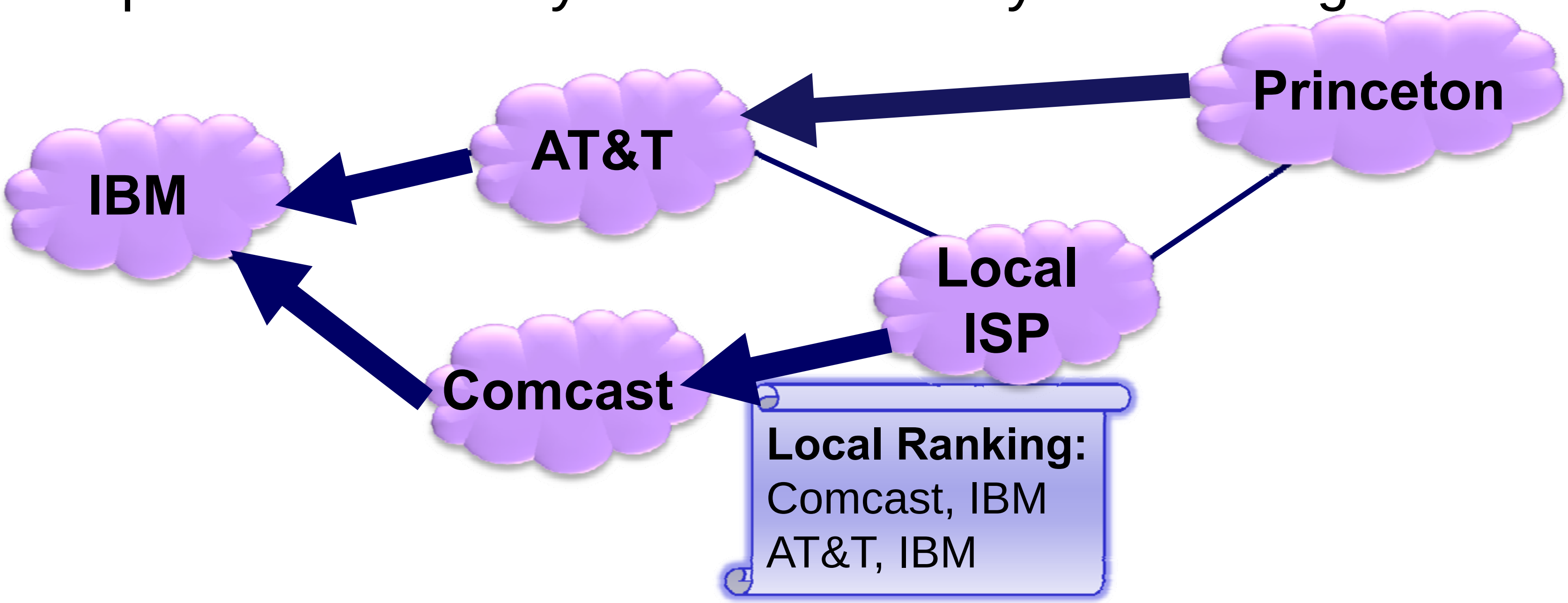
Let's look at utility models.

Modeling Utility (1)

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



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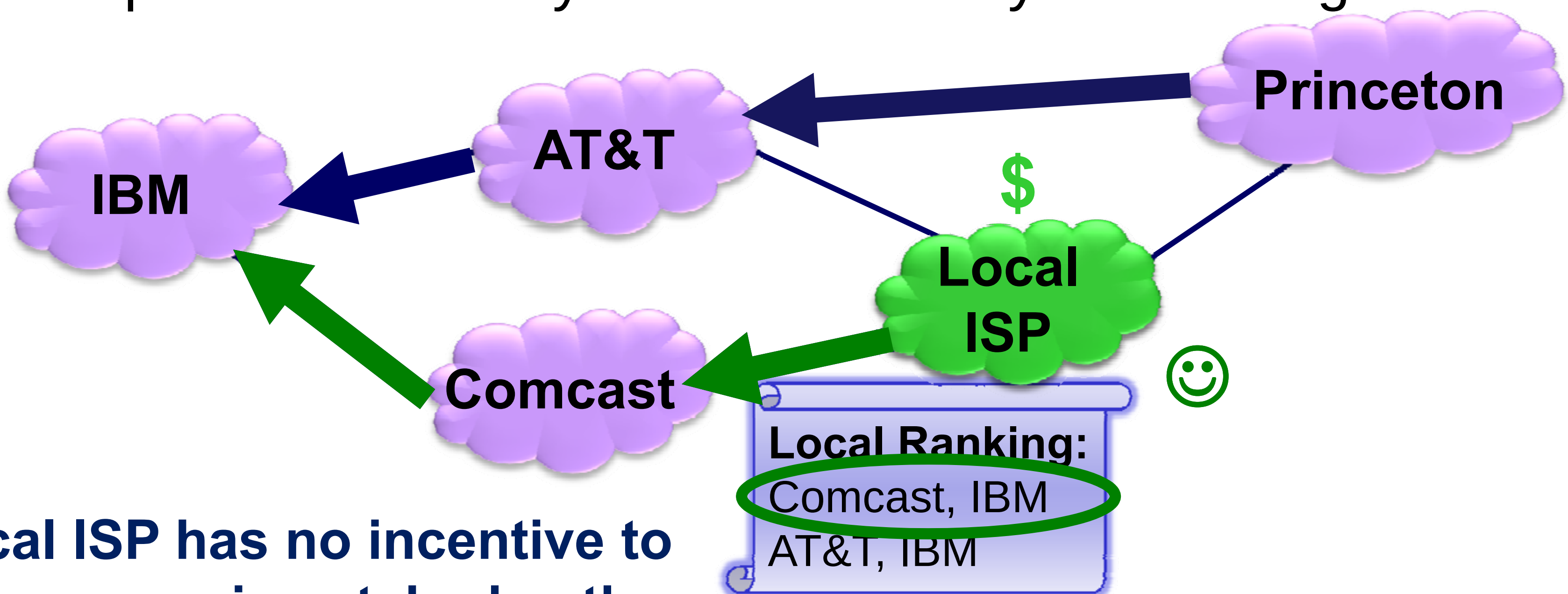


Local ISP has no incentive to announce mismatched paths.

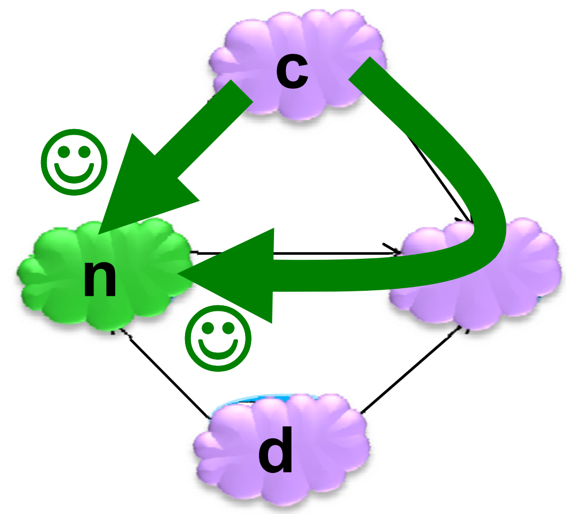
Modeling Utility with Traffic Attraction (1)

Our model of utility:

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



Modeling Utility with Traffic Attraction (2)

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Traffic-volume attractions:

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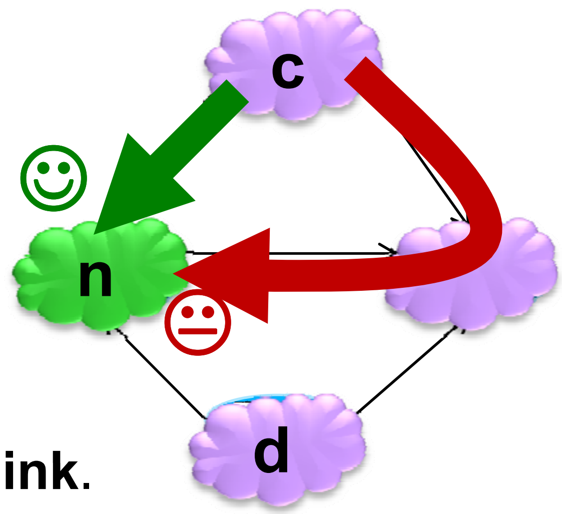


Customer attractions:

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

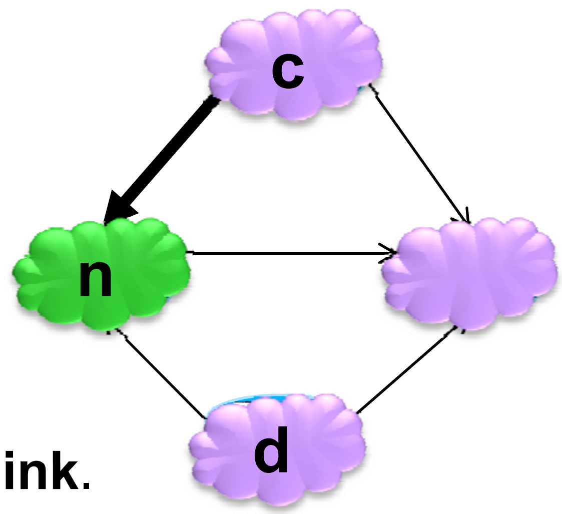
Modeling Utility with Traffic Attraction (3)

Our model of utility:

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:

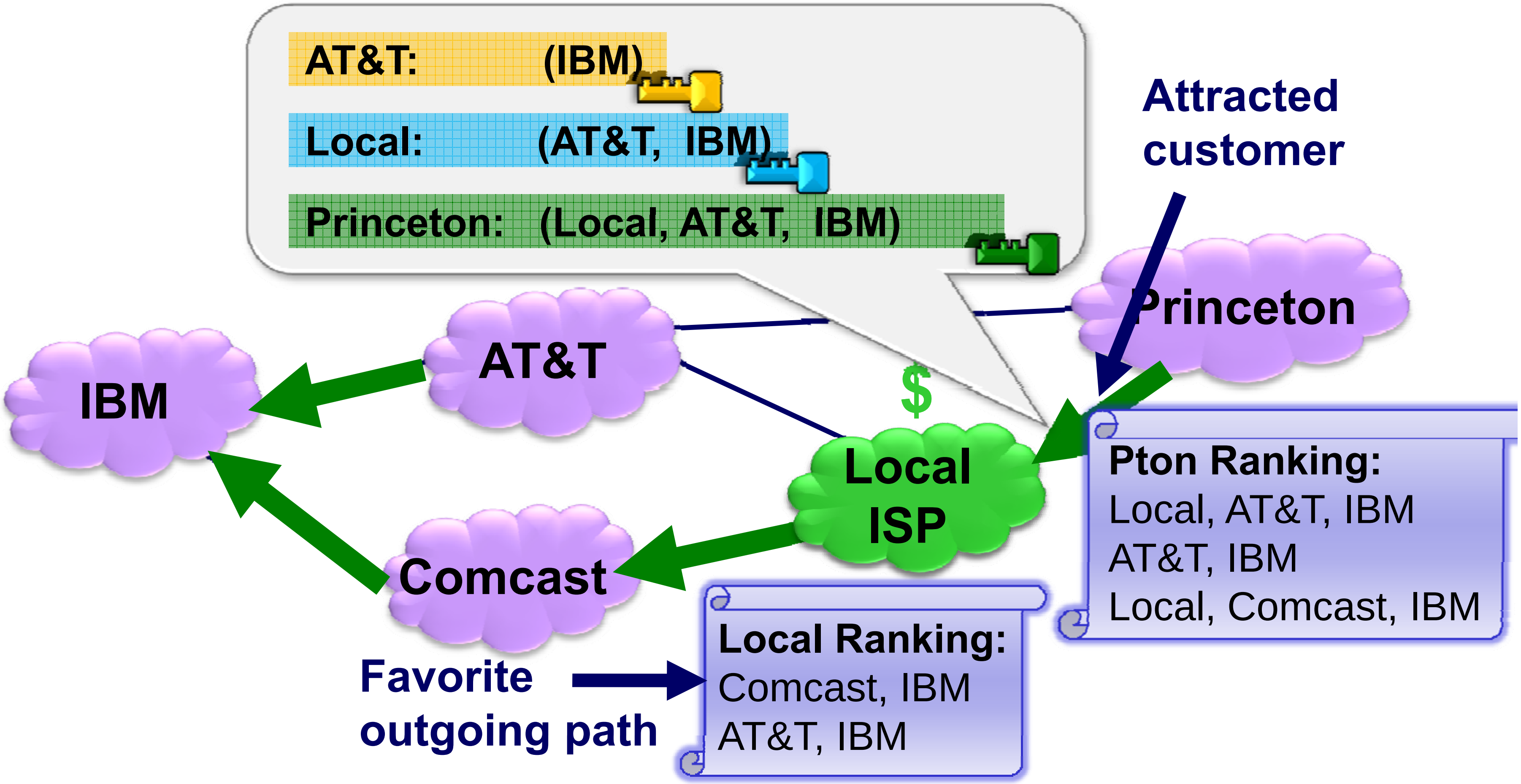
- **AS** wants to attract traffic from customers **via direct link**.
- Models bilateral economic relationships.

Generic attractions:

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

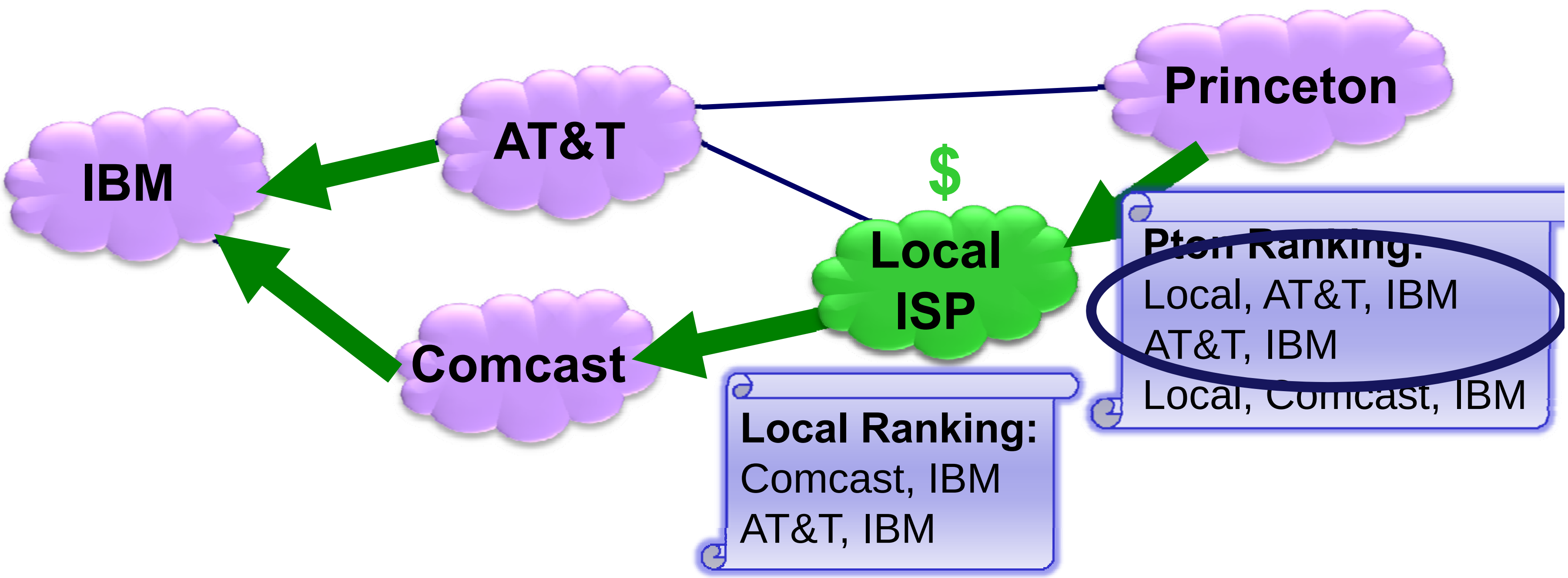
Result: Secure BGP is not Sufficient! (1)

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



Result: Secure BGP is not Sufficient! (2)

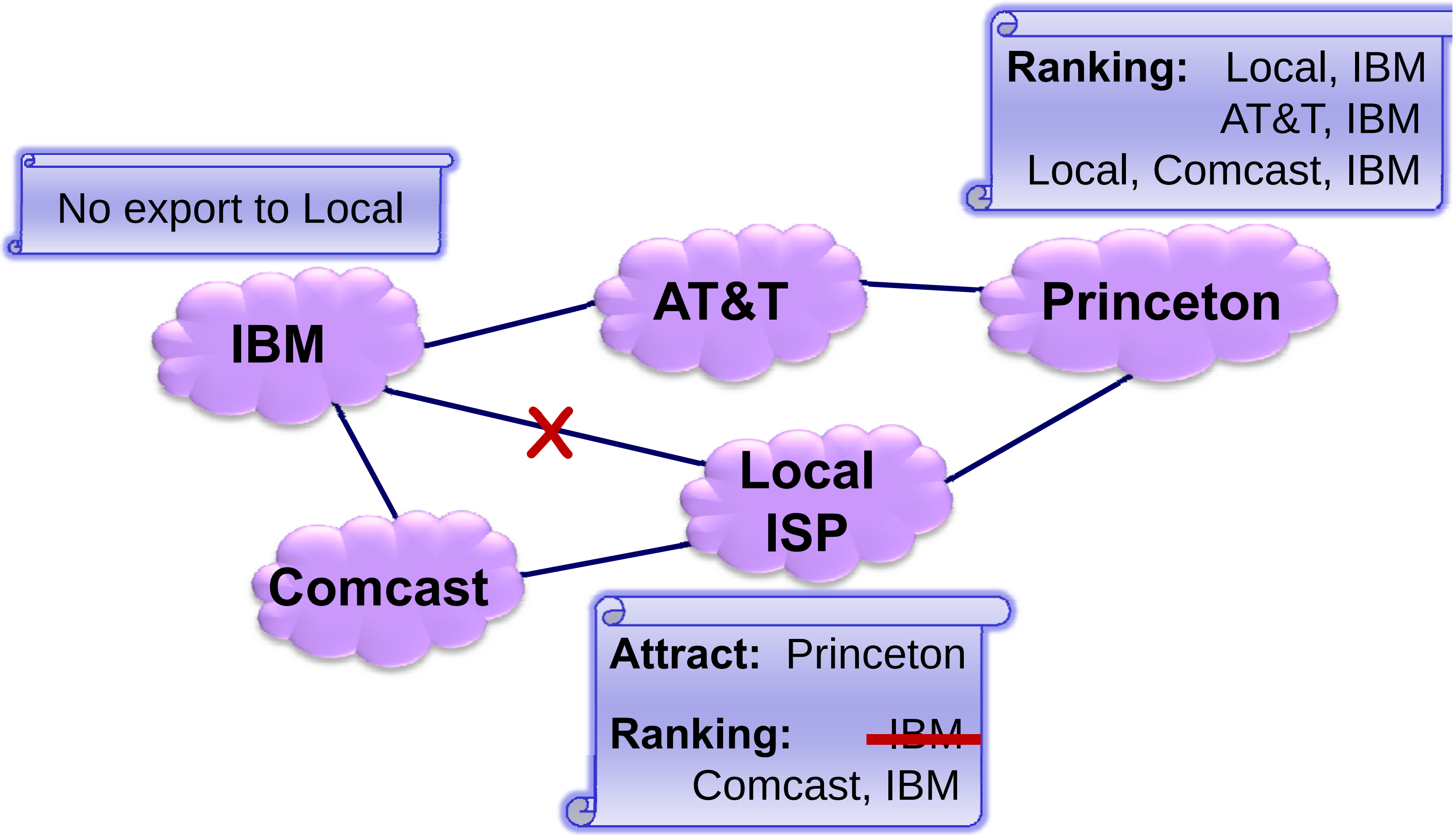
With **traffic-volume** OR **customer** attractions, there can be an incentive to announce mismatched paths, **even with Secure BGP**.



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

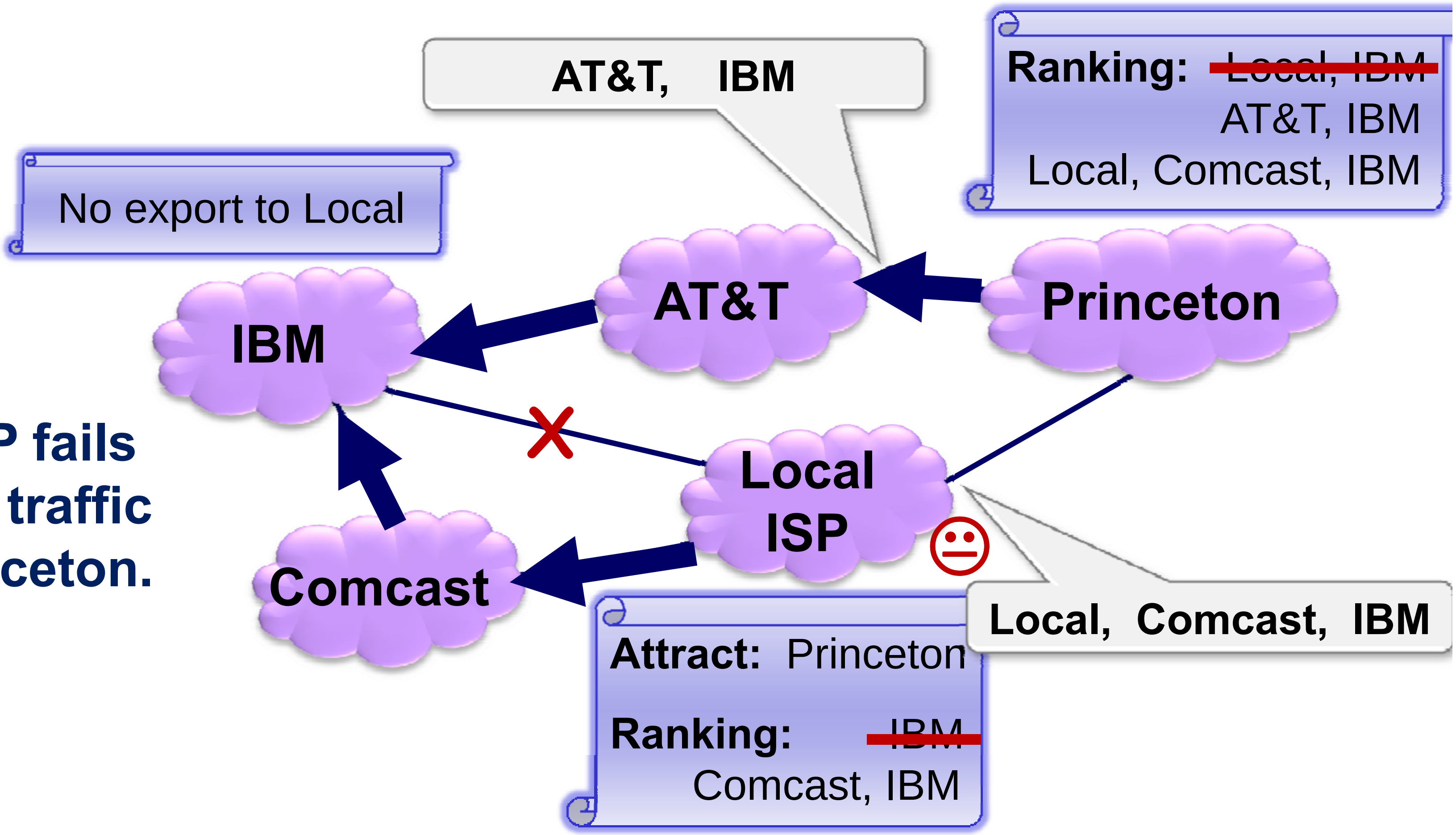
Result: Shortest-Path Policy is not Sufficient! (1)

With **traffic-volume** OR **customer** attractions, there can be an incentive to mismatch paths, **even with shortest-path policies.**



Result: Shortest-Path Policy is not Sufficient! (2)

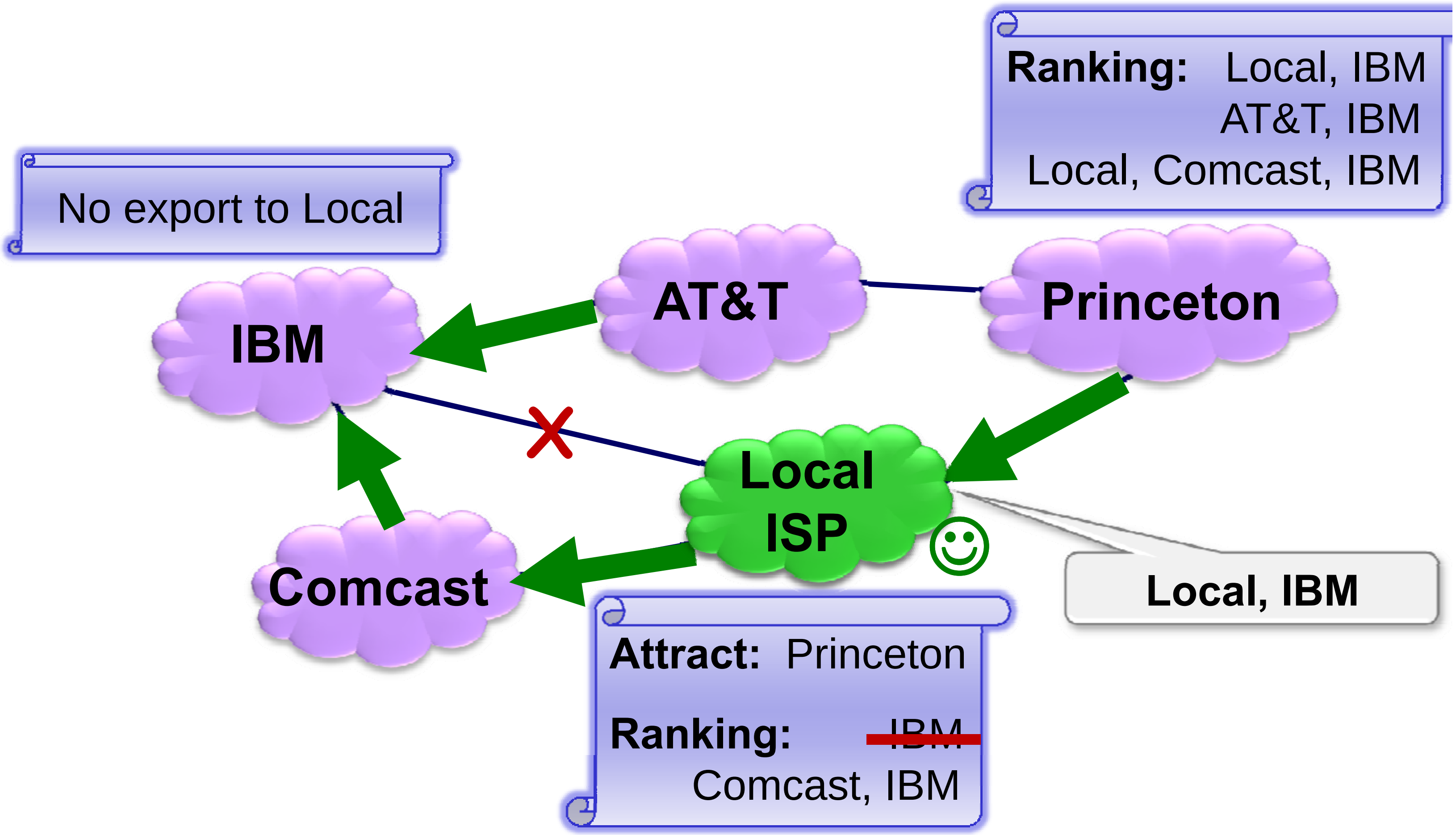
With **traffic-volume** OR **customer** attractions, there can be an incentive to mismatch paths, **even with shortest-path policies.**



Local ISP fails to attract traffic from Princeton.

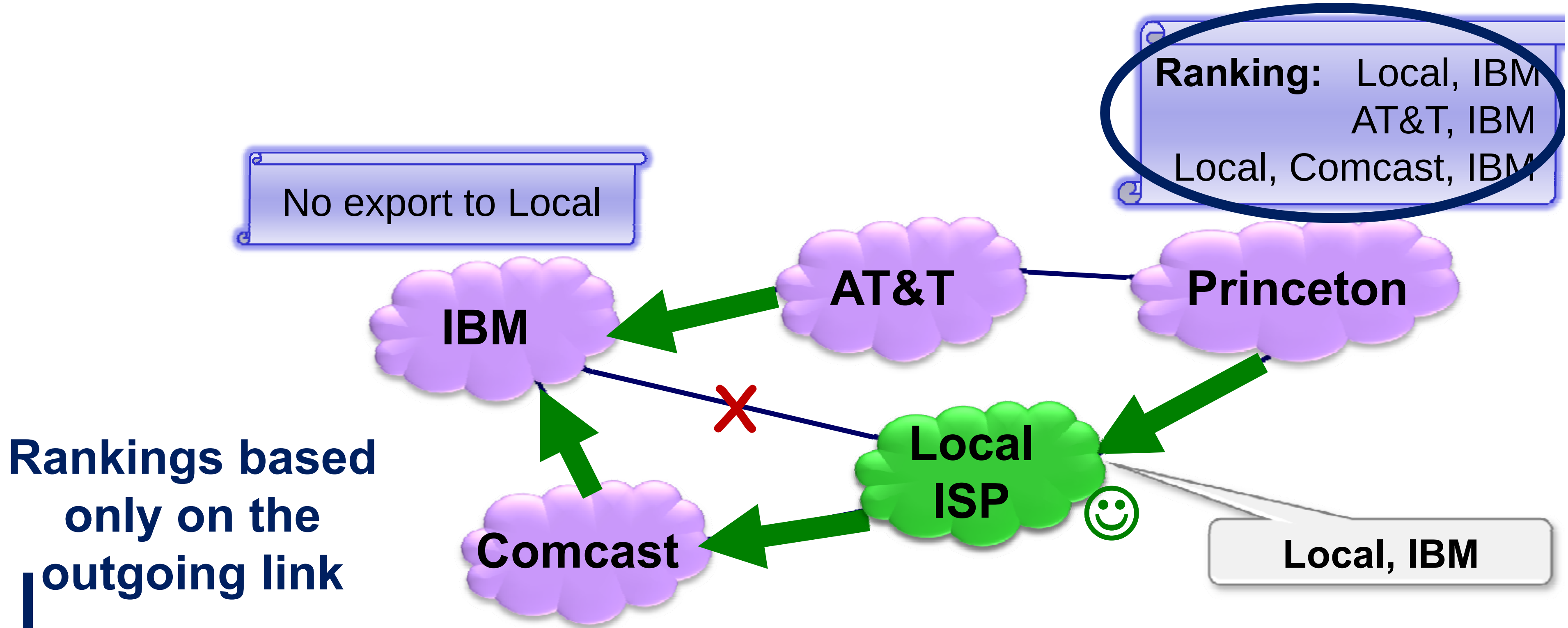
Result: Shortest-Path Policy is not Sufficient! (3)

With **traffic-volume** OR **customer** attractions, there can be an incentive to mismatch paths, **even with shortest-path policies.**



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

With **traffic-volume** OR **customer** attractions, there can be an incentive to mismatch paths, **even with shortest-path policies.**



Observation: Manipulation not possible with Secure BGP.

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

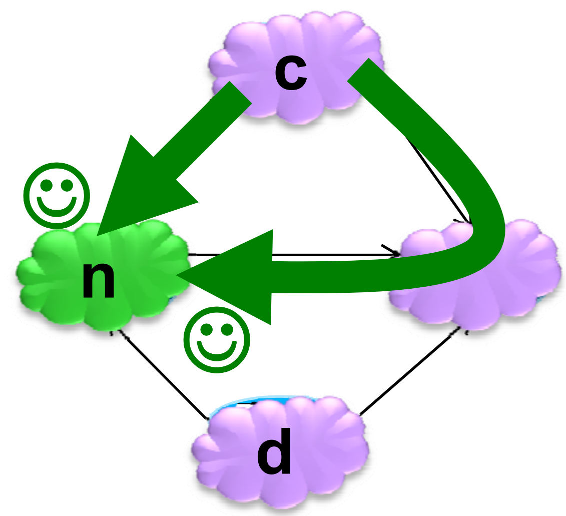
Traffic Volume Attractions

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).

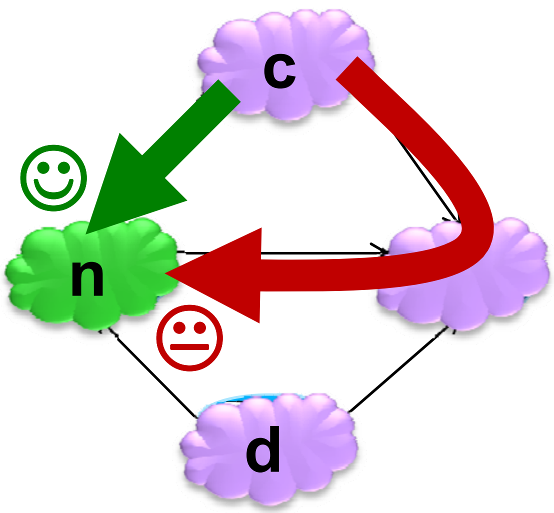
The exact statement of this result is in the paper

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**.

What about Customer Attractions? (2)

Are these sufficient if we have customer attractions?

1. **Secure BGP**, and
2. **Next-hop policies;**

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. **Secure BGP,** and
2. **Next-hop policies**

and there is no dispute wheel in the network

and every node uses all-or nothing export.

Removing any condition gives a counterexample 😐

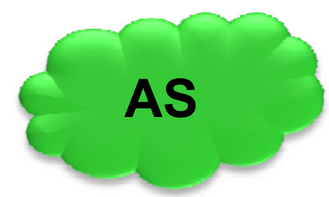
The exact statement of this result is in the paper

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).

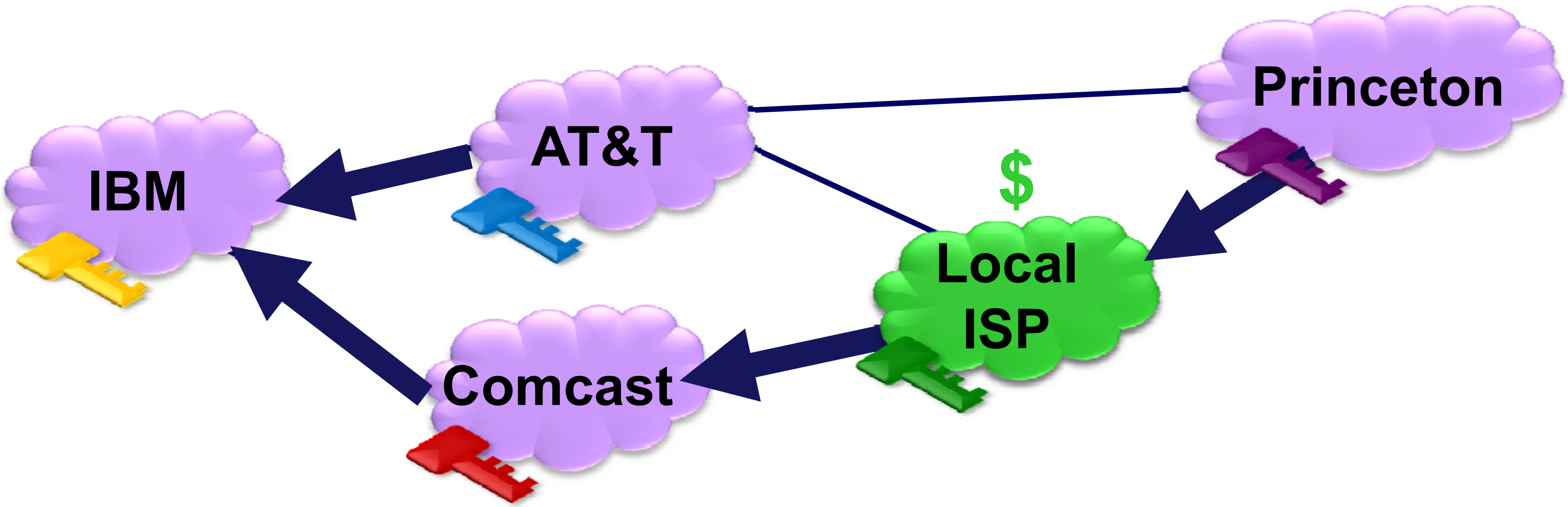
Also, notice how strongly results depend on utility model.



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:

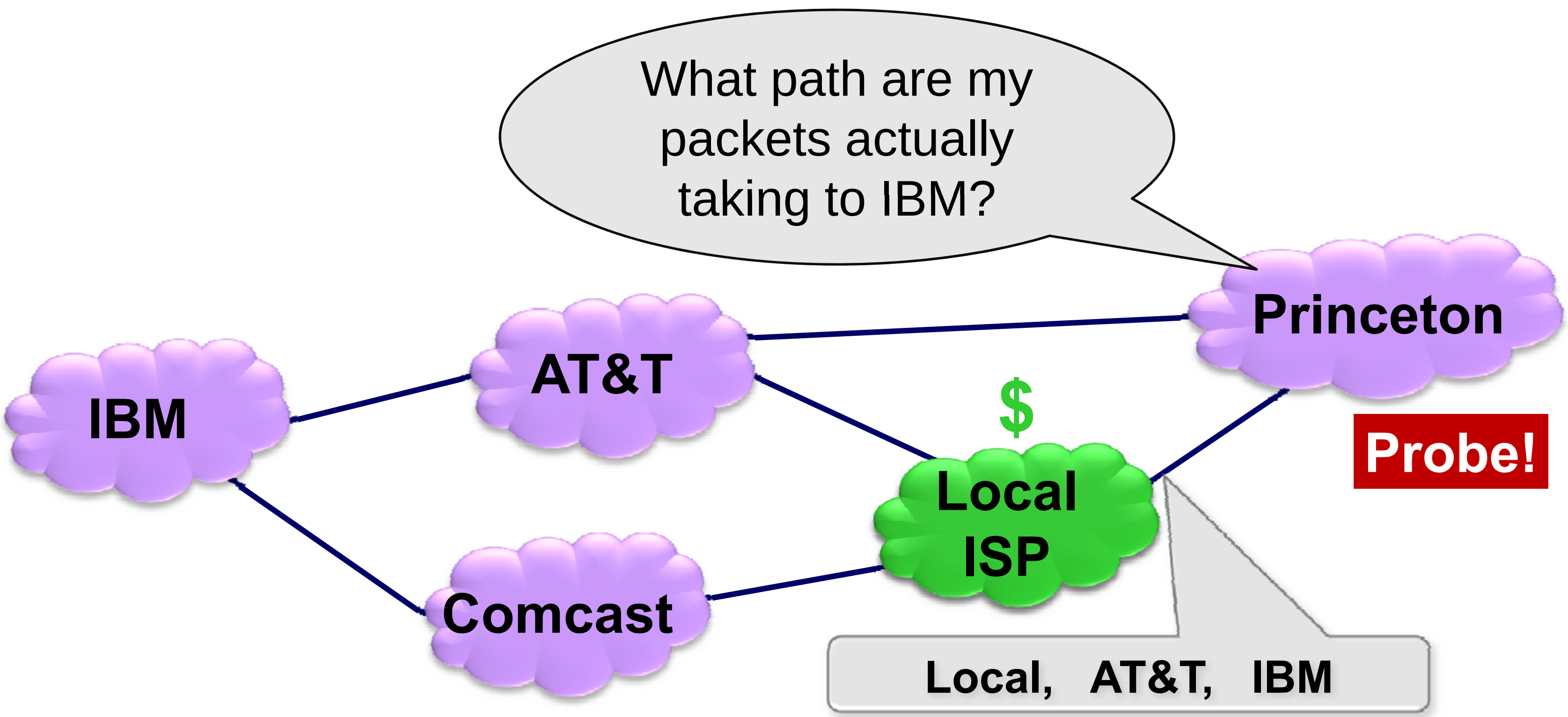
www.princeton.edu/~goldbe/

Matching Data Plane: Related Approaches (Backup)

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.**



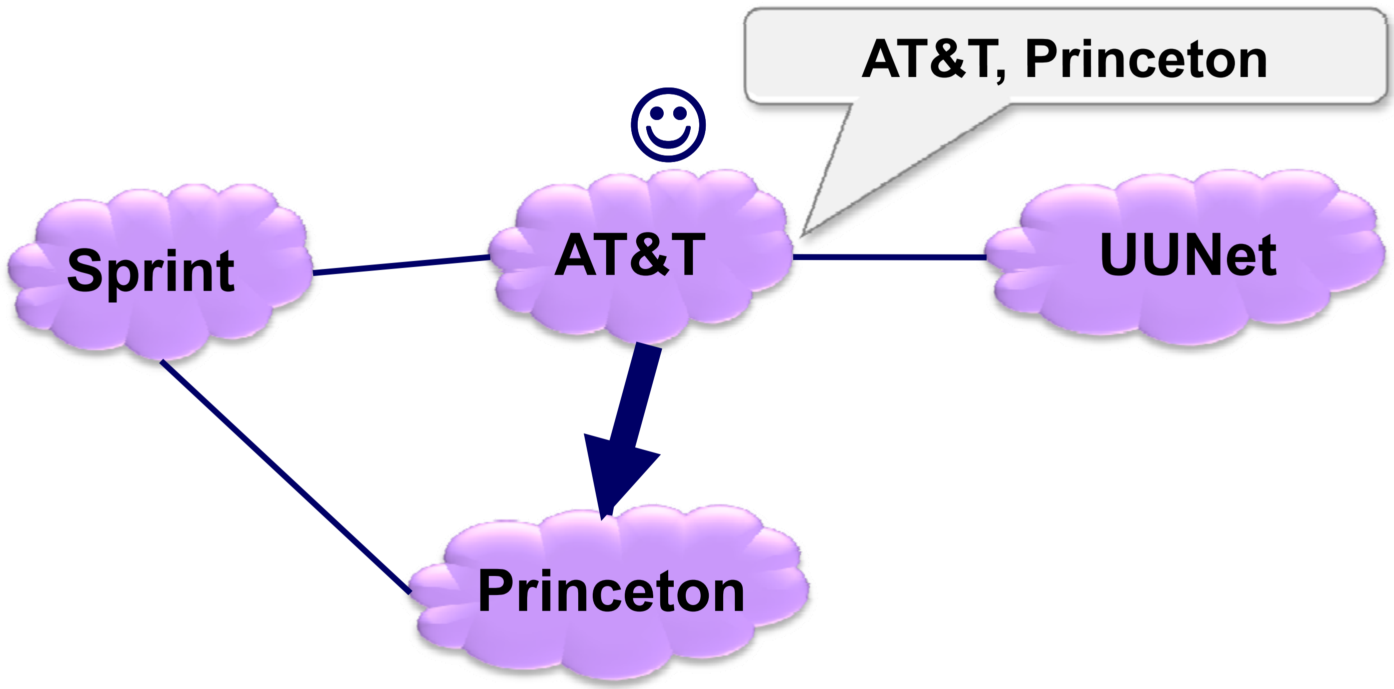
All-or-Nothing Export (1)

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

Path-based egress filtering is not allowed!

(Incompatible with practice.)

IF



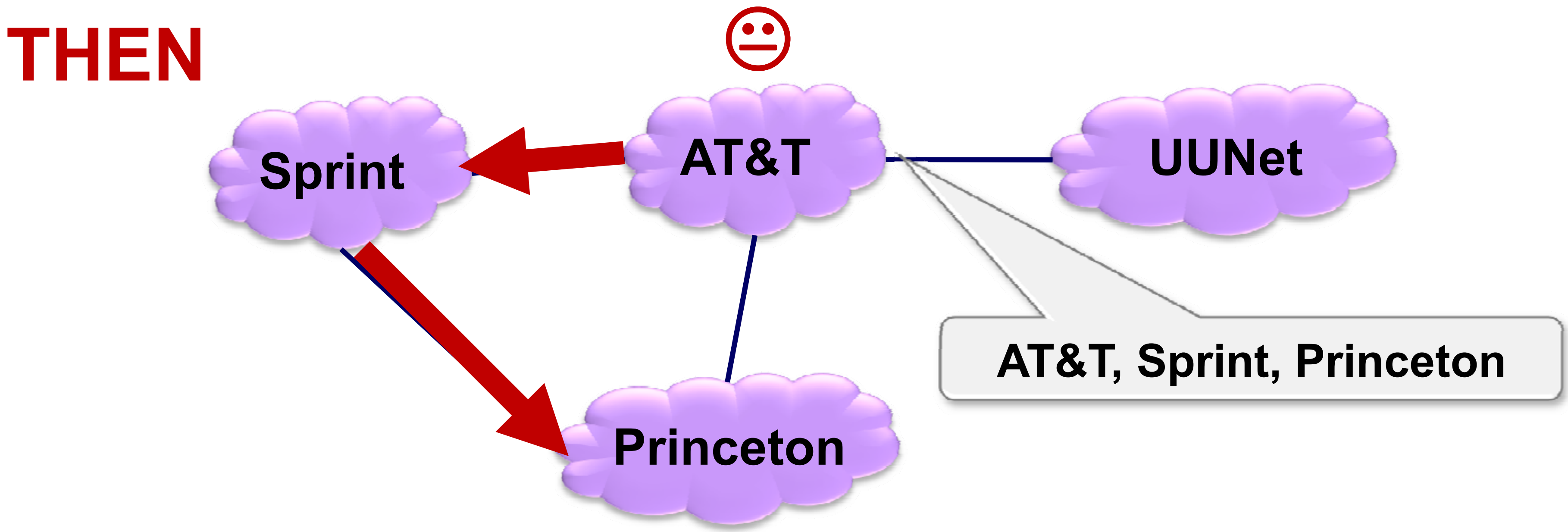
AT&T makes money because it delivers traffic to a customer.

All-or-Nothing Export (2)

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

Path-based egress filtering is not allowed!

(Incompatible with practice.)



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

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

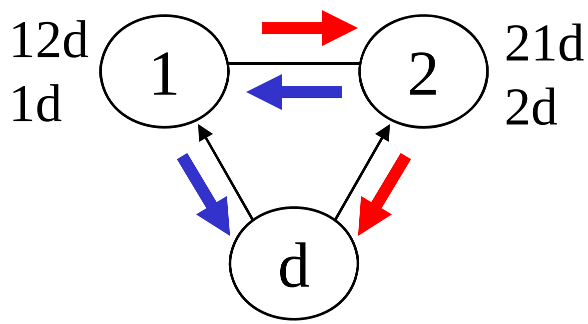
The set of neighbours to which **n** is
willing to announce path **P**

$$e_n(T)$$

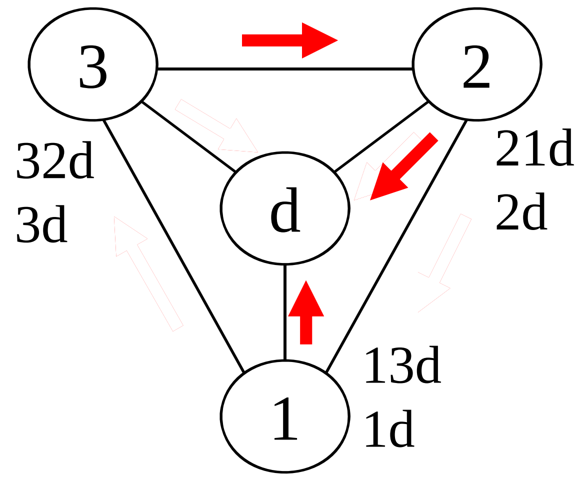
Formal model

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