CS/ECE 4457

Computer Networks:
Architecture and Protocols

Lecture 15
Border-Gateway Protocol

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Goals for Today's Lecture

- Wrap up Inter-domain routing (Border-Gateway Protocol (BGP))
  - Driven by "business goals", rather than "performance goals"
  - We will focus on a synchronous version:
    - One node in the network acts at a time
    - In practice, BGP implementations are asynchronous

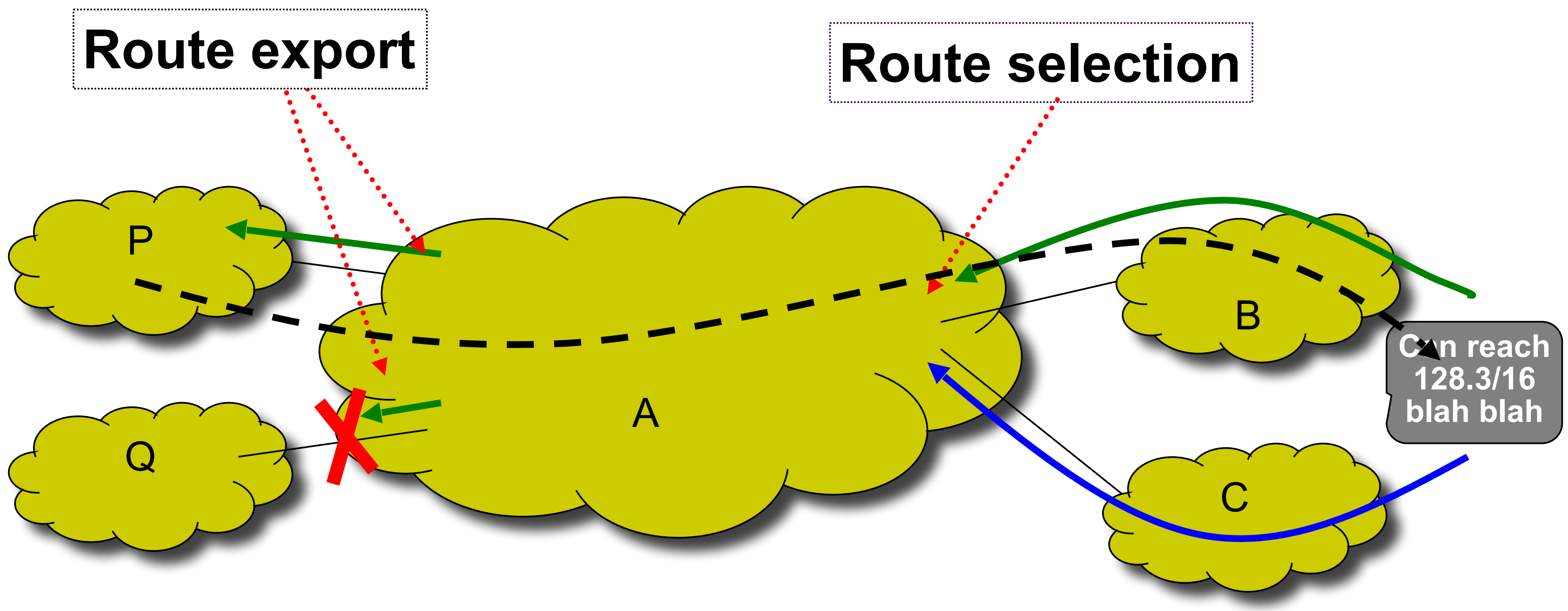
Recap from last lecture

Recap: BGP is Inspired by Distance Vector

- Per-destination route advertisements
- No global sharing of network topology
- Iterative and distributed convergence on paths
- But, four key differences
  - BGP does not pick shortest paths
  - Each node announces one or multiple PATHs per destination
  - Selective Route advertisement: not all paths are announced
  - BGP may aggregate paths
    - may announce one path for multiple destinations

Recap: Policy:

Imposed in how routes are selected and exported



- **Selection**: Which path to use
  - Controls whether / how traffic leaves the network
- **Export**: Which path to advertise
  - Controls whether / how traffic enters the network

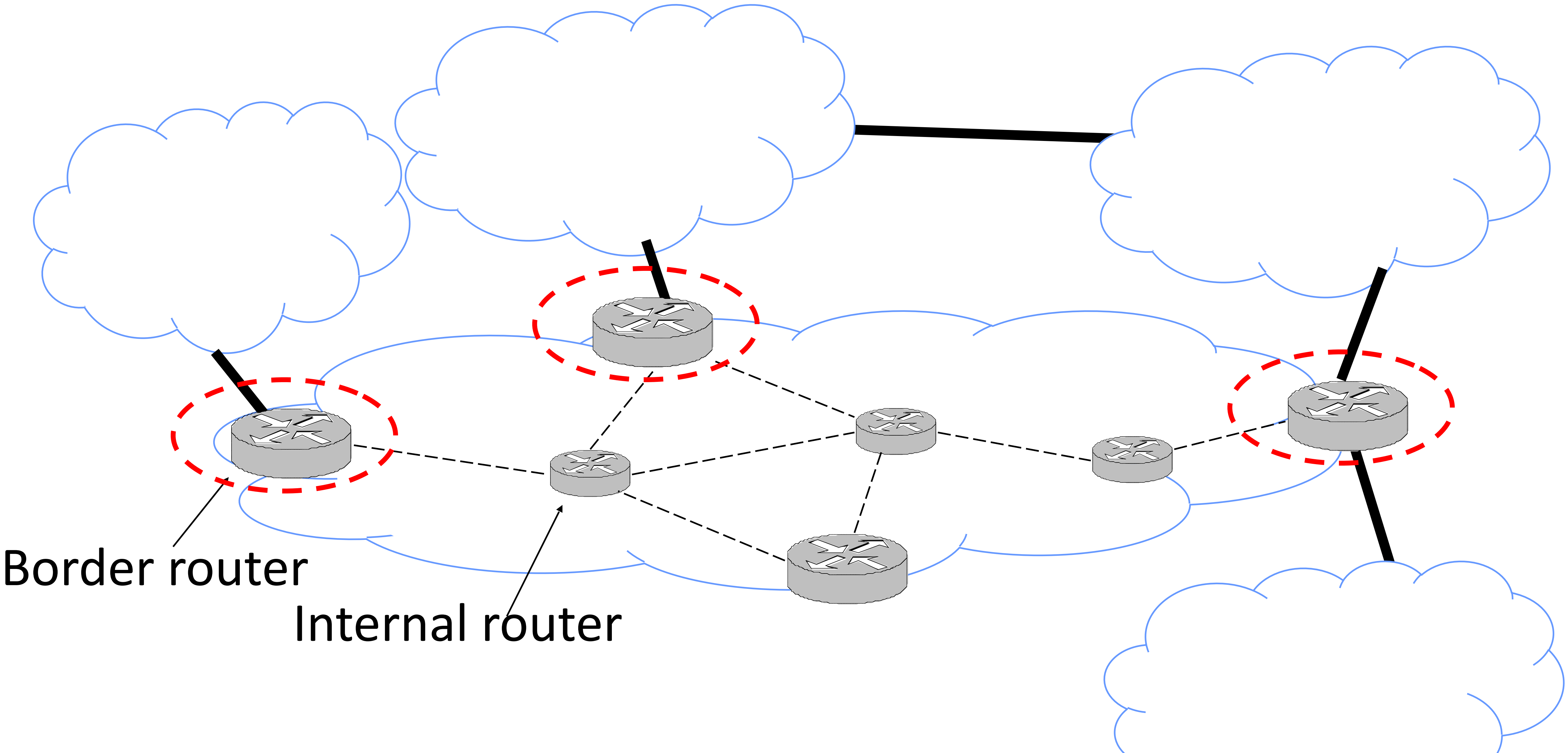
Recap: Typical Export Policy

Destination prefix advertised by…	Export route to…
Customer	Everyone (providers, peers, other customers)
Peer	Customers
Provider	Customers

Known as the "Gao-Rexford" rules
Capture common (but not required!) practice

BGP protocol details

Who speaks BGP?



Border routers at an Autonomous System

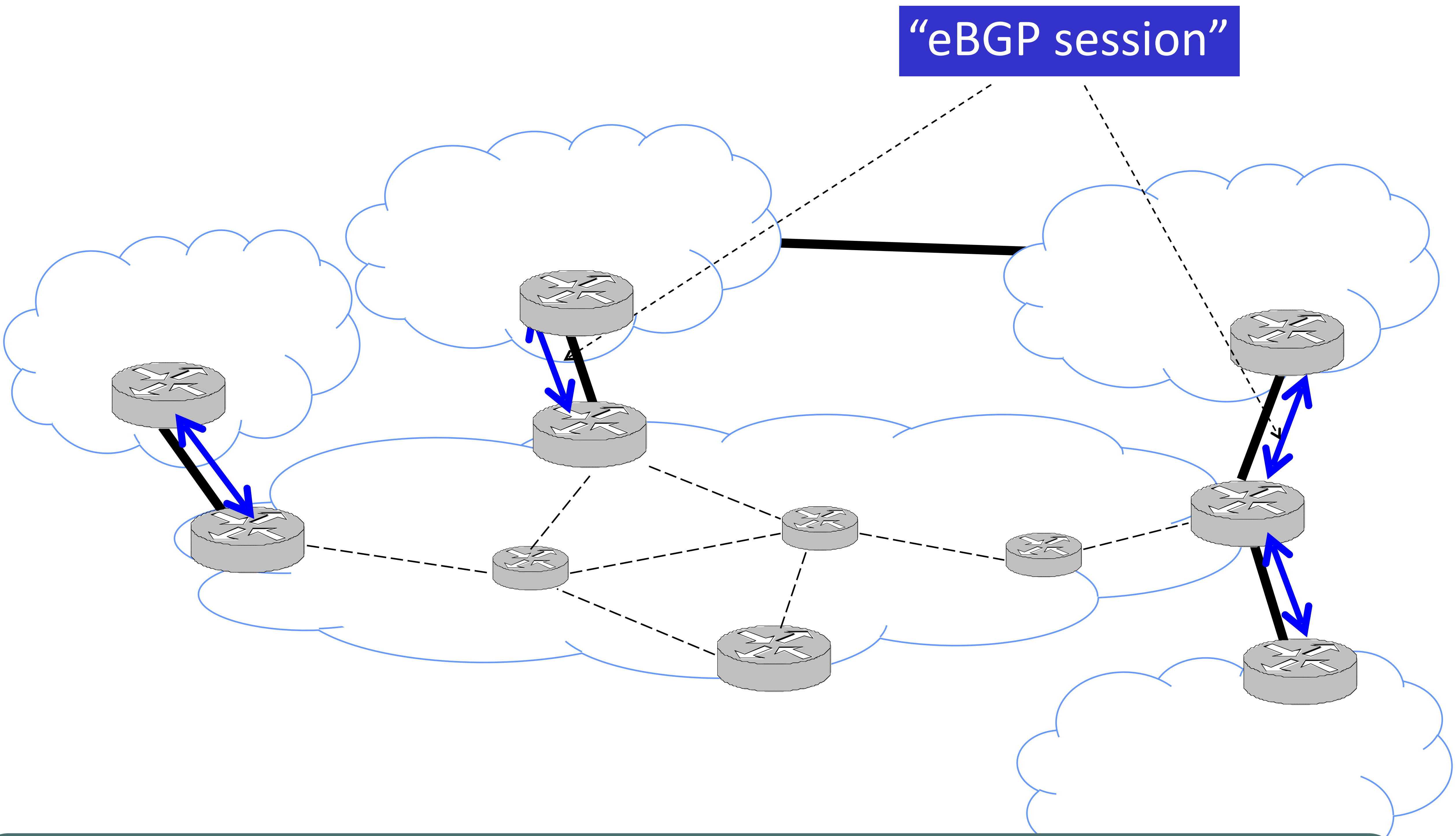
What Does “speak BGP” Mean?

- Implement the BGP Protocol Standard
  - Internet Engineering Task Force (IETF) RFC 4271

- Specifies what messages to exchange with other BGP “speakers”
  - Message types (e.g. route advertisements, updates)
  - Message syntax

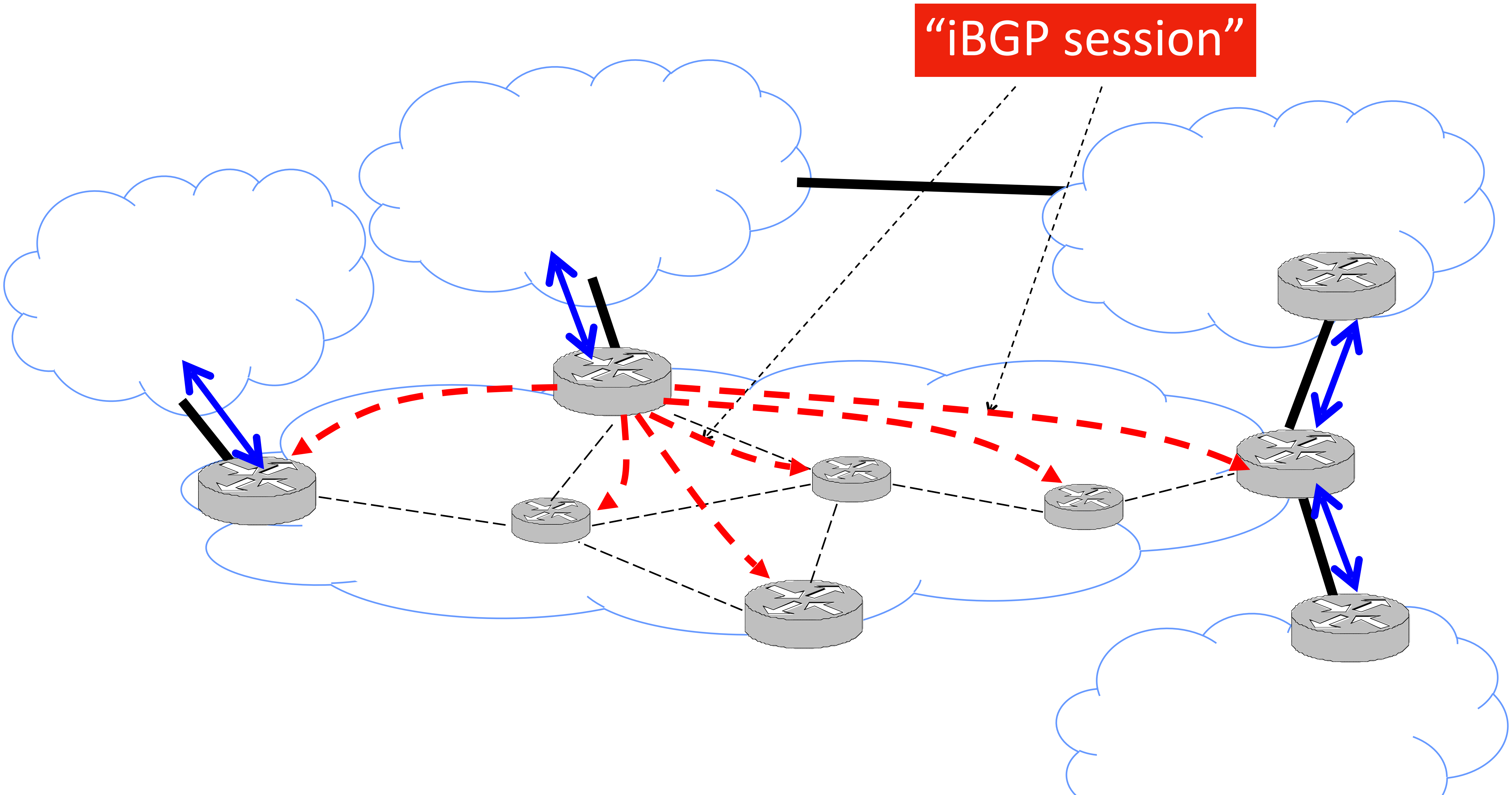
- Specifies how to process these messages
  - When you receive a BGP update, do x
  - Follows BGP state machine in the protocol spec and policy decisions, etc.

BGP Sessions



A border router speaks BGP with
border routers in other ASes

BGP Sessions



A border router speaks BGP with other (interior and border) routers in its own AS

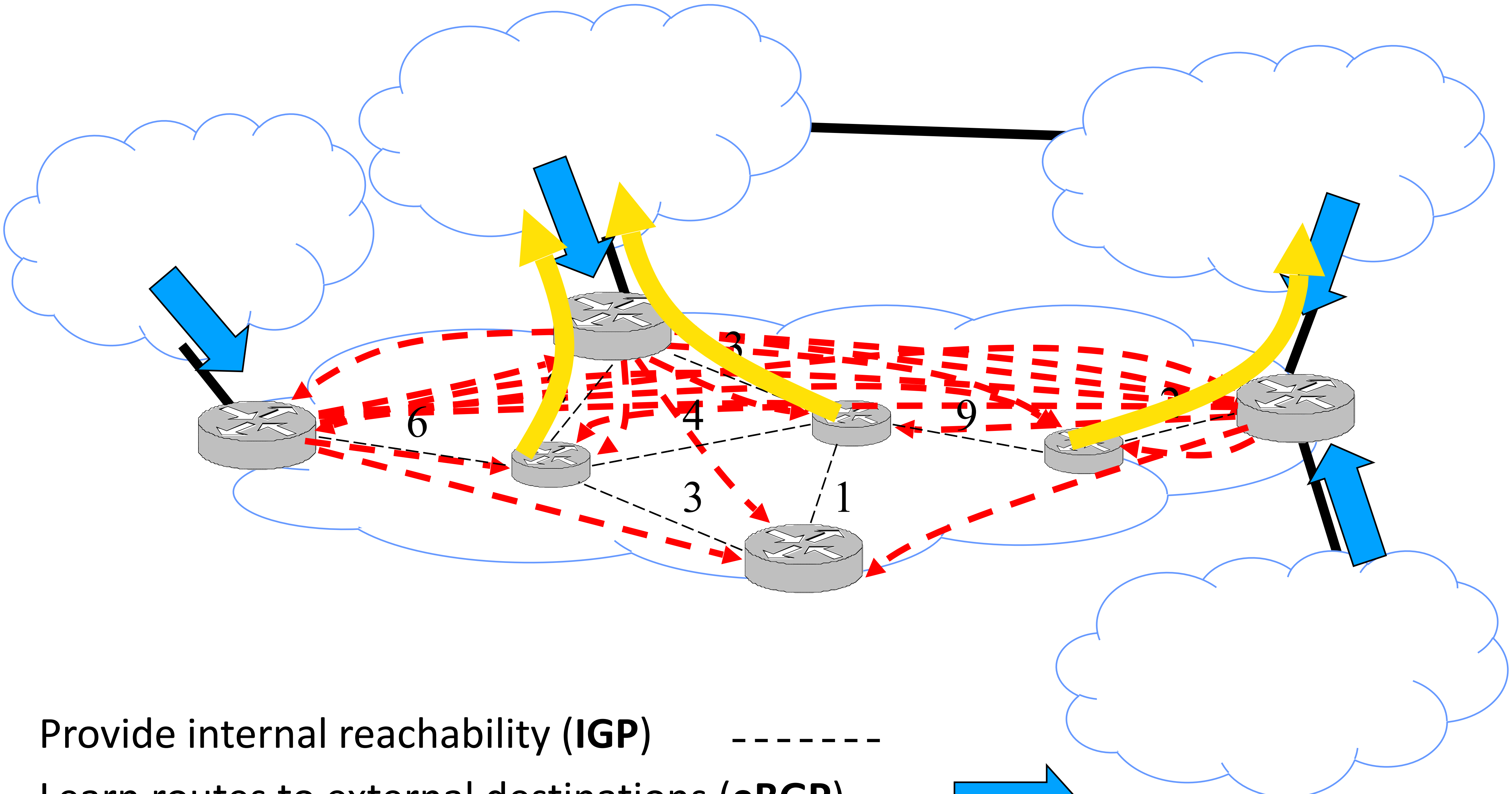
eBGP, iBGP, IGP

- eBGP: BGP sessions between border routers in different ASes
  - Learn routes to external destinations

- iBGP: BGP sessions between border routers and other routers within the same AS
  - Distribute externally learned routes internally

- IGP: Interior Gateway Protocol = Intradomain routing protocol
  - Provides internal reachability
  - e.g. OSPF, RIP

Putting the Pieces Together



1. Provide internal reachability (**IGP**) - - - - - - - -
2. Learn routes to external destinations (**eBGP**)
3. Distribute externally learned routes internally (**iBGP**)
4. Travel shortest path to egress (IGP)

Basic Messages in BGP

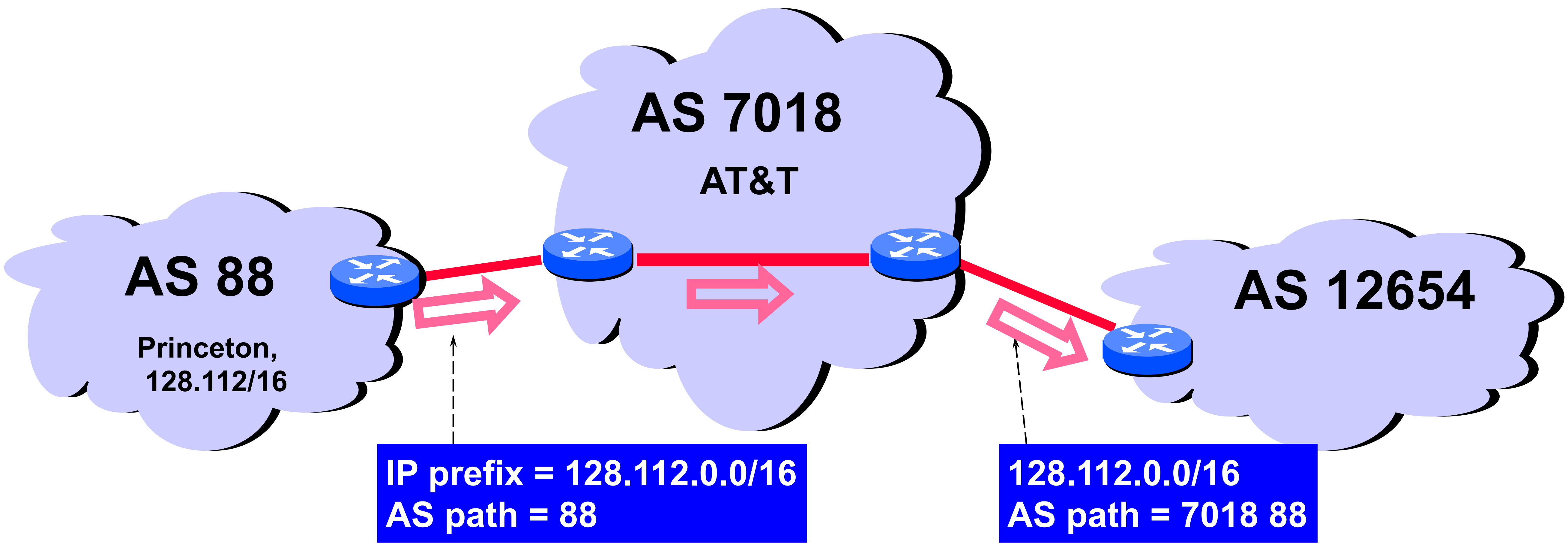
- **Open**
  - Establishes BGP session
- **Update**
  - Inform neighbor of new routes
  - Inform neighbor of old routes that become inactive
- **Keepalive**
  - Inform neighbor that connection is still viable

Route Updates

- Format: *<IP prefix: route attributes>*
- Two kinds of updates:
  - Announcements: new routes or changes to existing routes
  - Withdrawals: remove routes that no longer exist
- Route Attributes
  - Describe routes, used in selection/export decisions
  - Some attributes are local
    - i.e. private within an AS, not included in announcements
  - Some attributes are propagated with eBGP route announcements
  - Many standardized attributes in BGP

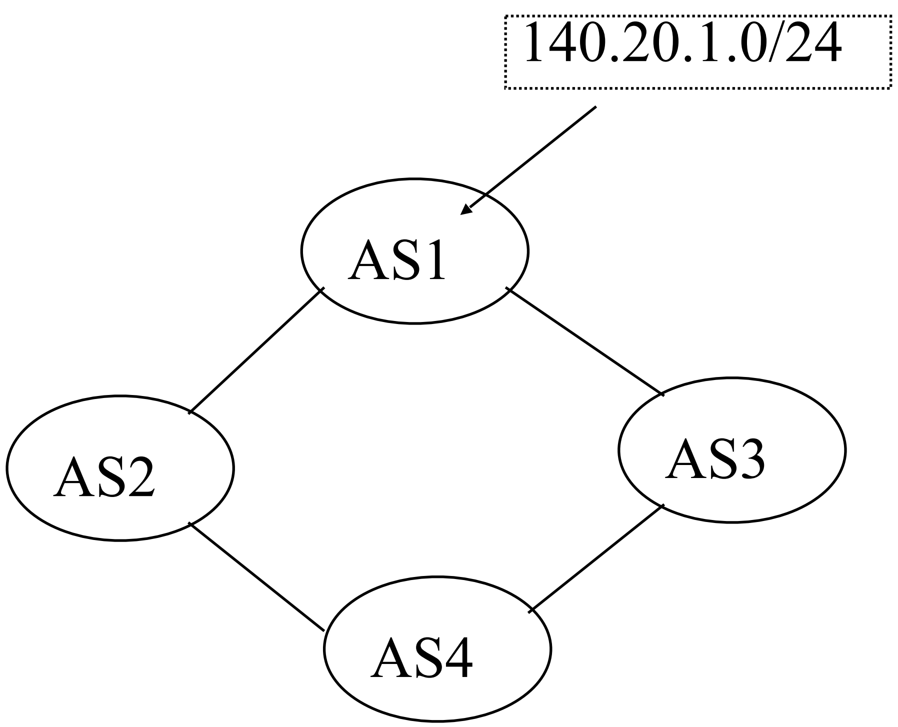
Route Attributes (1): `ASPATH`

- Carried in route announcements
- Vector that lists all the ASes a route advertisement has traversed (in reverse order)



Route Attributes (2): `LOCAL PREF`

- "Local Preference"
- Used to choose between different AS paths
- The higher the value, the more preferred
- Local to an AS; carried only in iBGP messages

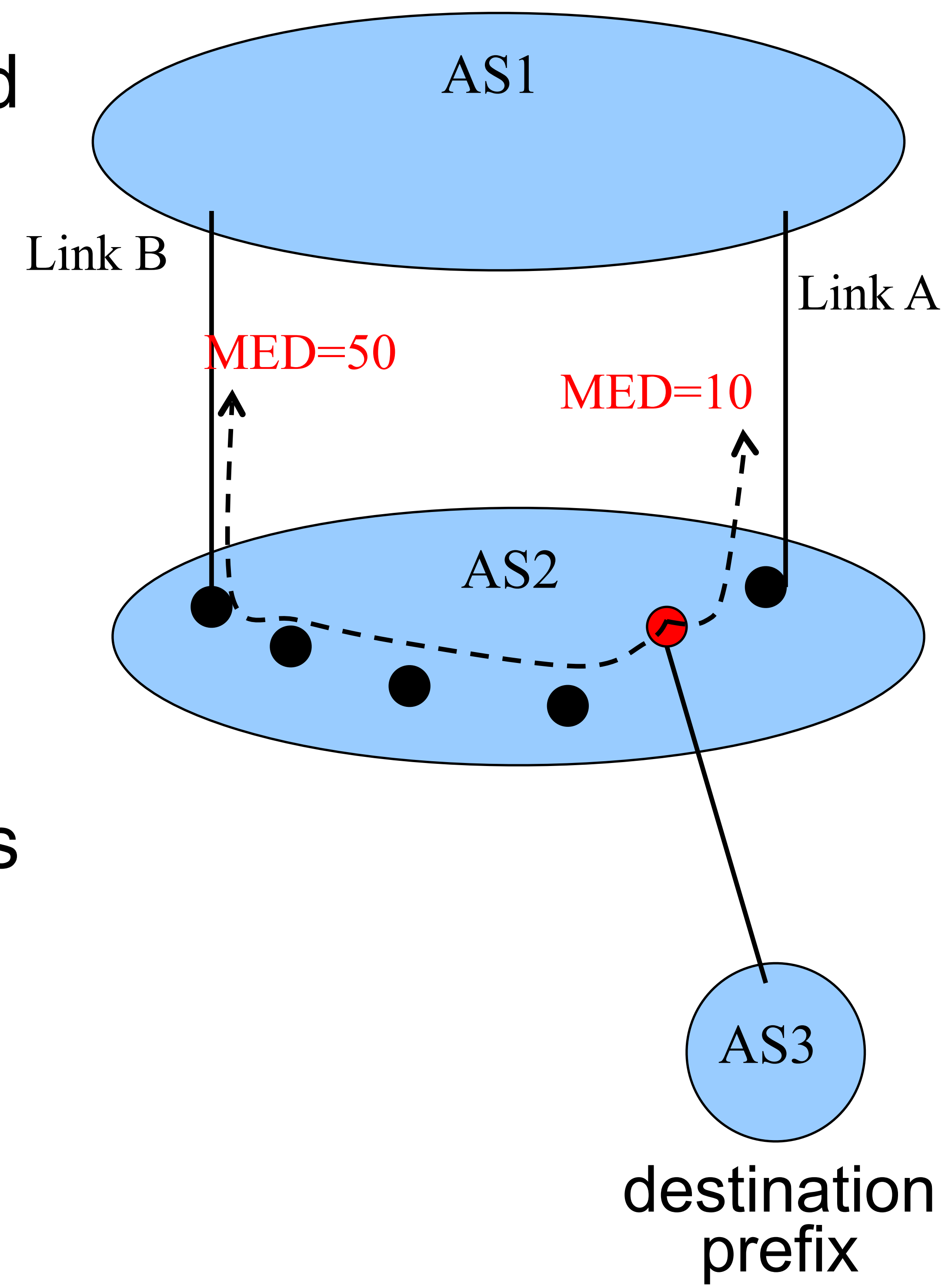


BGP table at AS4:

Destination	AS Path	Local Pref
140.20.1.0/24	AS3 AS1	300
140.20.1.0/24	AS2 AS1	100

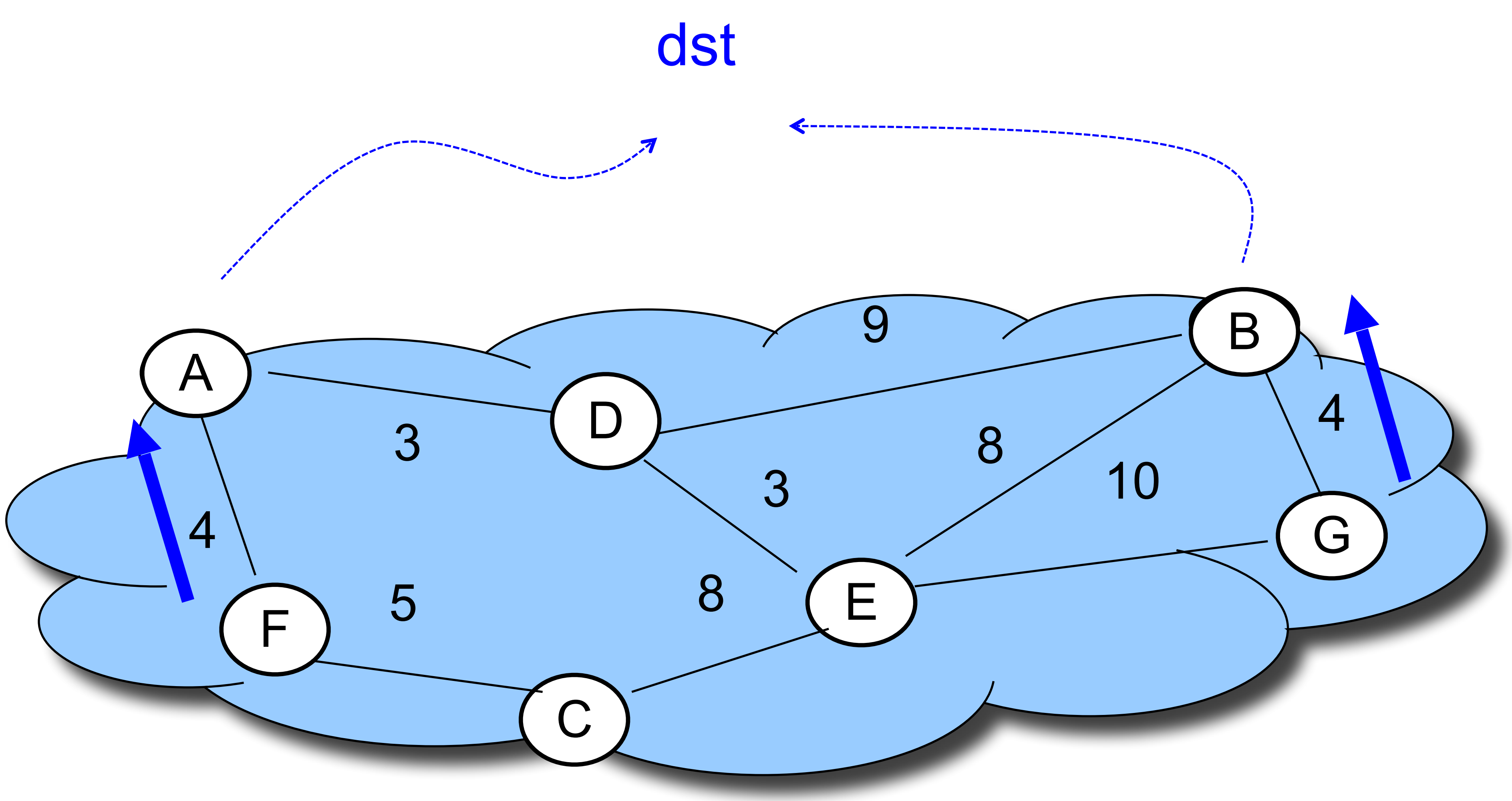
Route Attributes (3) : MED

- "Multi-Exit Discriminator"
- Used when ASes are interconnected via two or more links
  - Specifies how close a prefix is to the link it is announced on
- Lower is better
- AS announcing prefix sets MED
- AS receiving prefix (optionally!) uses MED to select link



Route Attributes (4): IGP Cost

- Used for hot-potato routing
  - Each router selects the closest egress point based on the path cost in intra-domain protocol



Using Attributes

- Rules for route selection in priority order

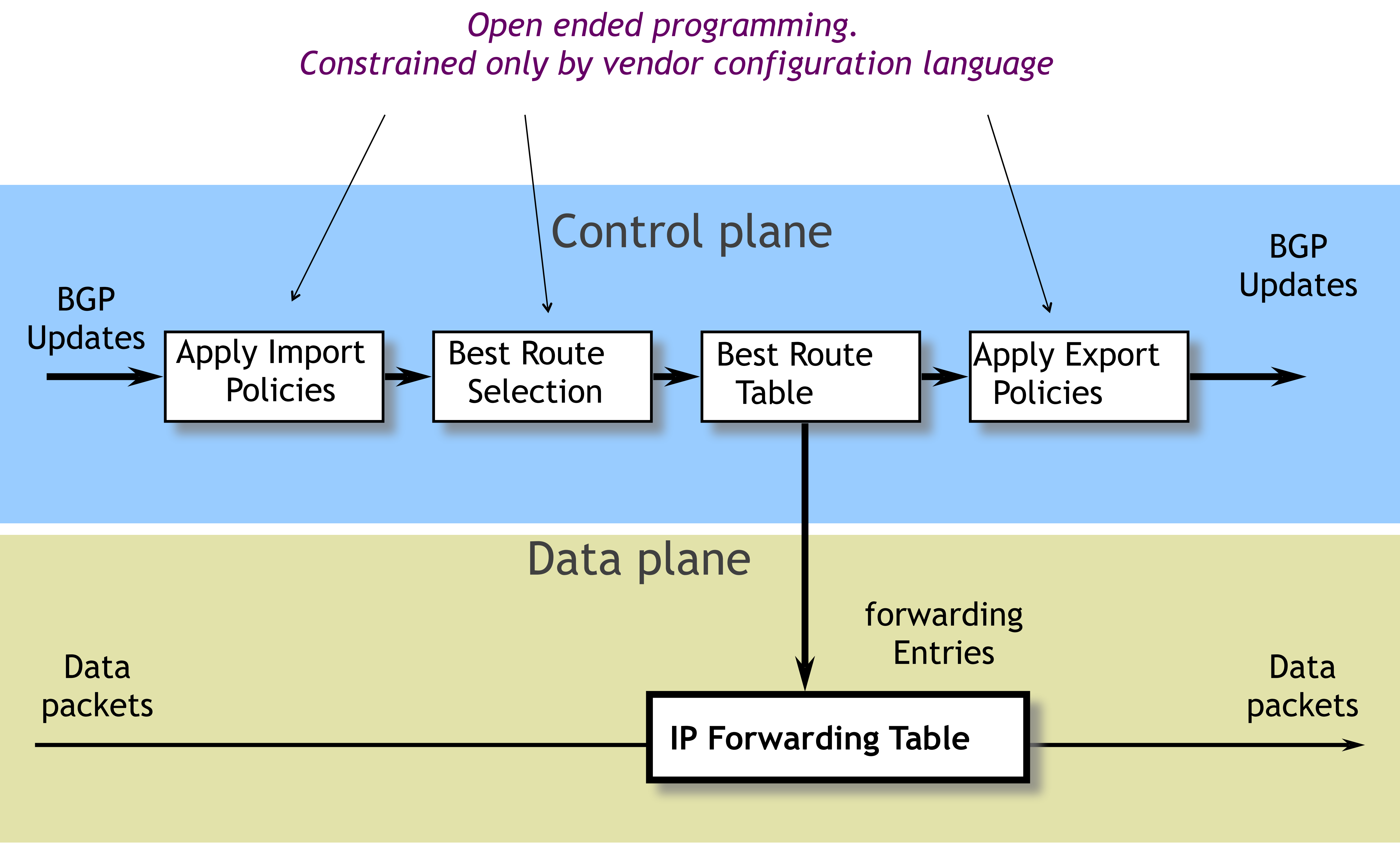
    1. Make or save money (send to customer > peer > provider)
    2. Maximize performance (smallest AS path length)
    3. Minimize use of my network bandwidth (“hot potato”)
    4. …

Using Attributes

- Rules for route selection in priority order

Priority	Rule	Remarks
1	`LOCAL PREF`	Pick highest `LOCAL PREF`
2	`ASPATH`	Pick shortest `ASPATH` length
3	`MED`	Lowest `MED` preferred
4	eBGP > iBGP	Did AS learn route via eBGP (preferred) or iBGP?
5	iBGP path	Lowest IGP cost to next hop (egress router)
6	Router ID	Smallest next-hop router's IP address as tie-breaker

BGP Update Processing



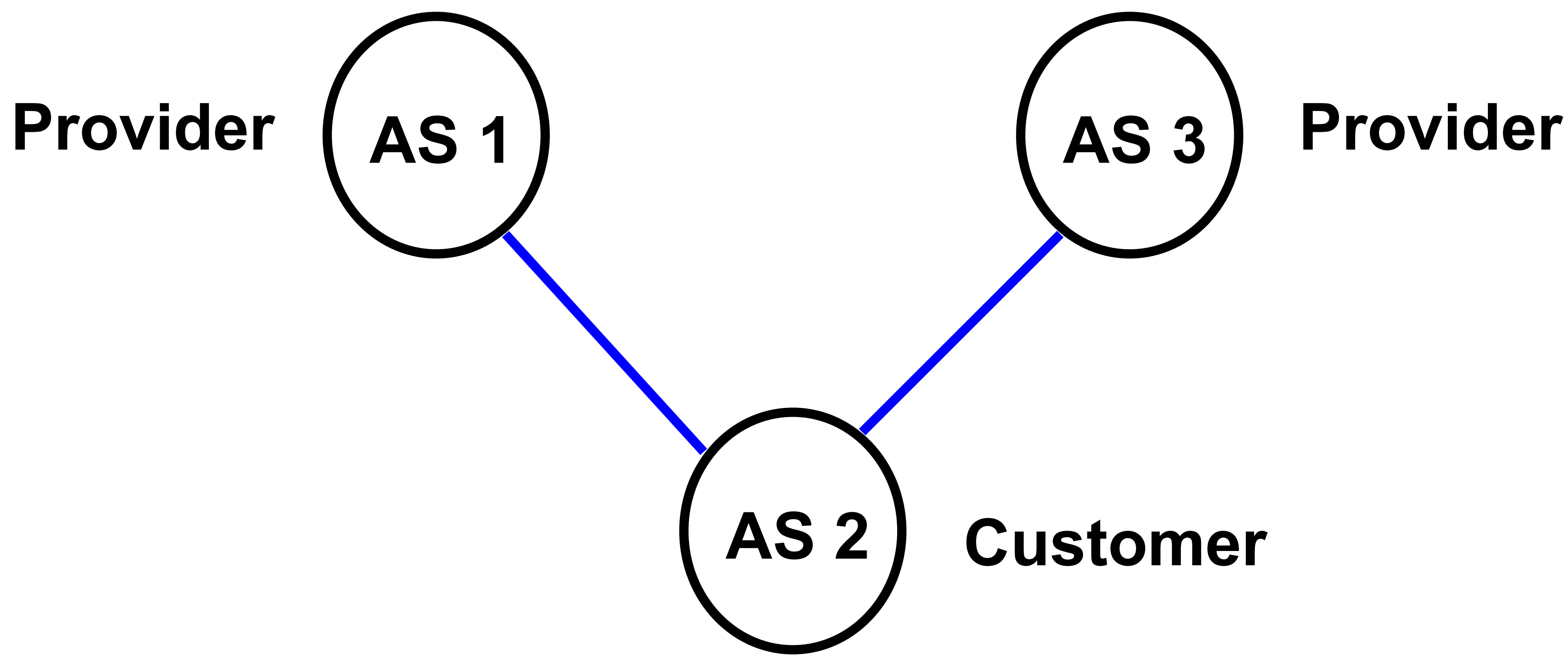
BGP Issues

BGP: Issues

- Reachability
- Security
- Convergence
- Performance
- Anomalies

Reachability

- In normal routing, if graph is connected then reachability is assured
- With policy routing, this doesn't always hold



Security

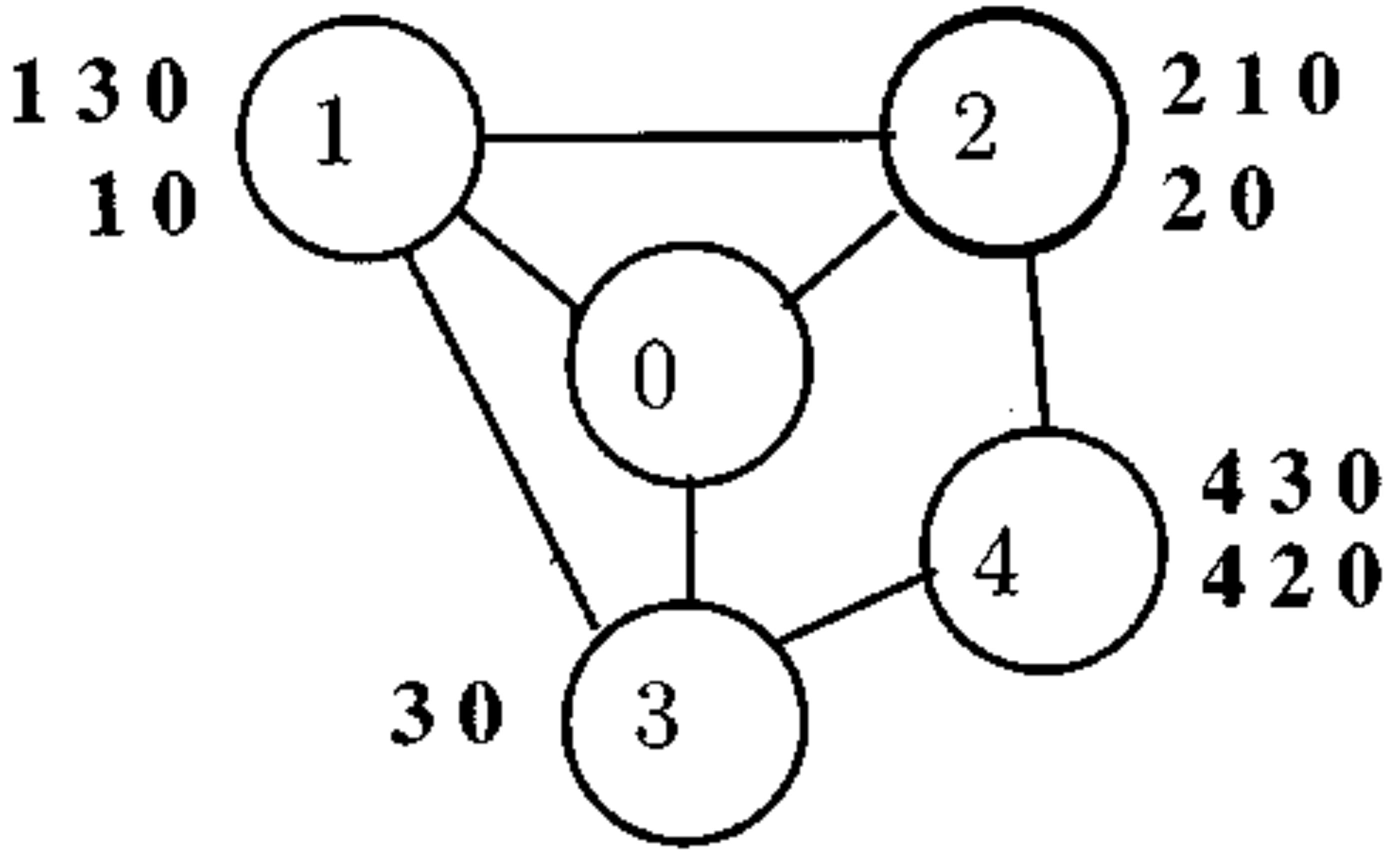
- An AS can claim to serve a prefix that they actually don't have a route to (blackholing traffic)
  - Problem not specific to policy or path vector
  - Important because of AS autonomy
- An AS may forward packets along a route different from what is advertised
  - Tell customers about a fictitious short path…

Convergence

- If all AS policies follow Gao-Rexford rules,
  - Preferring routes from customers > peers > providers
  - Then BGP is guaranteed to converge (safety)

- For arbitrary policies, BGP may fail to converge!

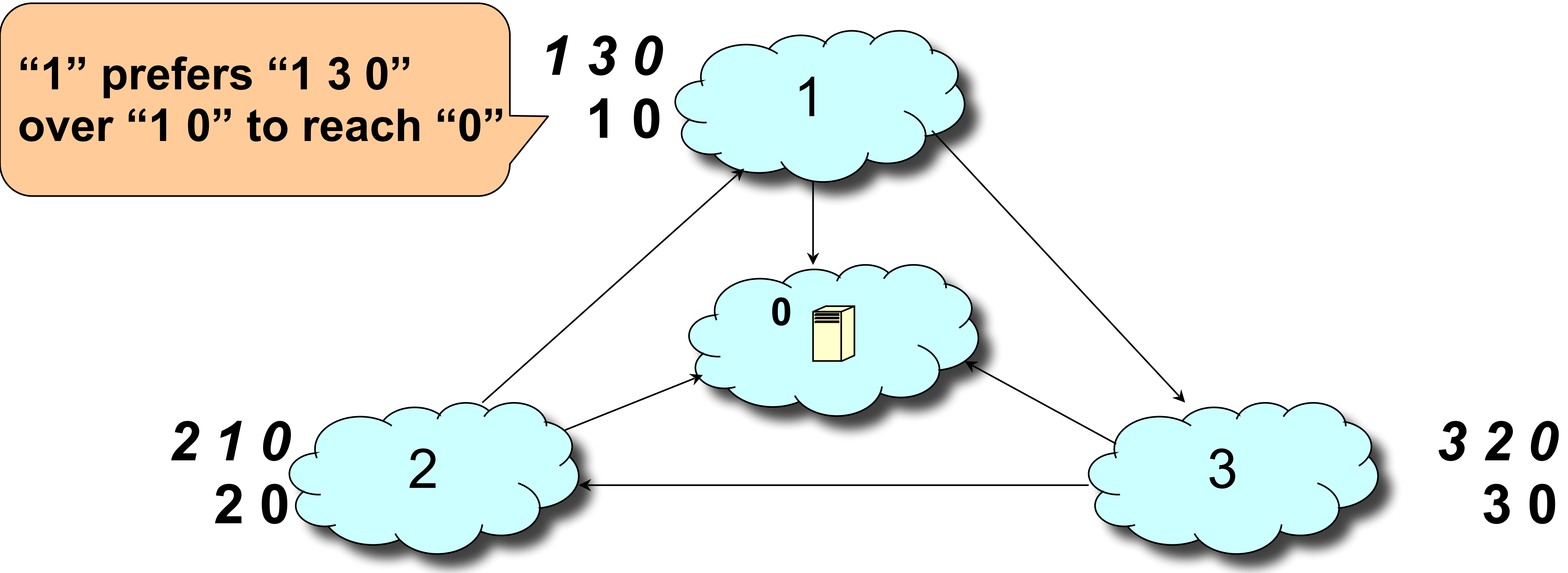
BGP Example (All good)



GOOD GADGET

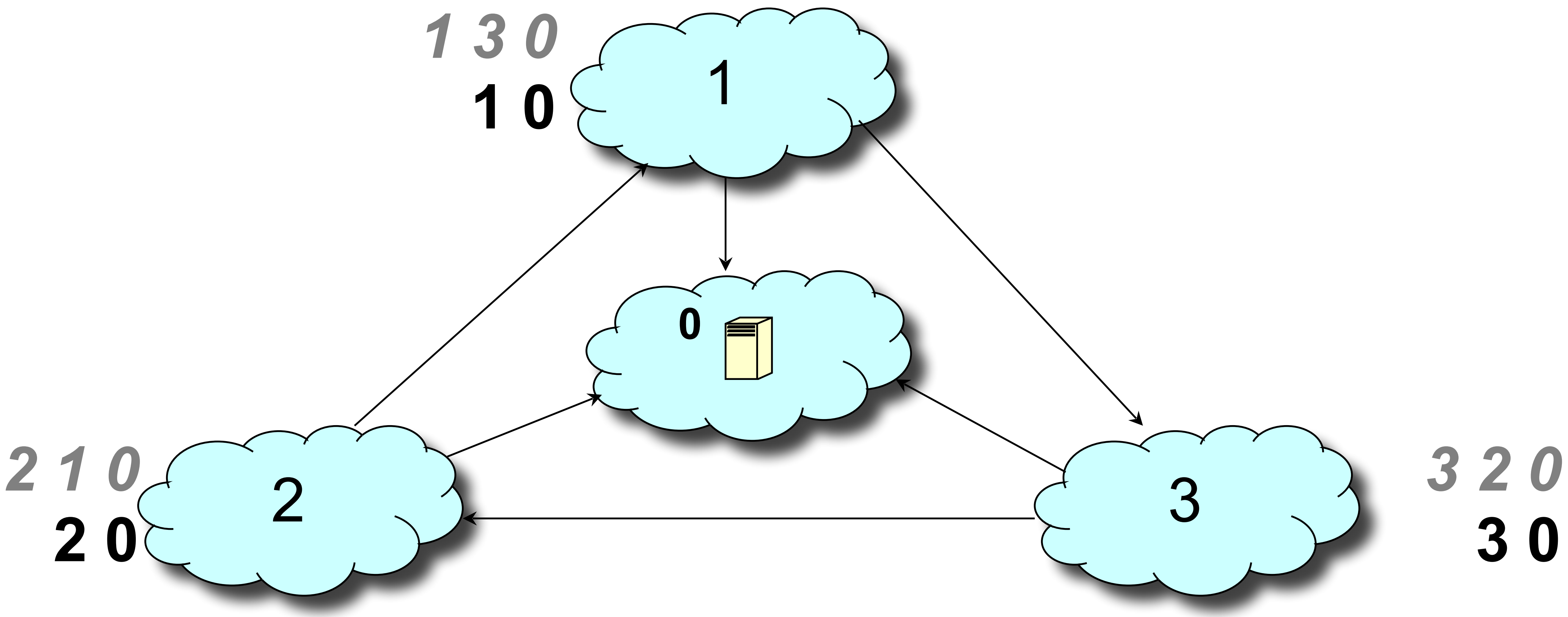
	1	2	3	4
R1	10	20	**30**	-
R2	10	20	**30**	430
R3	130	20	30	430

Example of Policy Oscillation



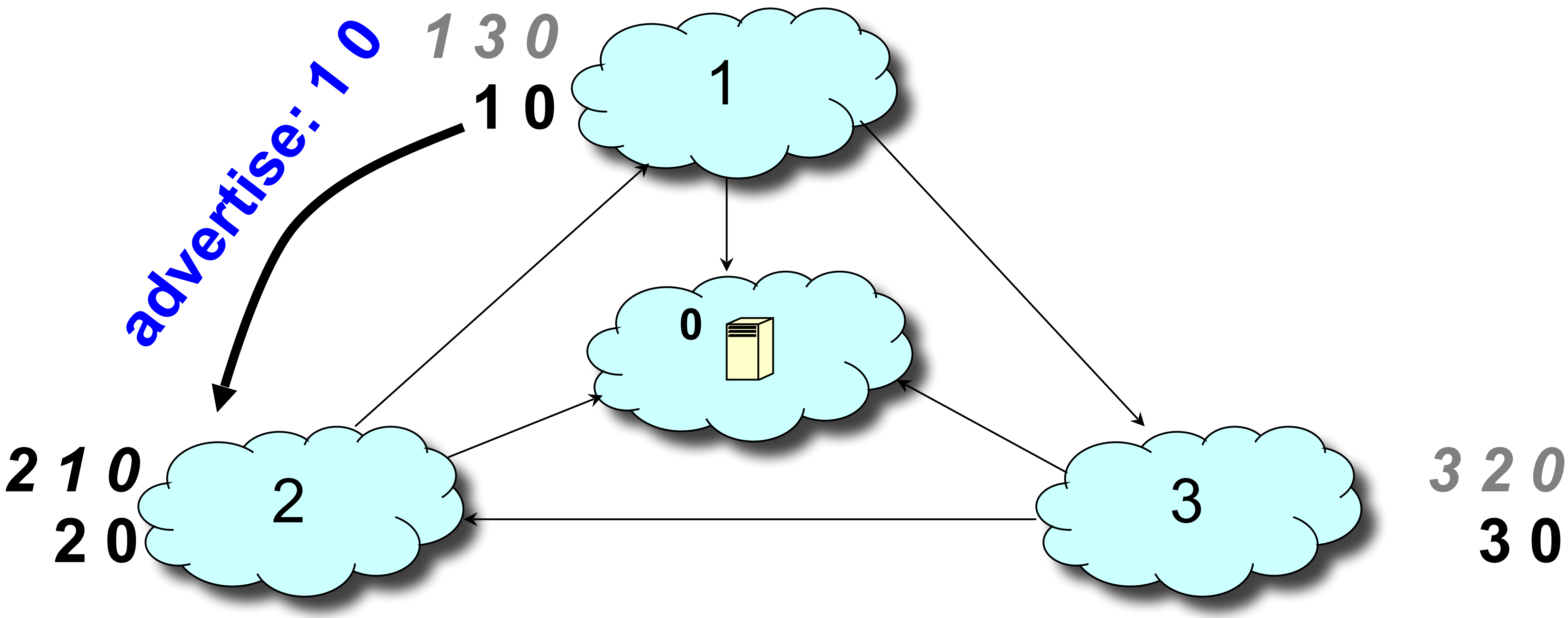
Step-by-step Policy Oscillation

Initially: nodes 1, 2, 3 know only shortest path to 0

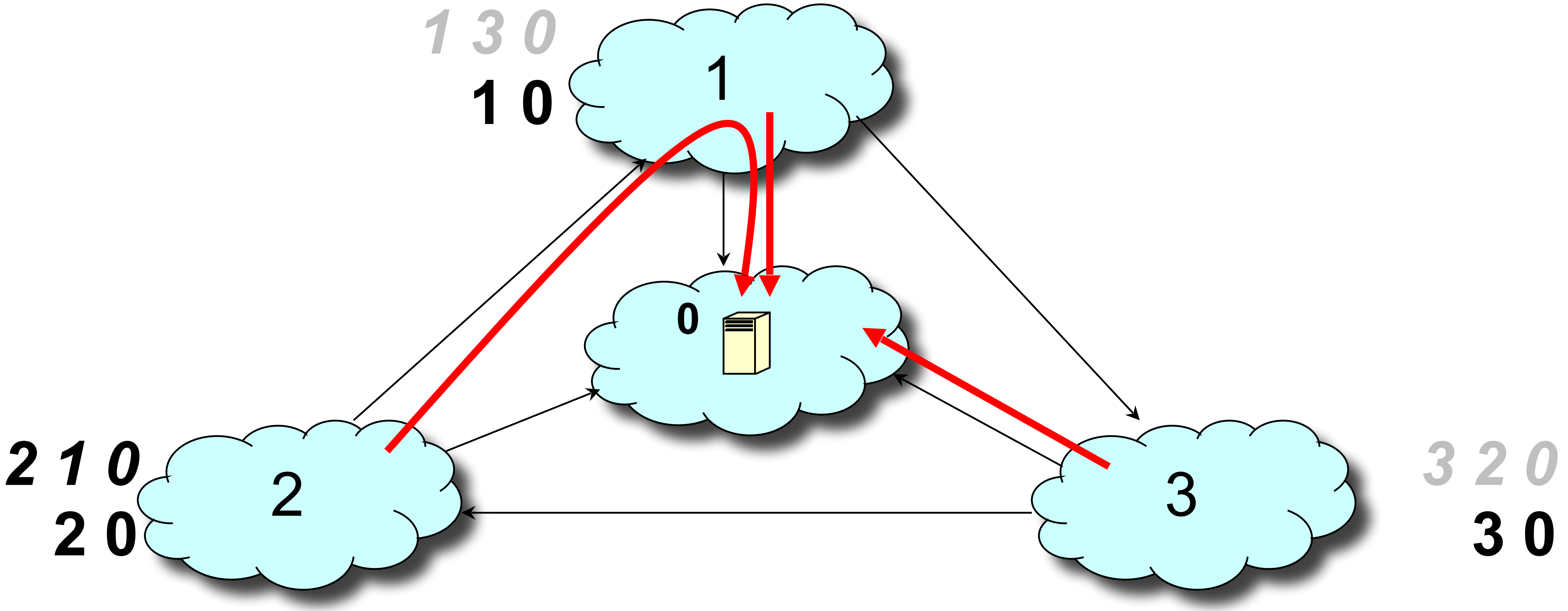


Step-by-step Policy Oscillation

1 **advertises** its path 1 0 to 2

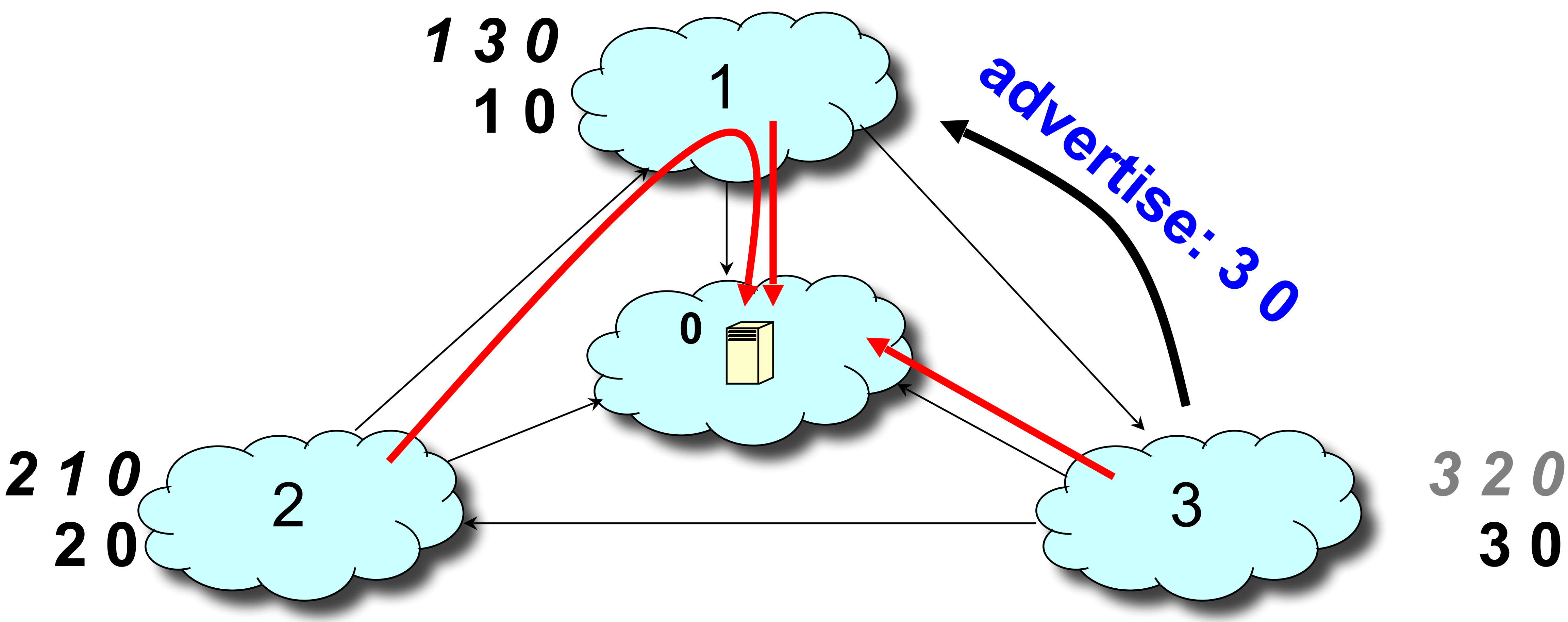


Step-by-step Policy Oscillation

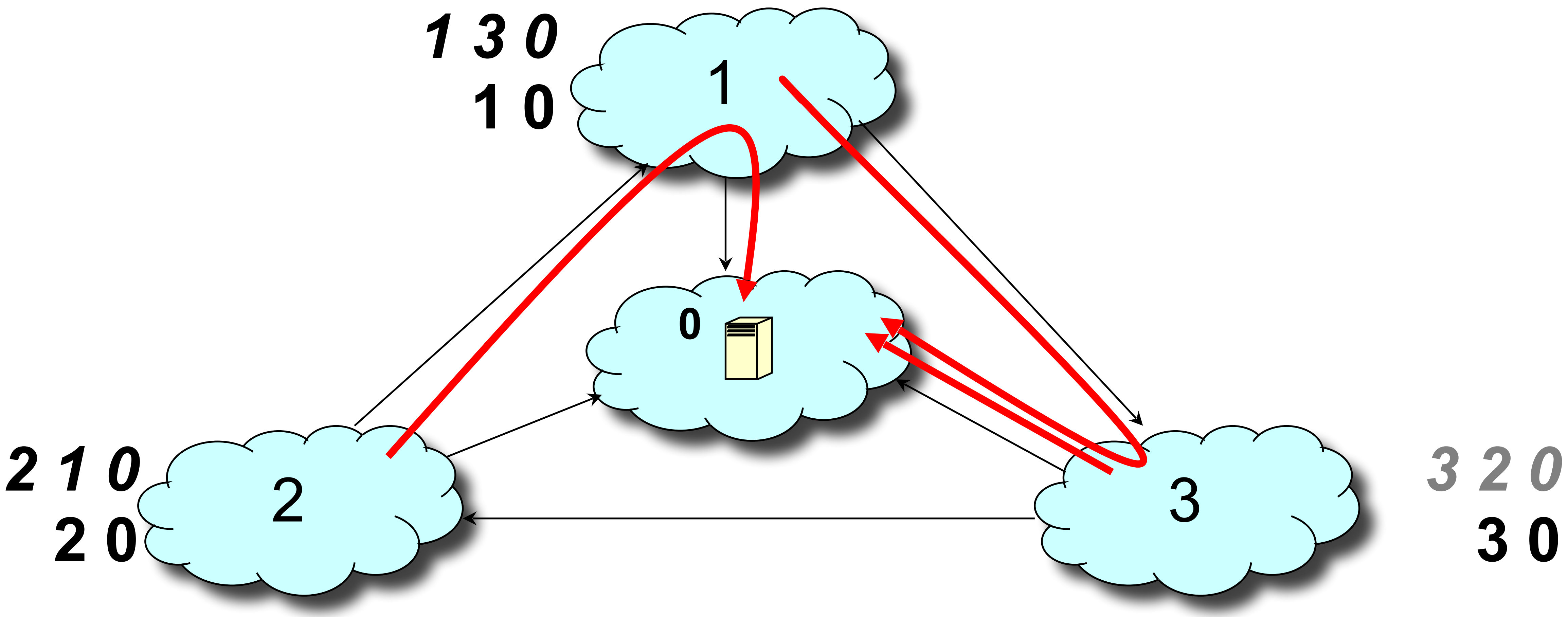


Step-by-step Policy Oscillation

3 **advertises** its path 3 0 to 1

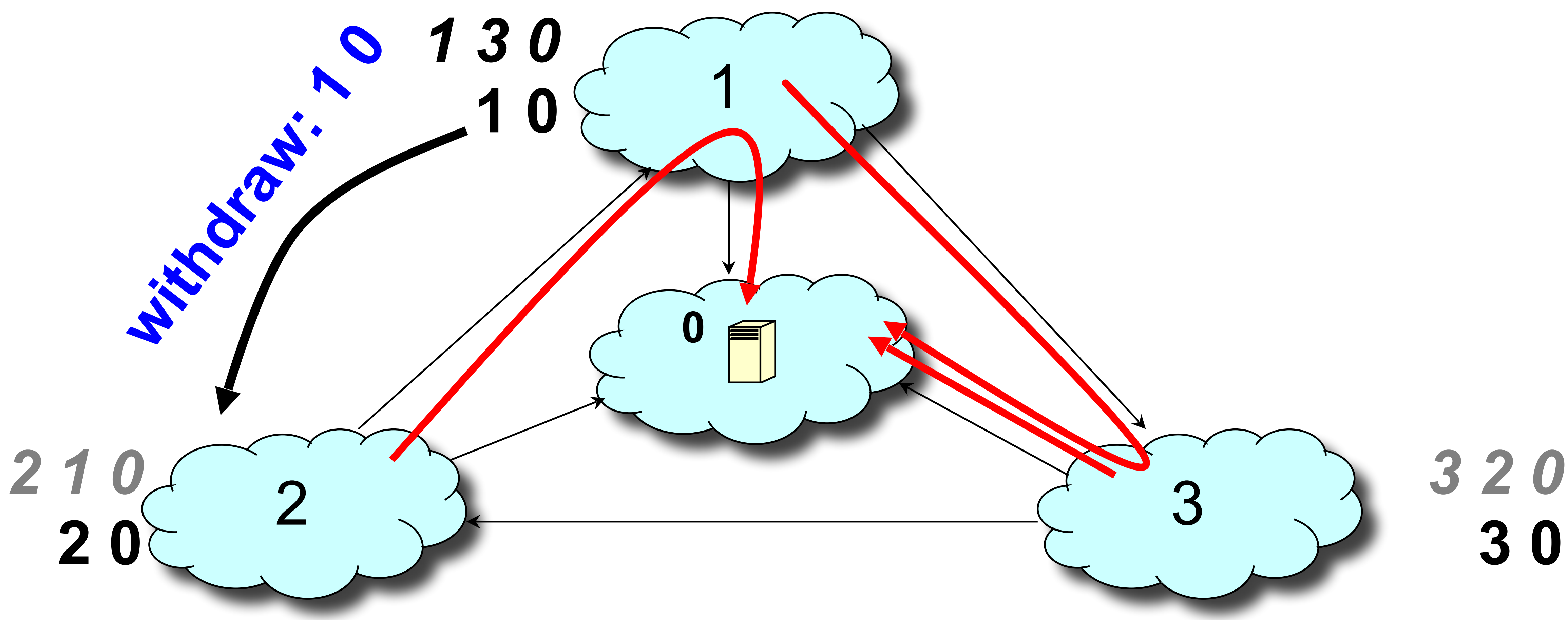


Step-by-step Policy Oscillation

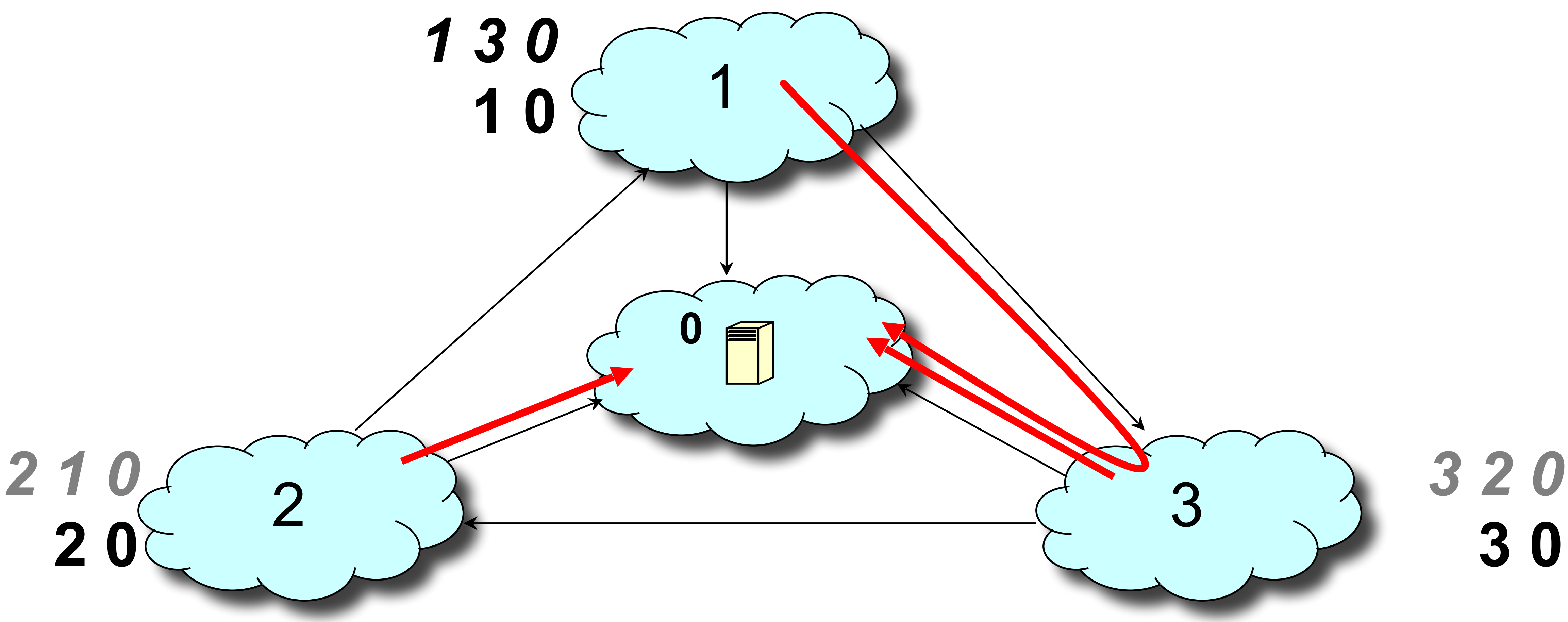


Step-by-step Policy Oscillation

1 **withdraws** its path 1 0 from 2

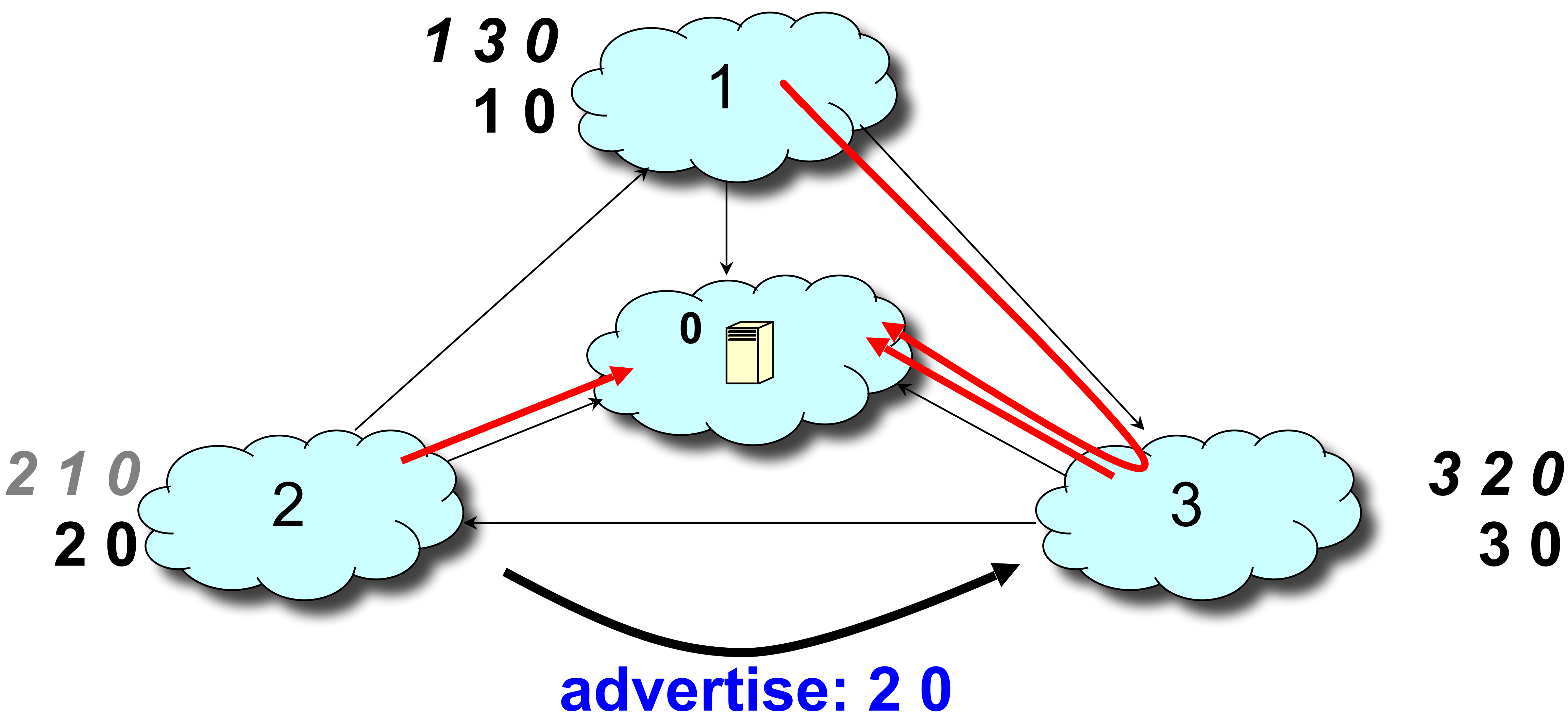


Step-by-step Policy Oscillation

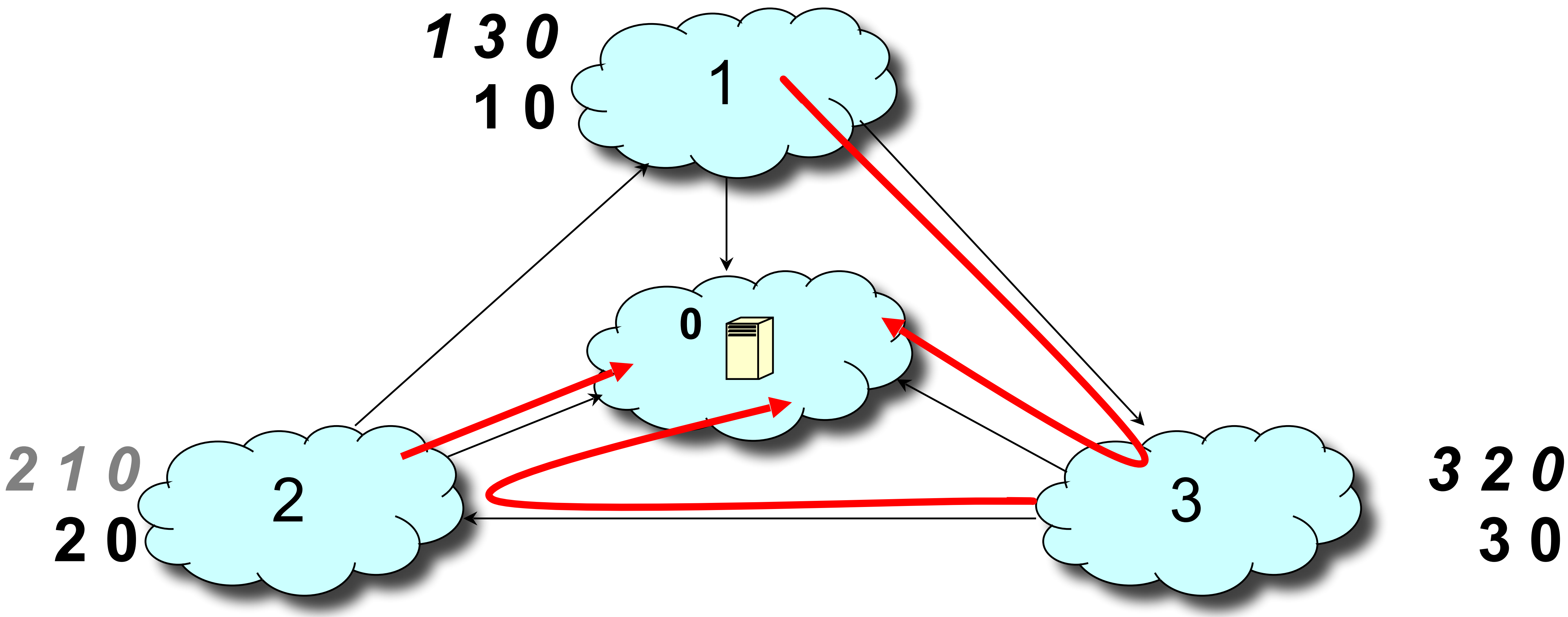


Step-by-step Policy Oscillation

2 **advertises** its path 2 0 to 3

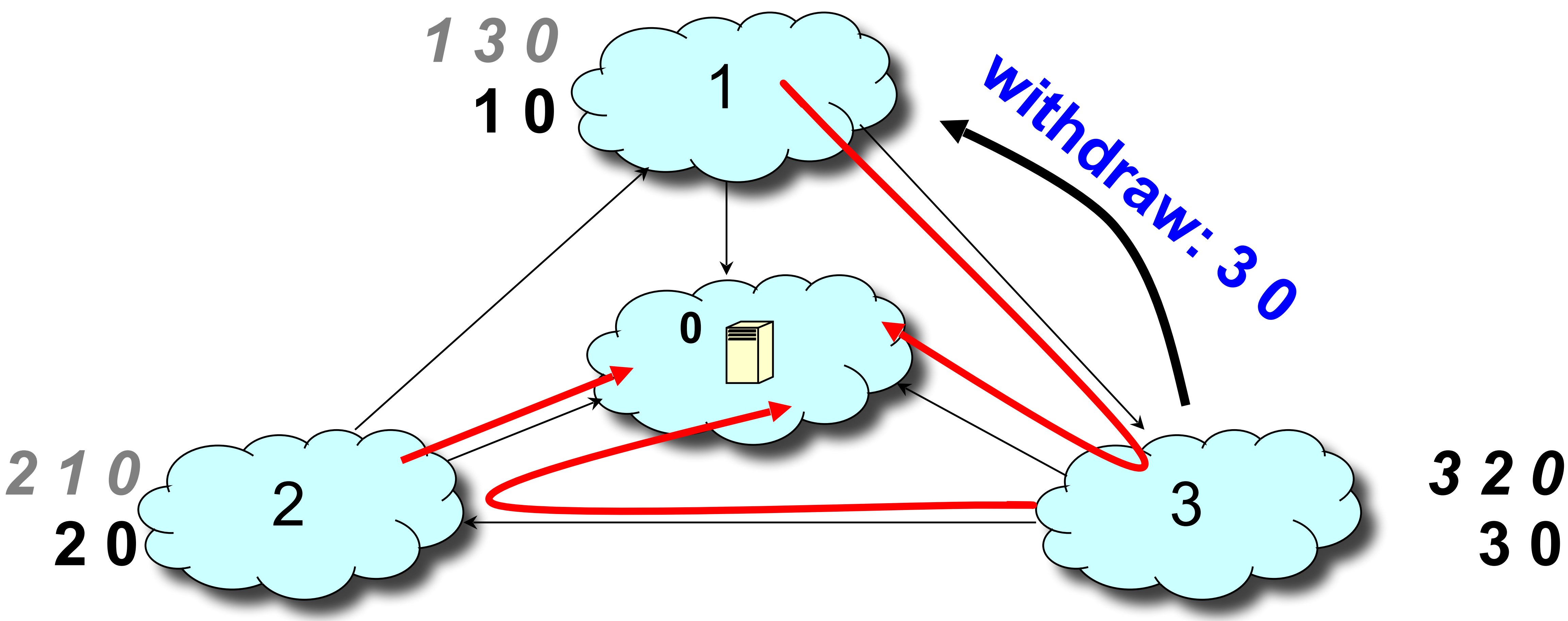


Step-by-step Policy Oscillation

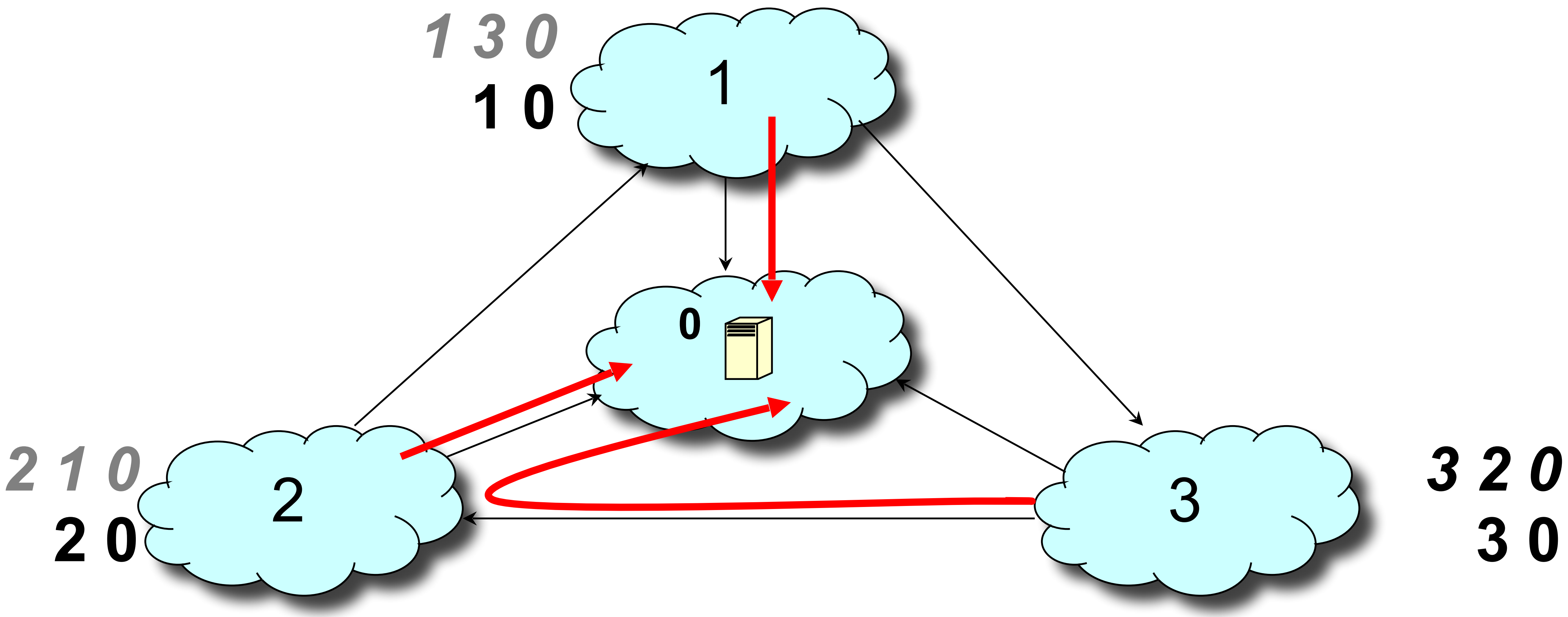


Step-by-step Policy Oscillation

3 **withdraws** its path 3 0 from 1

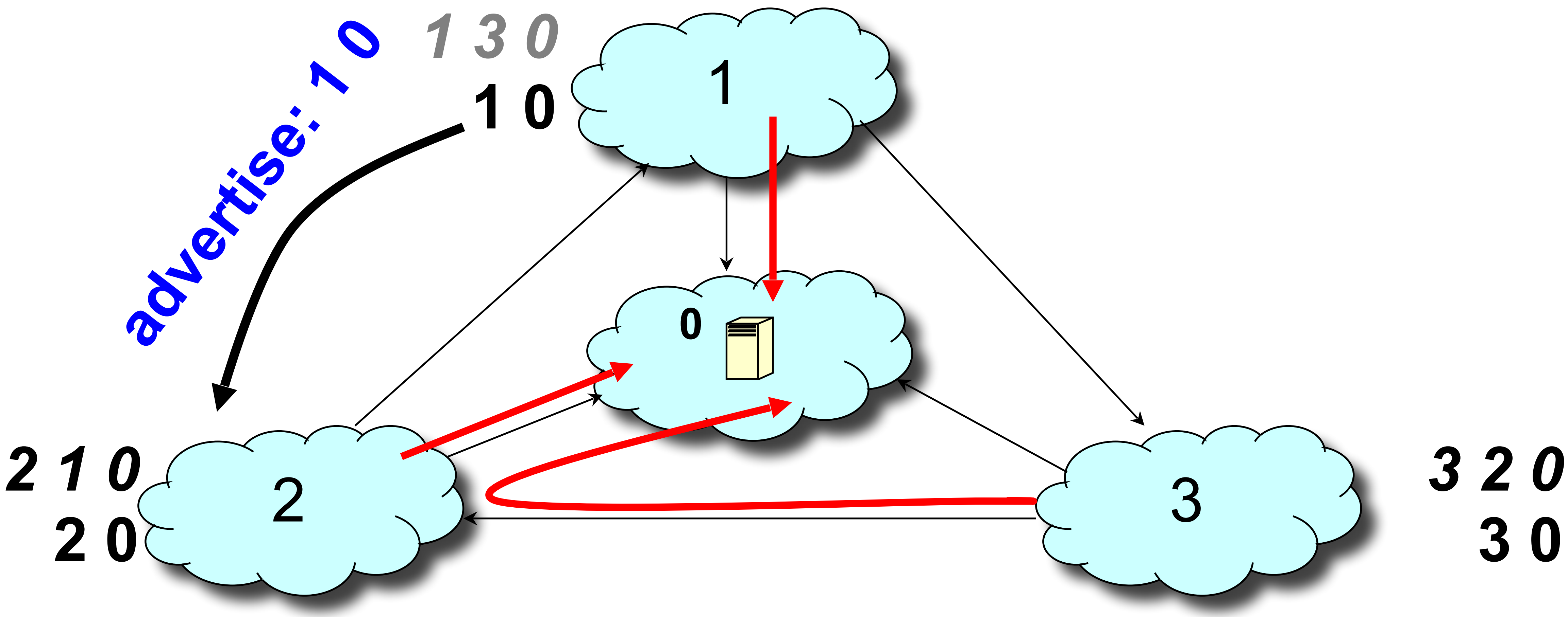


Step-by-step Policy Oscillation

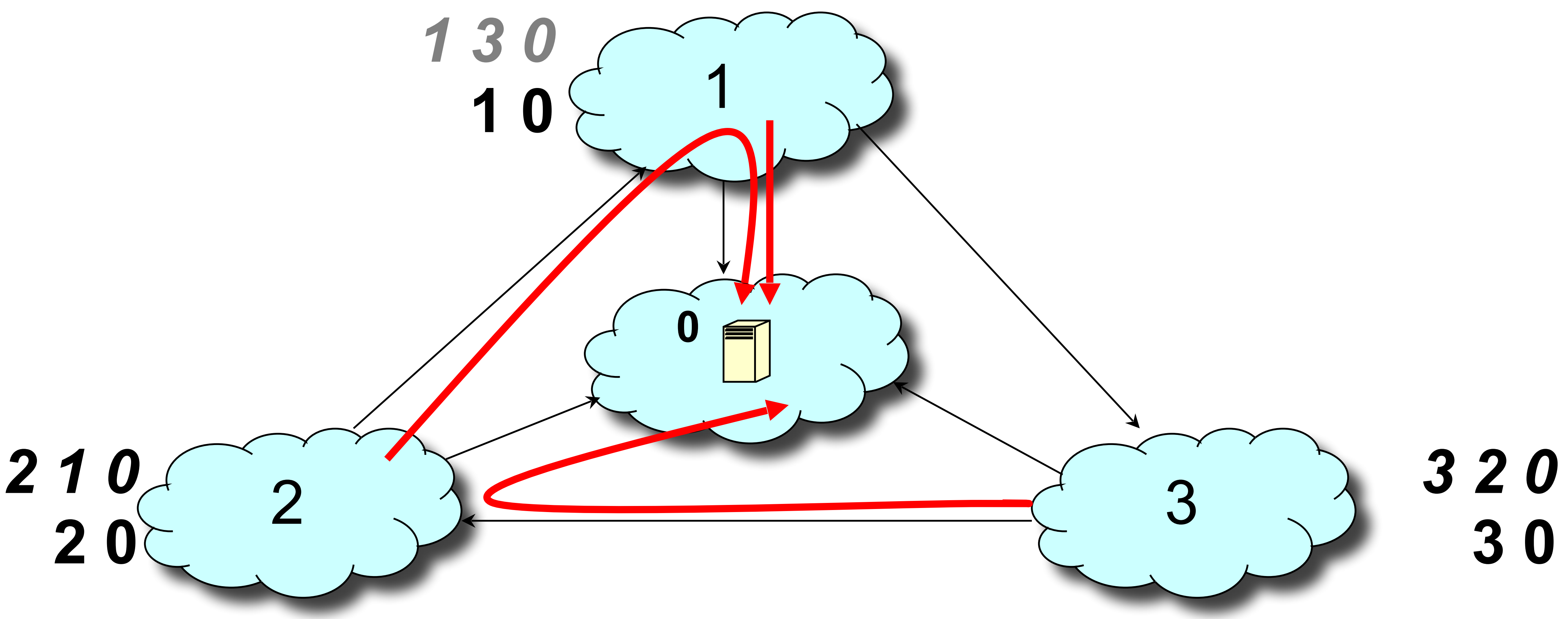


Step-by-step Policy Oscillation

1 **advertises** its path 1 0 to 2

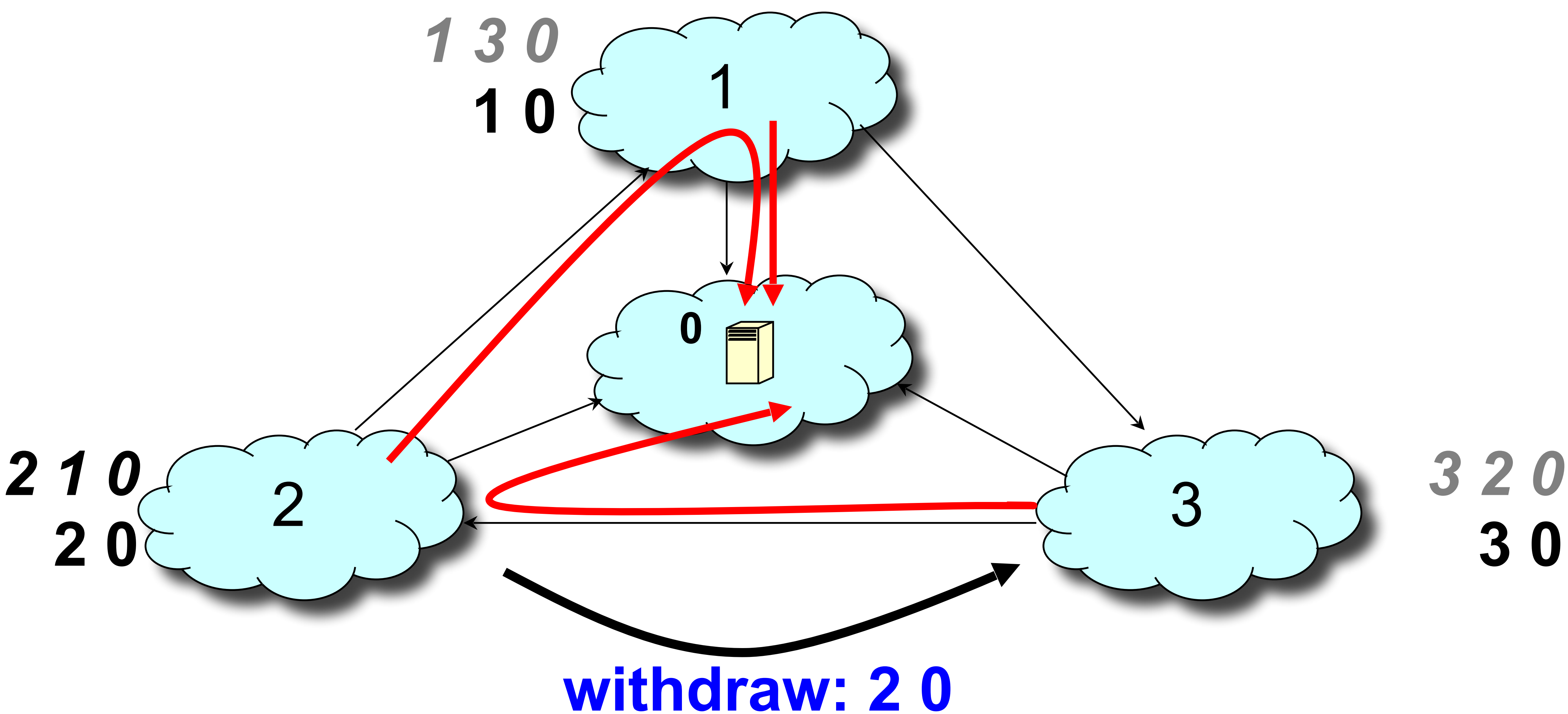


Step-by-step Policy Oscillation

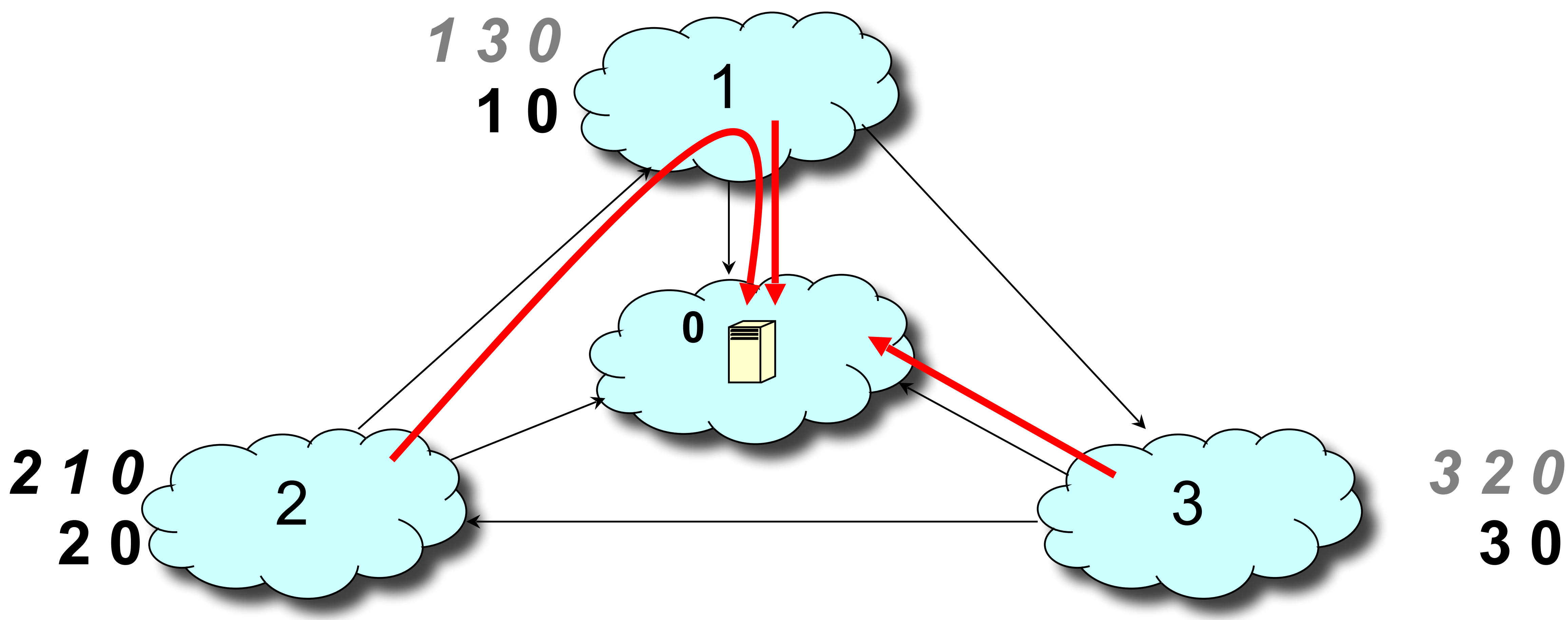


Step-by-step Policy Oscillation

2 **withdraws** its path 2 0 from 3

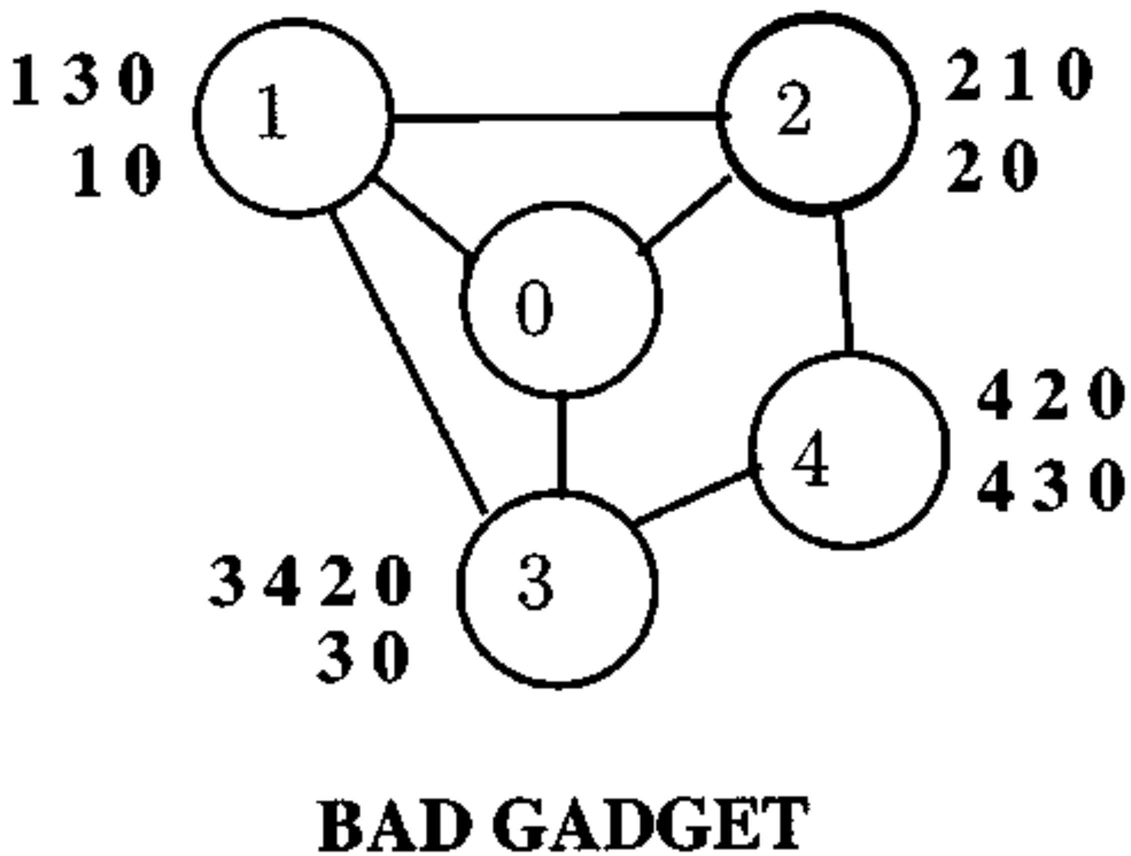


Step-by-step Policy Oscillation



We are back to where we started!

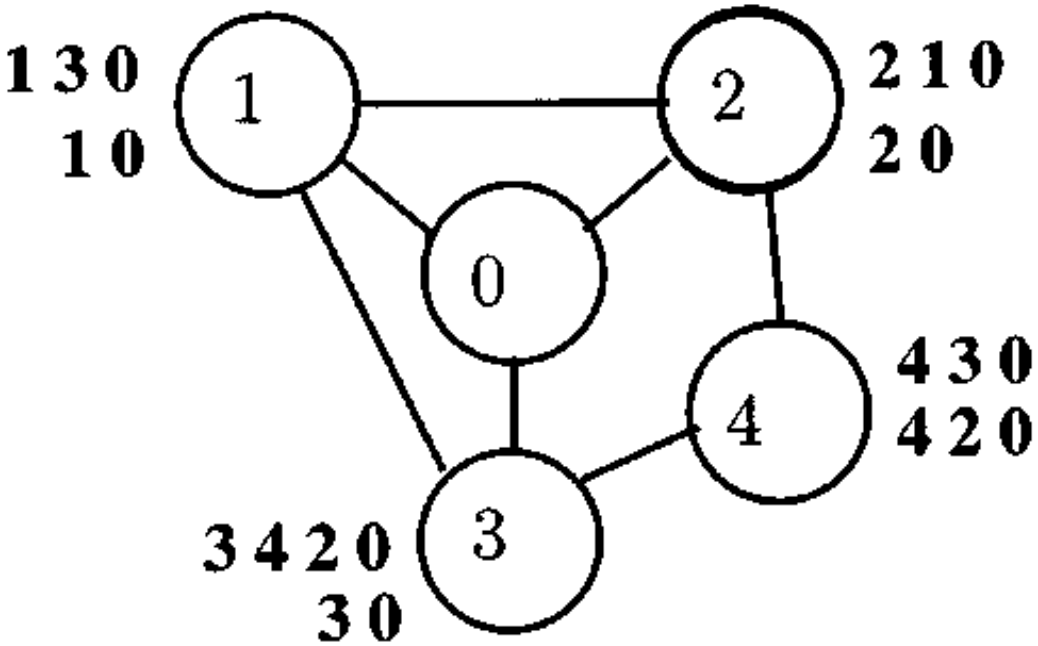
BGP Example (Persistent Loops)



	1	2	3	4
R1	10	**20**	30	-
R2	10	20	30	**420**
R3	**10**	20	3420	420
R4	10	**210**	3420	420
R5	10	210	3420	**-**
R6	10	210	**30**	-
R7	**130**	210	30	-
R8	130	**20**	30	-
R9	130	20	30	**420**
R10	130	20	**3420**	420
R11	10	20	3420	420

BGP Example (Bad bad bad)

	1	2	3	4
R1	10	20	**30**	-
R2	10	20	**30**	430
R3	130	20	30	430



NAUGHTY GADGET

	1	2	3	4
R1	10	**20**	30	-
R2	10	20	30	**420**
R3	**10**	20	3420	420
R4	10	**210**	3420	420
R5	10	210	3420	**-**
R6	10	210	**30**	-
R7	**130**	210	30	-
R8	130	**20**	30	-
R9	130	20	30	**420**
R10	130	20	**3420**	420
R11	10	20	3420	420

Convergence

- If all AS policies follow Gao-Rexford rules,
  - Preferring routes from customers > peers > providers
  - Then BGP is guaranteed to converge (safety)

- For arbitrary policies, BGP may fail to converge!

Performance Non-Issues

- Internal Routing
  - Domains typically use "hot potato" routing
  - Not always optimal, but economically expedient
- Policy not about performance
  - So policy-chosen paths aren't shortest
- AS path length can be misleading
  - 20% of paths inflated by at least 5 router hops

Performance (example)

- AS path length can be misleading
  - An AS may have many router-level hops