Lecture 7: Intra-Domain Routing

Credits: Based on lecture by Rob Sherwood

What

- **Last time: Intra-domain routing protocols (IGP)**
  - Last time
  - OSPF link state
  - RIP distance vector
- **Today: Inter-domain routing protocols (EGP)**
  - Border Gateway Protocol v4
  - Path vector routing protocol: list possible paths
  - No other EGP's today…why?

Why Inter vs. Intra?

- **Why not just use OSPF everywhere?**
  - E.g., hierarchies of OSPF areas
  - Hint: scaling is not the only limitation
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  -

Why Inter vs. Intra?

- **Why not just use OSPF everywhere?**
  - E.g., hierarchies of OSPF areas
  - Hint: scaling is not the only limitation
- **BGP is a policy control and information hiding protocol**
  - intra == trusted, inter == untrusted

Why Study BGP?

- **Critical protocol: makes the Internet run**
  - Only widely deployed EGP
- **Active area of problems!**
  - Efficiency
  - Cogent vs. Level3: Internet partition
  - Pakistan accidentally took down YouTube
  - Spammers use prefix hijacking

Outline

- History (very briefly!)
- Function
- Properties
- Policies
- Example
- Problems and proposed solutions

History

- **Why border *gateway* protocol?**
- **Historical distinction:**
  - 1989: BGPv1, "directional" routing [RFC 1105]:
  - 1990: BGPv2, bunch of incompatible changes [RFC 1163]
  - 1991: BGPv3, resolves connection "collisions" [RFC 1267]
  - 1994: BGPv4 (proposed) [RFC 1654]
  - 1995: BGPv4 (actual), w. CIDR support [RFC 1771]
  - Latest revision of BGPv4 spec [RFC 4271]
- **Additional information:**
  - Application of BGP in Internet [RFC 1772]
  - Experience w. BGPv4 [RFC 1773]
  - Protocol analysis [RFC 1774]

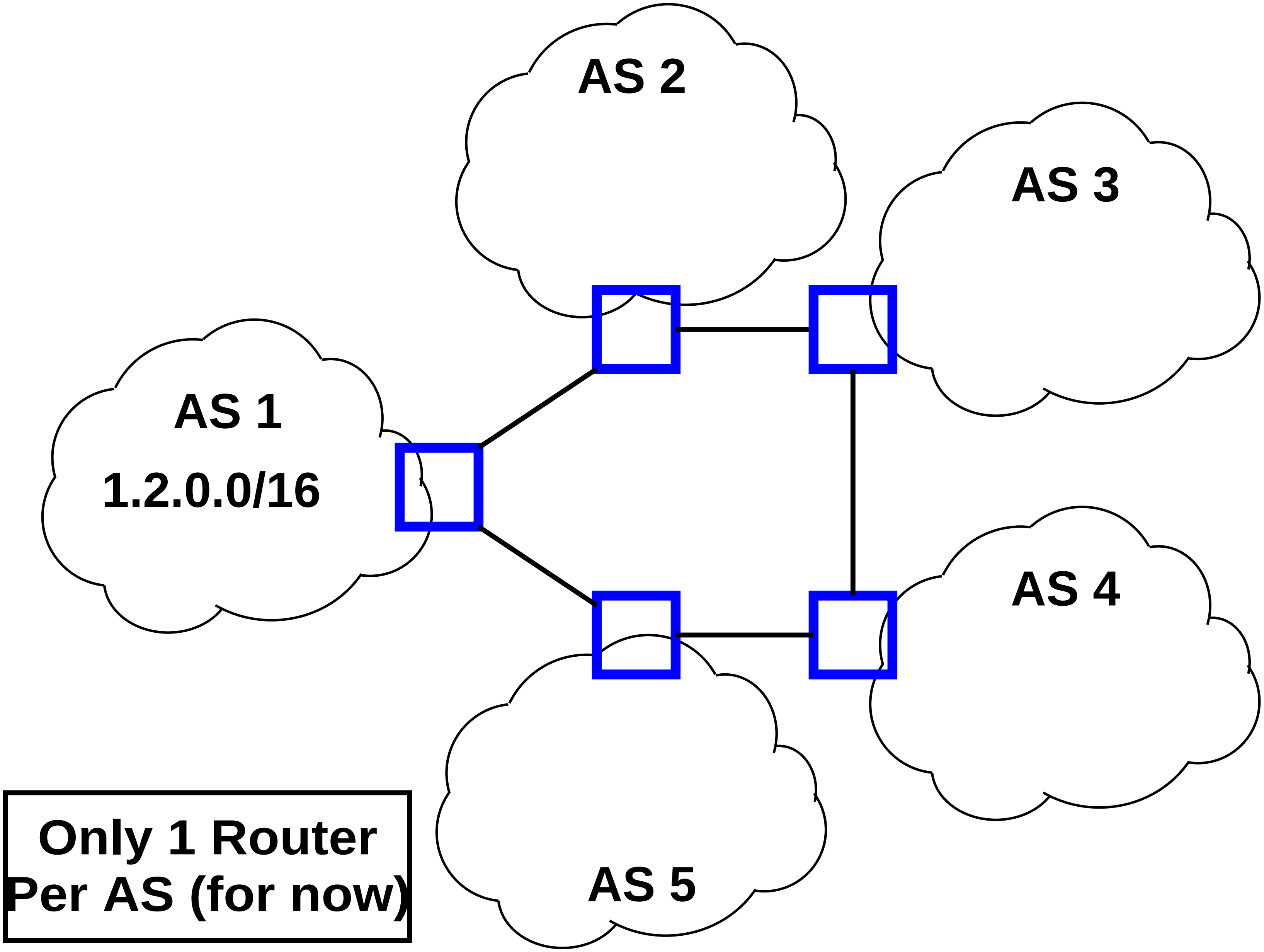
High Level

- **Recall notion of Autonomous System (AS)**
  - Organizations that participate in EGP
  - Assigned AS Number, originally 16 bits, now 32 [RFC 4893]
- **Abstract each AS down to a single node**
- **Exchange prefix-reachability with all neighbors**
- **"I can reach prefix 171.67.0.0/14 through ASes 15444 3549 174 46749 32"**
- **Select a single path by routing *policy***
- **Critical: learn many paths, propagate only one!**
  - Add your ASN to advertised paths

BGP State

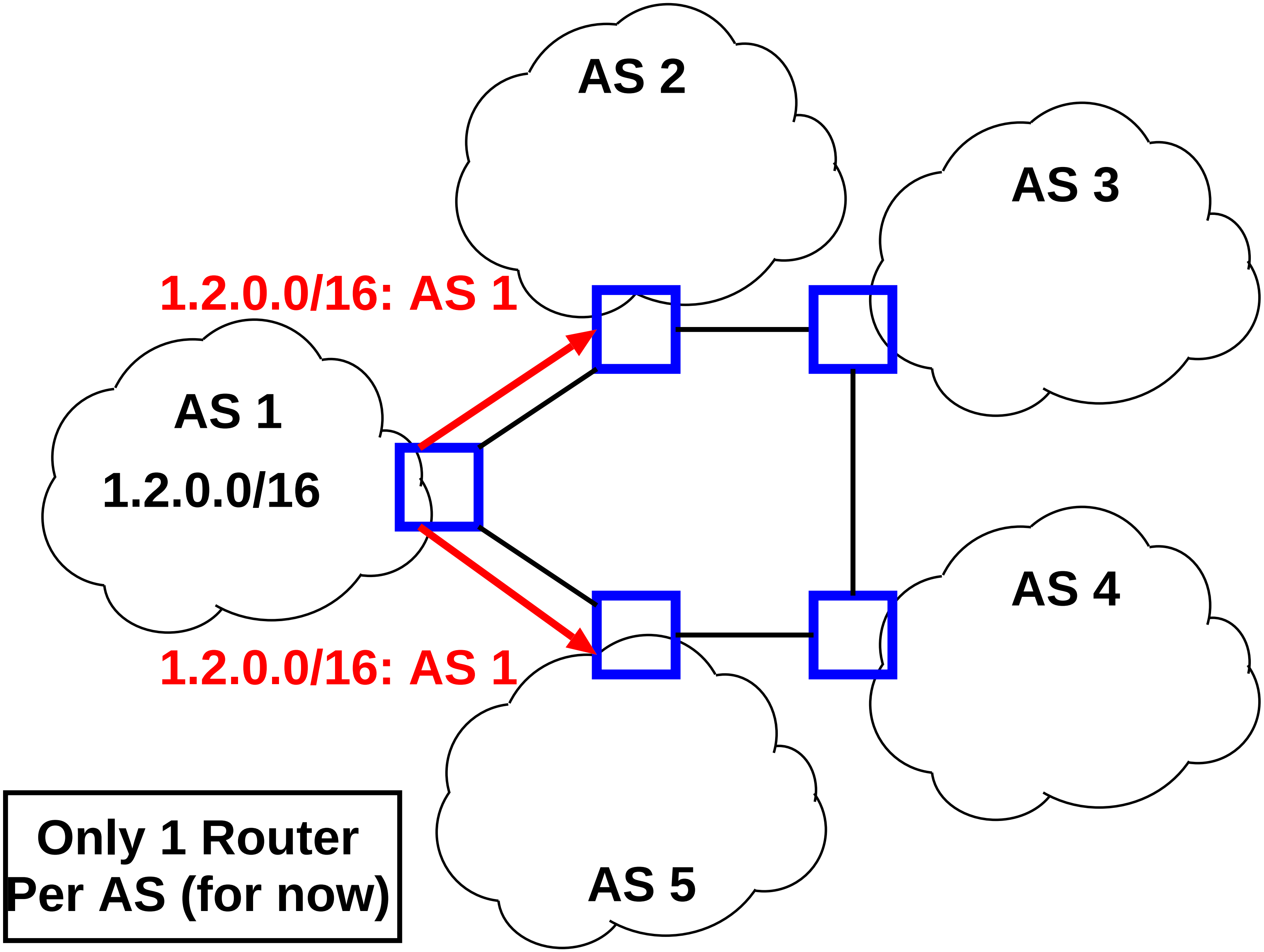
- **BGP speaker conceptually maintains 3 sets of state**
- **Adj-RIBs-In**
  - Stands for “Adjacent Routing Information Base, Incoming”
  - Has unprocessed routes learned from other BGP speakers
  - Contains both reachable and unreachable routes (in case later become reachable and can be added to Loc-RIB)
- **Loc-RIB (Local RIB)**
  - Contains routes from Adj-RIBs-In selected by policy
  - First hop of each route must be reachable by IGP or static route
- **Adj-RIBs-Out (Adj-RIBs, Outgoing)**
  - Subset of Loc-RIB to be advertised to peer speakers

BGP Example



Only 1 Router Per AS (for now)

BGP Example



Only 1 Router
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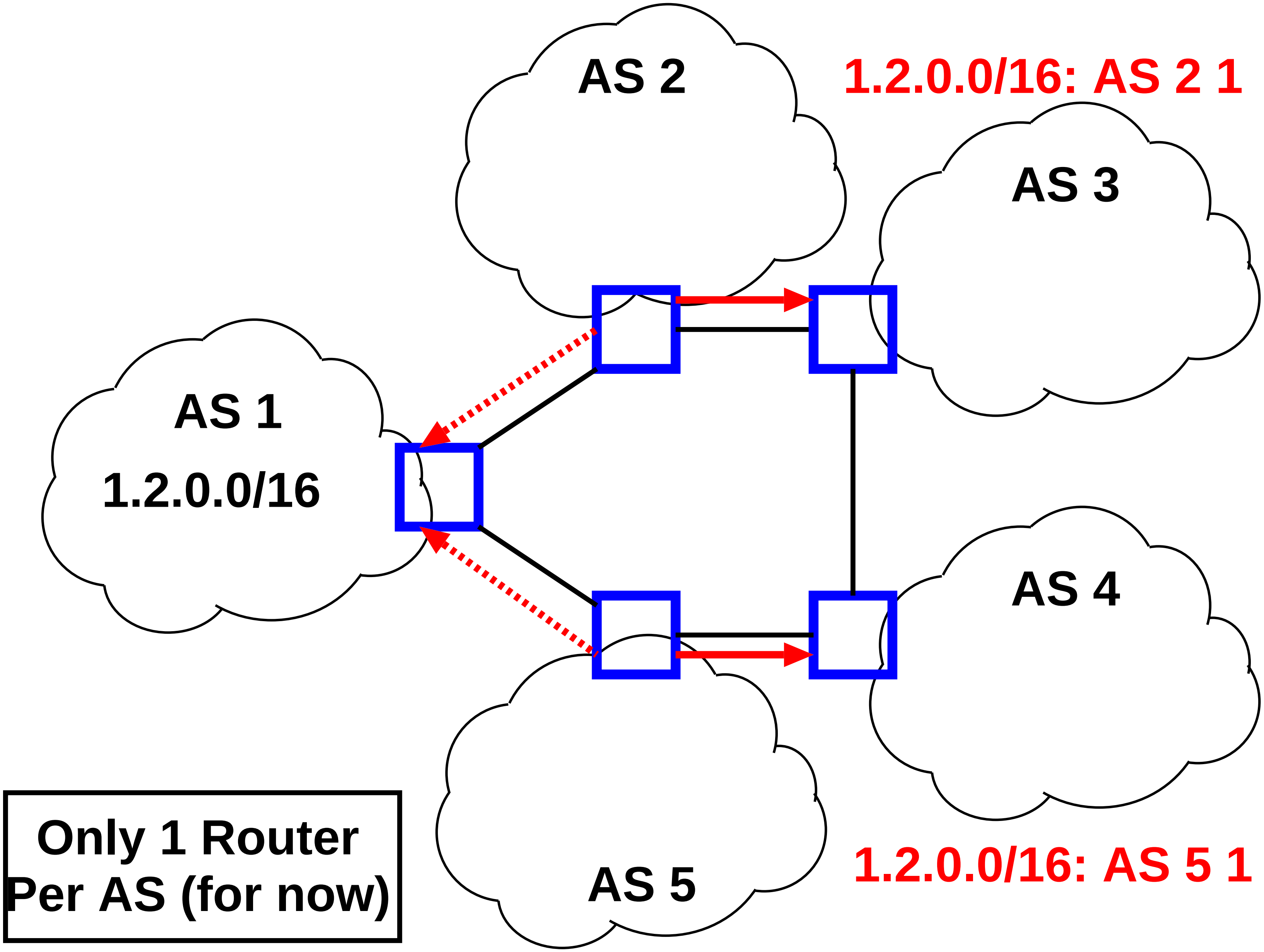
BGP Example



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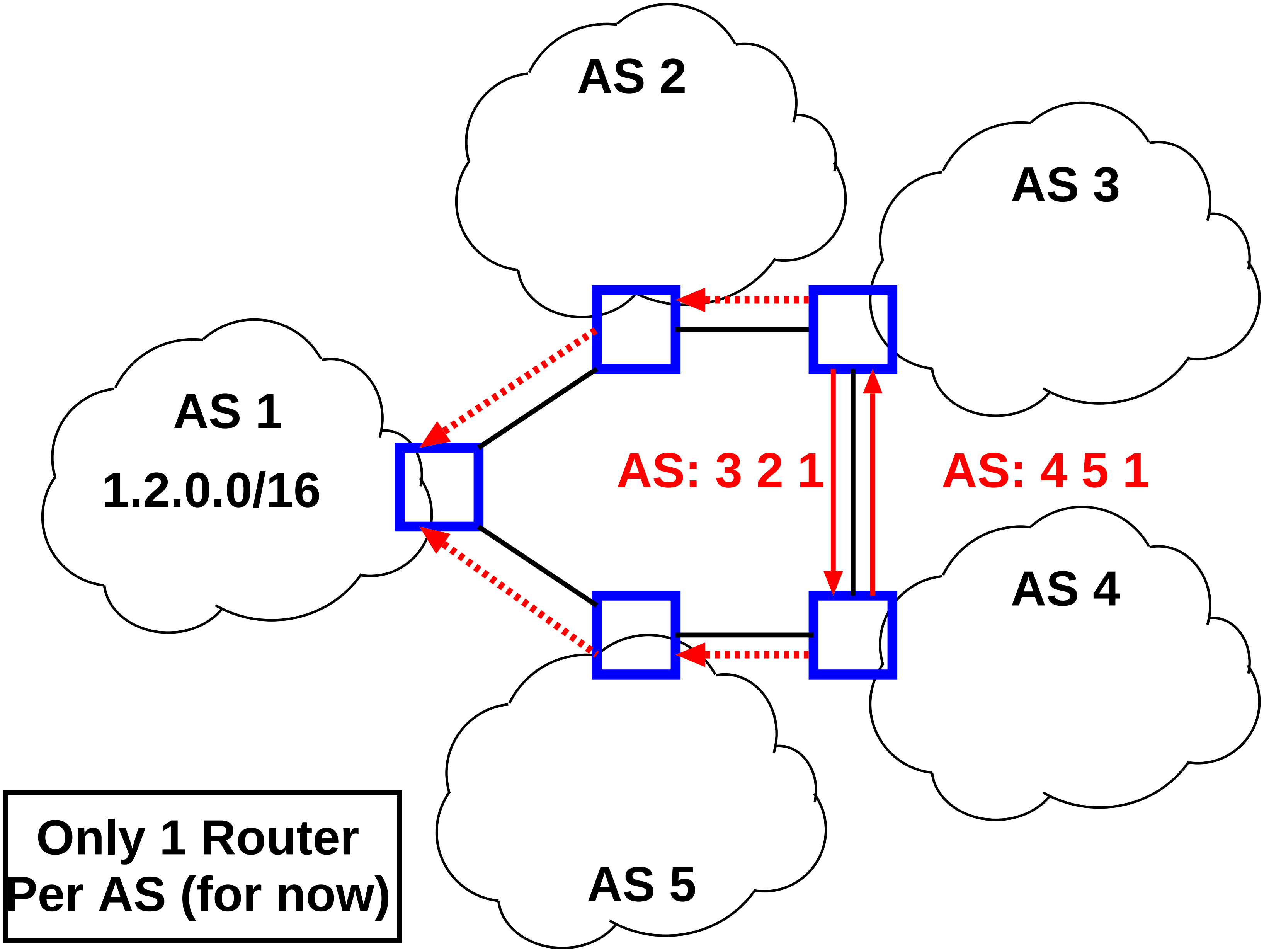

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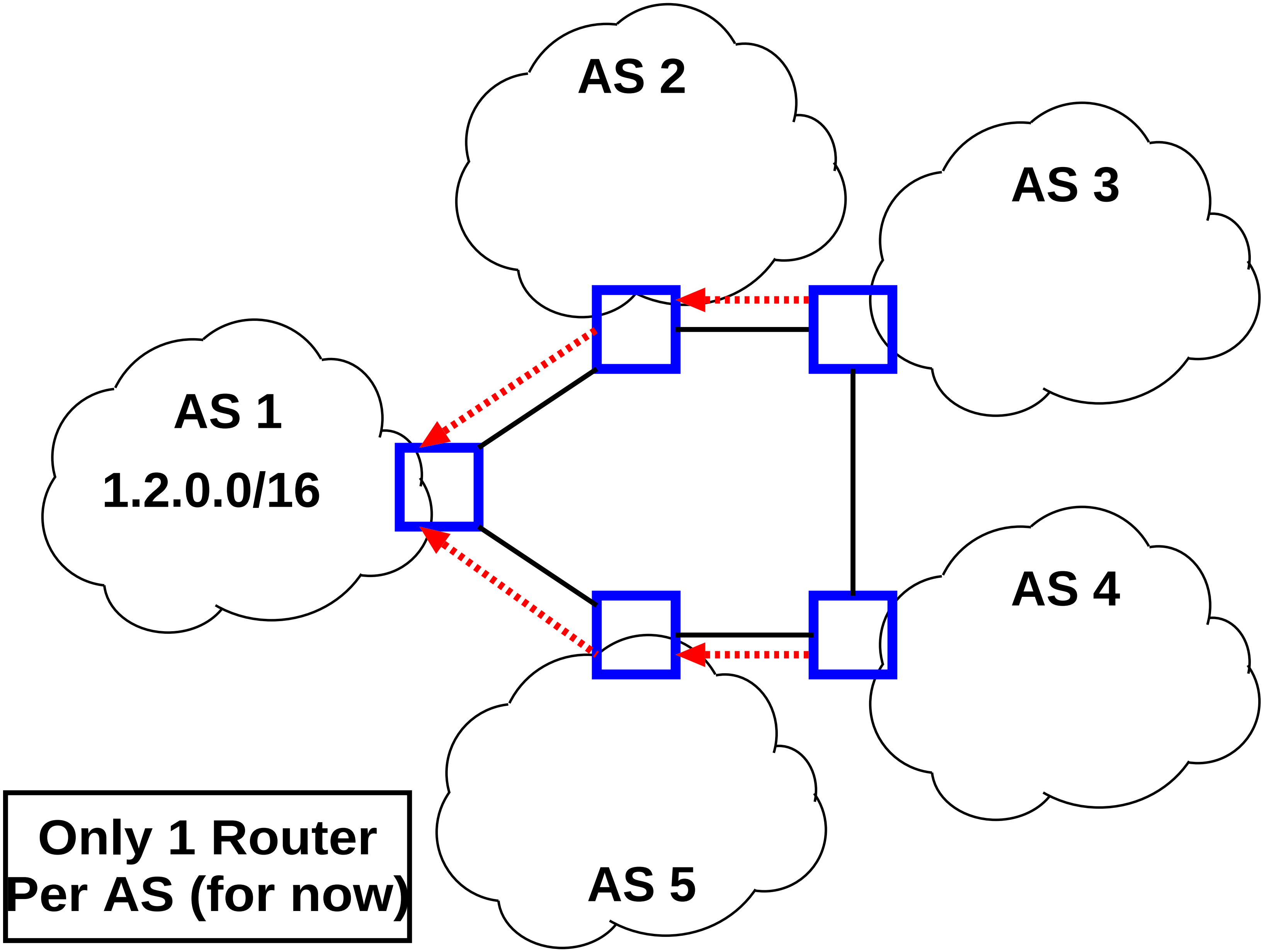

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BGP Implications

- **Explicit AS path == loop free!**
  - Except under churn, IGP/EGP mismatch, etc.
- **Not all ASes know all paths**
- **AS abstraction loss of efficiency**
- **Shortest AS path not guaranteed**
- **Scaling**
  - 32K ASes
  - 300K+ prefixes

BGP protocol details

- **Border routers must connect over TCP port 179**
  - Bidirectionally exchange messages over long-lived connection
- **Base protocol has four message types**
  - OPEN – Initialize connection. Identifies BGP peers and must be first message sent in each direction
  - UPDATE – Announce routing changes (most important msg)
  - NOTIFICATION – Announce error when closing connection
  - KEEPALIVE – Make sure peer is alive
- **Extensions can define more message types**
  - E.g., ROUTE-REFRESH [RFC 2918]

Anatomy of an UPDATE

- **Withdrawn routes: List of withdrawn IP prefixes**
- **Network Layer Reachability Information (NLRI)**
  - List of IP prefixes to which path attributes apply
- **Path attributes – various info. about NLRI**
  - ORIGIN, AS_PATH, NEXT_HOP, MULTI_EXIT_DISC, LOCAL_PREF, ATOMIC_AGGREGATE, AGGREGATOR, . . .
  - Each attribute has 1-byte type, and 1-byte flags, plus length
  - Can introduce new types of path attribute—e.g., used AS4_PATH for 32-bit AS numbers

Transport Details

- **OPEN msg negotiates capabilities [RFC 3392]**
  - E.g., to advertise support for AS4_PATH
- **A full information exchange after connection is expensive!**
  - Keep connection open indefinitely to exchange periodic updates
- **Session resets are expensive (both in CPU and to the entire network!) and should be avoided.**

Advertisements

- **NLRI: 171.67.0.0/14**
- **AS Path: ASN 15444 3549 174 46749 32**
- **Next Hop IP: just like in RIPv2**
- **Knobs for traffic engineering**
  - Metric, Weight, LocalPath, MED, Communities
  - Lots of voodoo

Getting Your Hands Dirty

- **RouteViews Project:** `http://www.routeviews.org/`

  ```
  - telnet route-views.linx.routeviews.org
  - show ip bgp 171.67.0.0/14 longer-prefixes
  ```

- **Note that all paths are learned internally**
- **Not a production device**

2-minute stretch

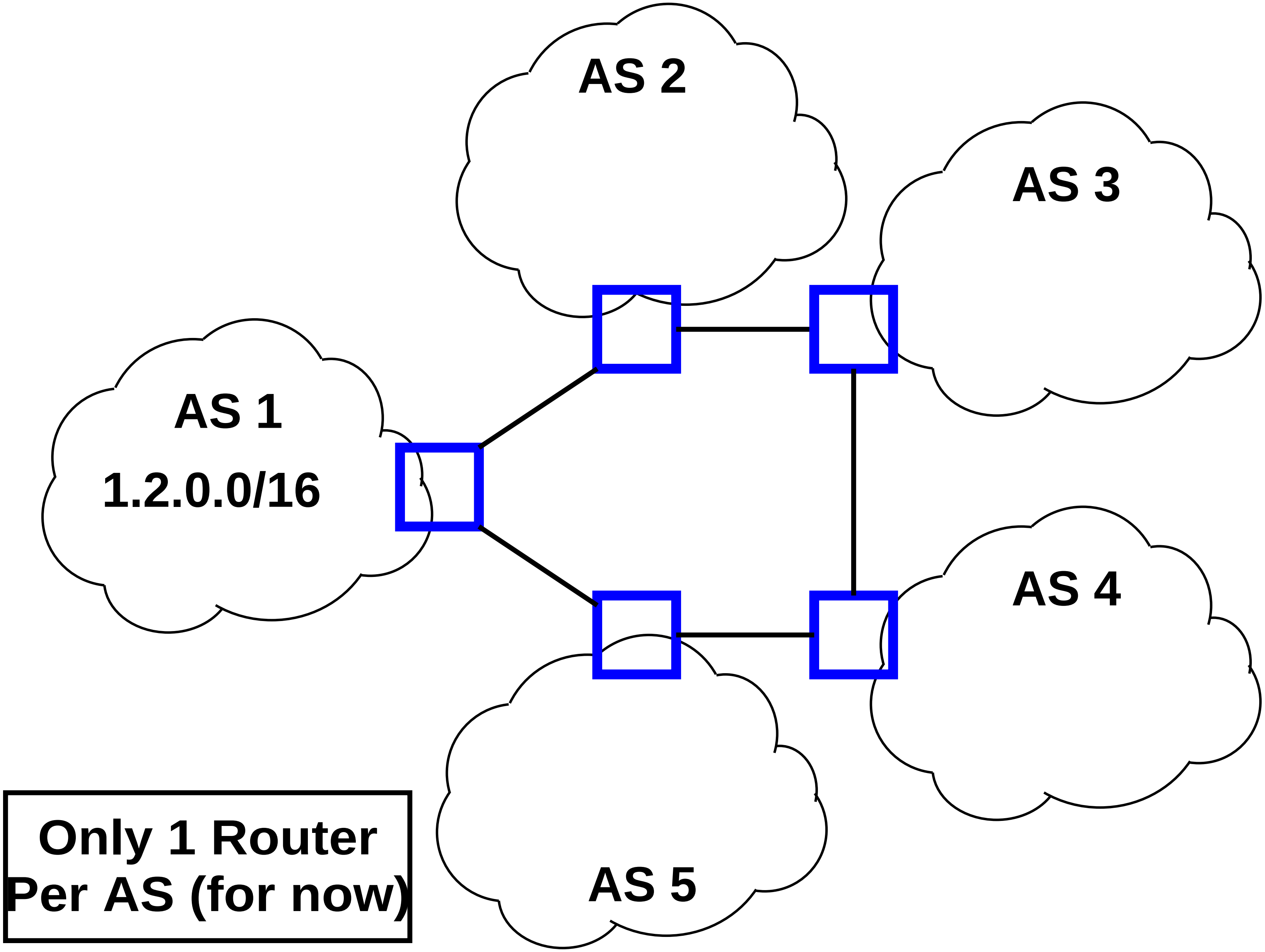
Route Selection 1/2

- **Next-Hop reachable?**
- **Prefer highest weight**
    - Computed using some AS-specific local policy
- **Prefer highest local-pref**
- **Prefer locally originated routes**
- **Prefer routes with shortest AS path length**

Route Selection 2/2

- **Prefer path with lowest origin type**
- **Prefer route with lowest MED value**
  - But note can only compare MEDs from same AS
- **Prefer eBGP over iBGP**
- **Prefer routes with lowest cost to egress point**
  - Hot-potato routing
- **Tie-braking rules**
  - E.g., lowest router-id, oldest route

External vs. Internal BGP



Only 1 Router
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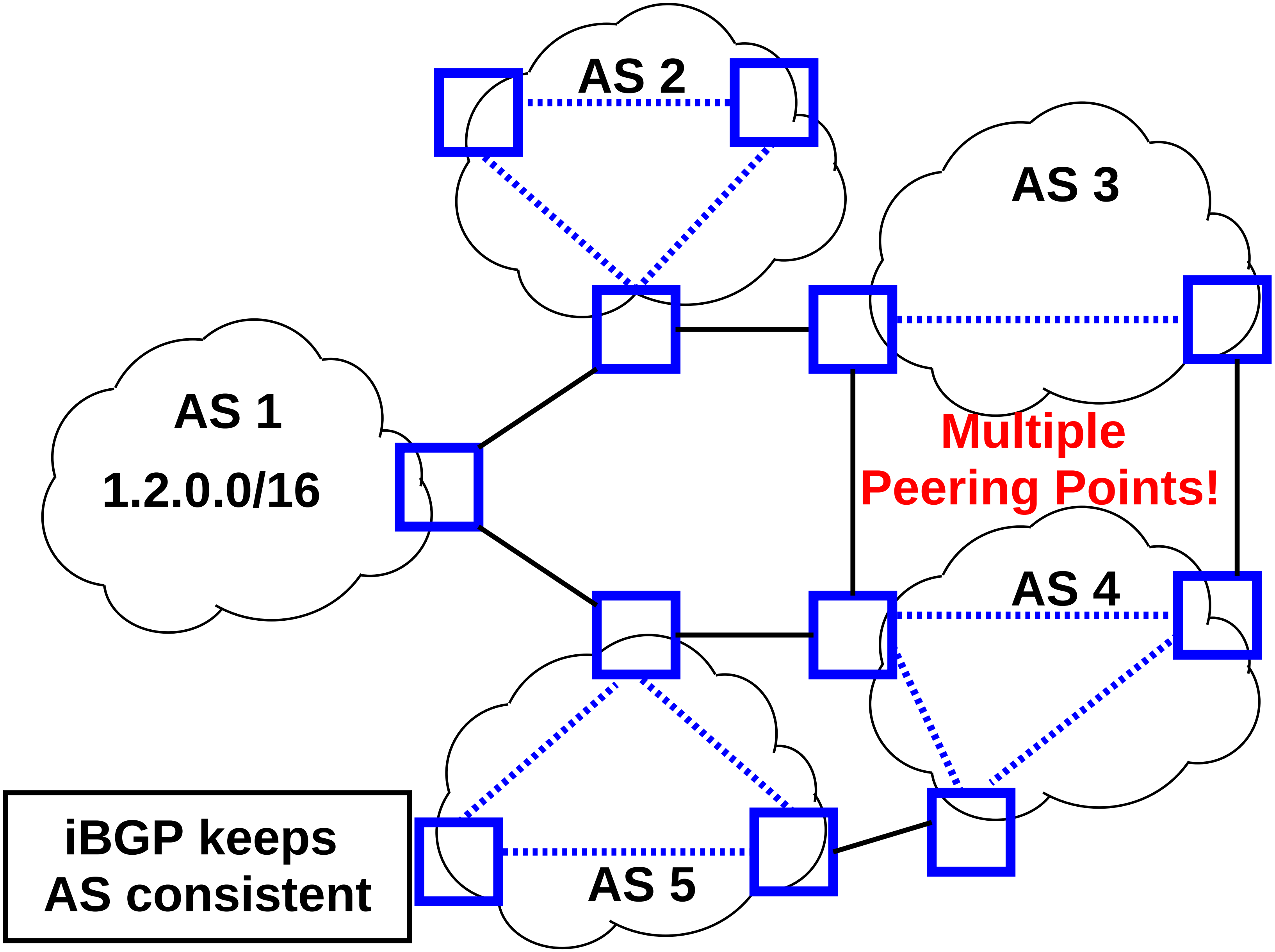
External vs. Internal BGP



Multiple Peering Points!

iBGP keeps AS consistent

Customer/Provider AS relationships

- **Customers pay for connectivity**
  - E.g., Stanford pays Cogent
- **Customer is a stub, provider is a transit**
  - Amount and cost structure can vary wildly
- **Many customers are multi-homed**
  - Stanford also connects to Calren/Internet2
- **Typical policy: prefer routes from customers**

Peer relationships

- **ASes agree to exchange traffic for free**
  - Penalties/renegotiate if imbalance
- **Tier 1 ISPs have no default route: all peer with each other**
- **You are Tier $i + 1$ if you have a default route to a Tier i**

BGP Relationship Drama

- Cogent vs. Level3
- Level3 and Cogent were peers
- In 2005, Level3 decided to start charging Cogent
- Cogent said No
- Internet partition: Cogent's customers couldn't get to Level3's customers and vice versa
  - Other ISPs were affected as well
- They came to a new, undisclosed agreement 3 weeks later

BGP Problems and Solutions

- Security
- Convergence
- Scaling (route reflectors)
- Traffic engineering – AS preprending
- Multiple stable solutions – BGP ”Wedgies”

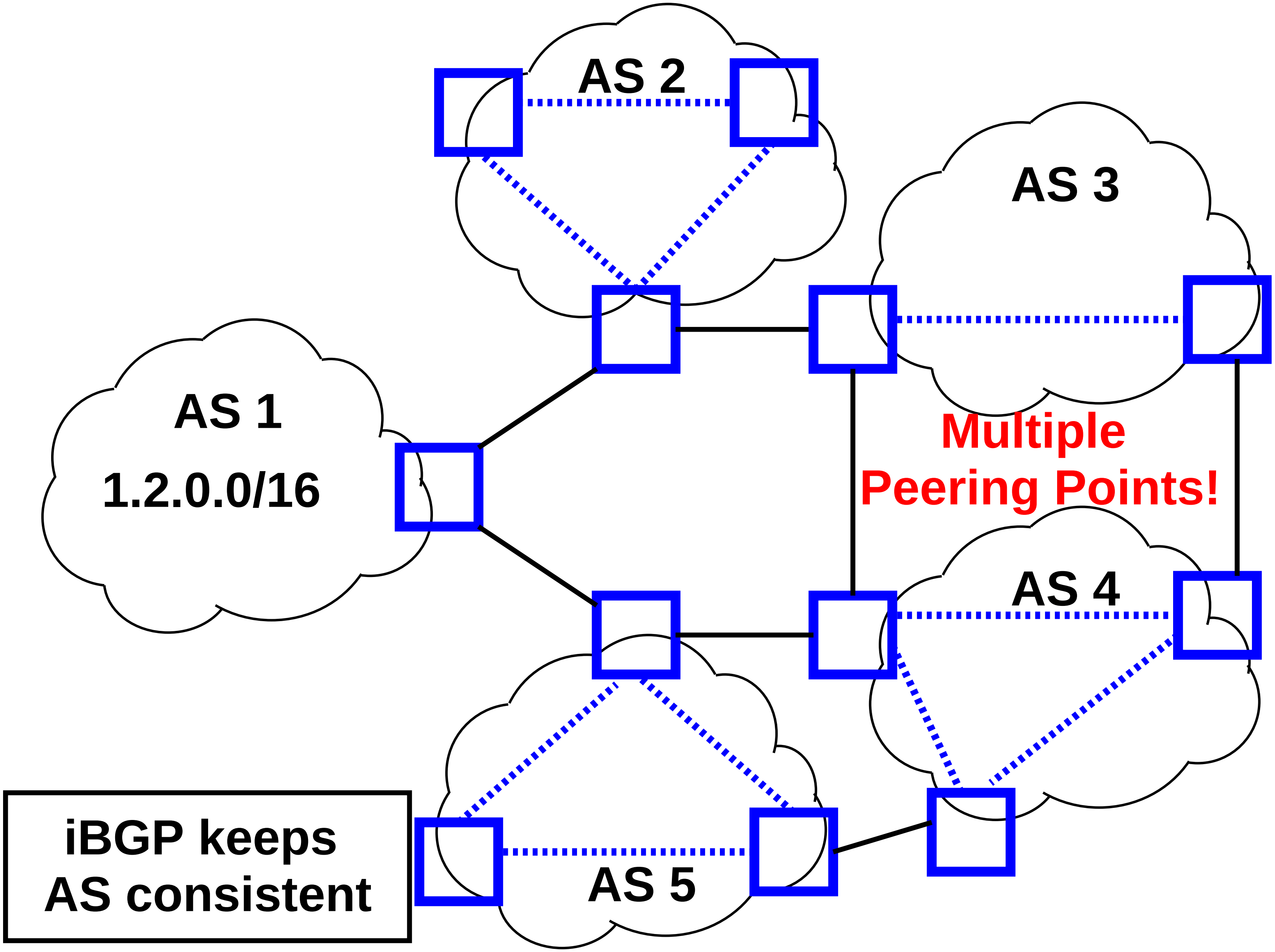
BGP Security

- **Anyone can source a prefix announcement**
  - BGP is not very secure
- **YouTube's prefix is 208.65.152.0/22**
- **Pakistani government ordered YouTube blocked**
  - PieNET advertised 208.65.152.0/23 and 208.65.152.128/23
  - Longest prefix match caused world-wide outage
- **Spammers steal unused IP space to hide [Feamster]**
  - Advertise very *short* prefixes—why?
- **Secure BGP is currently in the works**

BGP Convergence

- **Given a change, how long until the network re-stabilizes?**
  - …depends on the change: sometimes never.
  - Open research problem: “tweak and pray”
  - Distributed setting is challenging
- **Easier: Does there exist a stable configuration?**
  - Distributed: open research problem
  - Centralized: NP-Complete problem! [Griffin’99]

Scaling iBGP: Route Reflectors

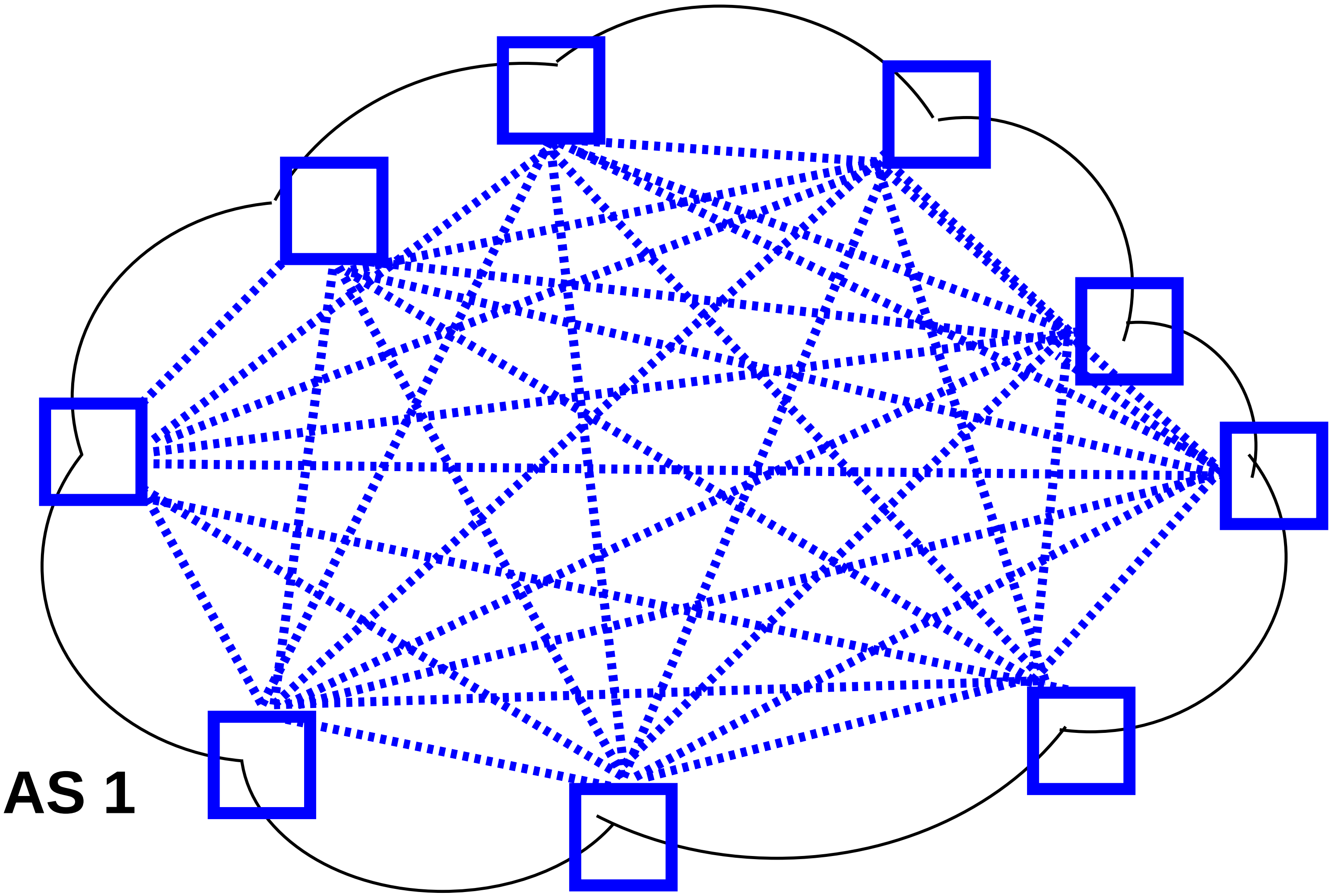


Multiple Peering Points!

iBGP keeps AS consistent

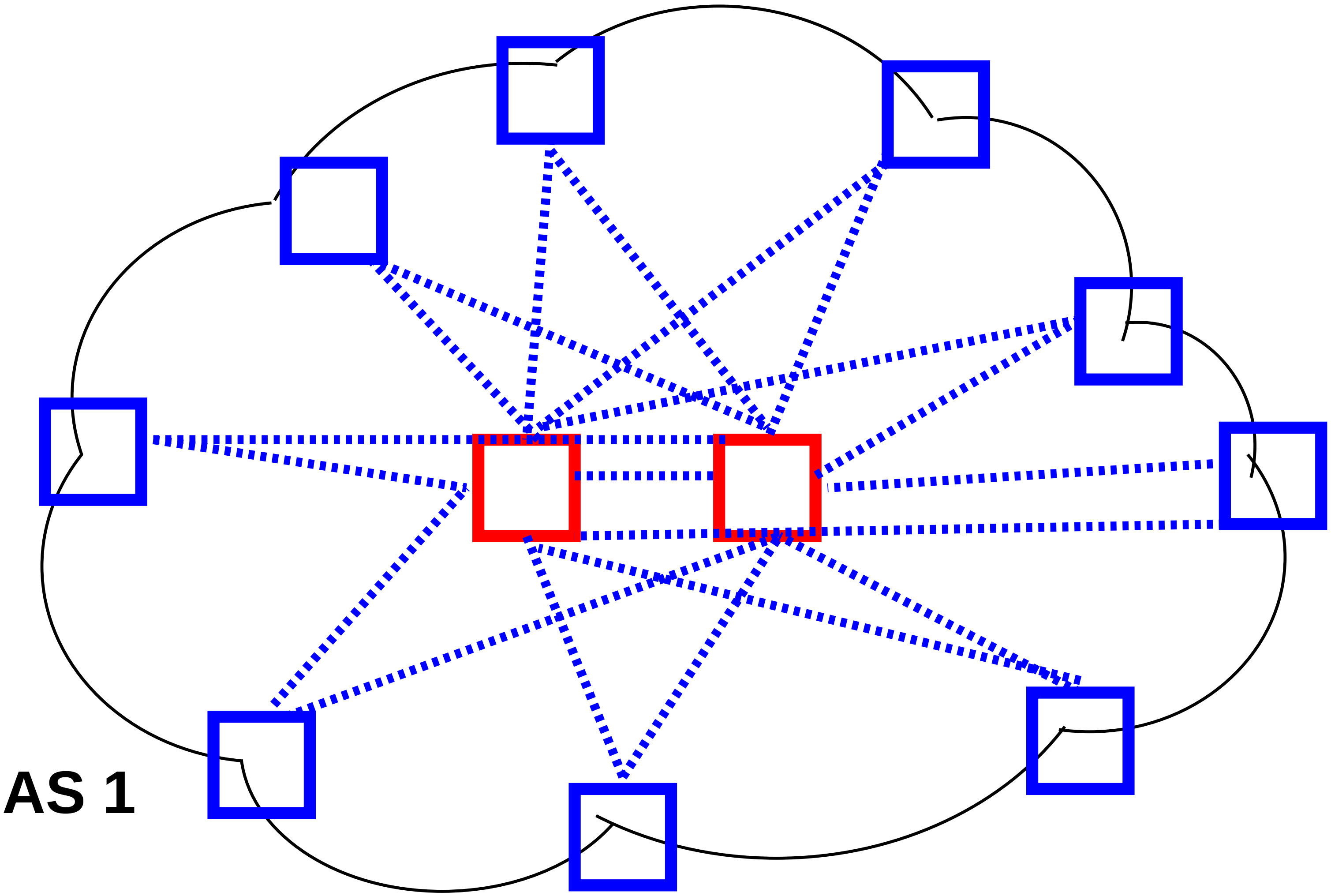
Scaling iBGP: Route Reflectors

iBGP Mesh == O(n^2) mess



Scaling iBGP: Route Reflectors

Solution: Route Reflectors
O(n*k)



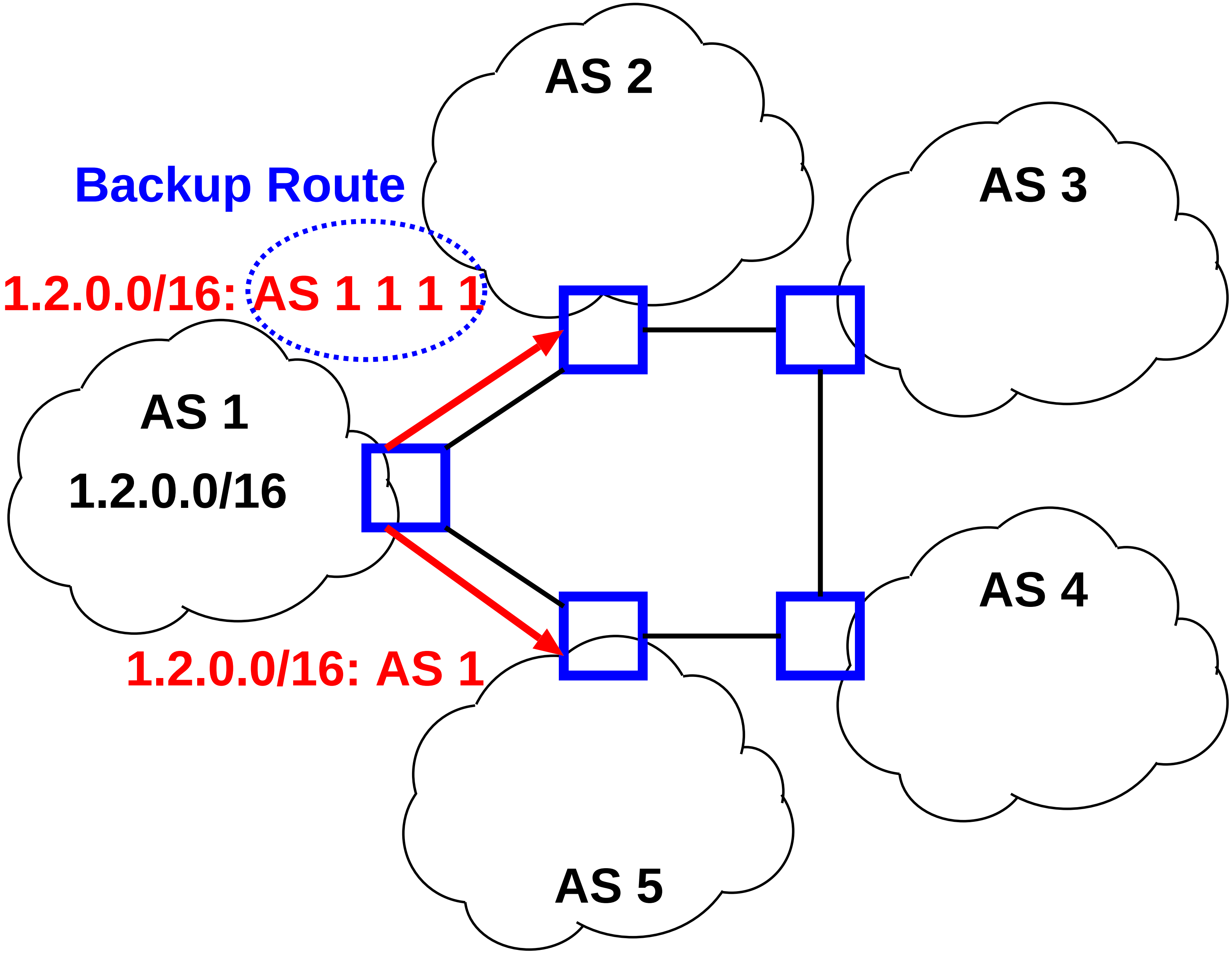
Traffic Engineering

- “Route-map” programs to set weights
- Route filtering: input and output
- More specific routes: longest prefix
- AS prepending: ″32 32 32 32″
- Imprecise science

BGP Wedgies [RFC 4264]

- **A Common config:**
  - Prefer customer routes over non-customer
  - Then prefer shortest AS path

BGP Wedgies [RFC 4264]



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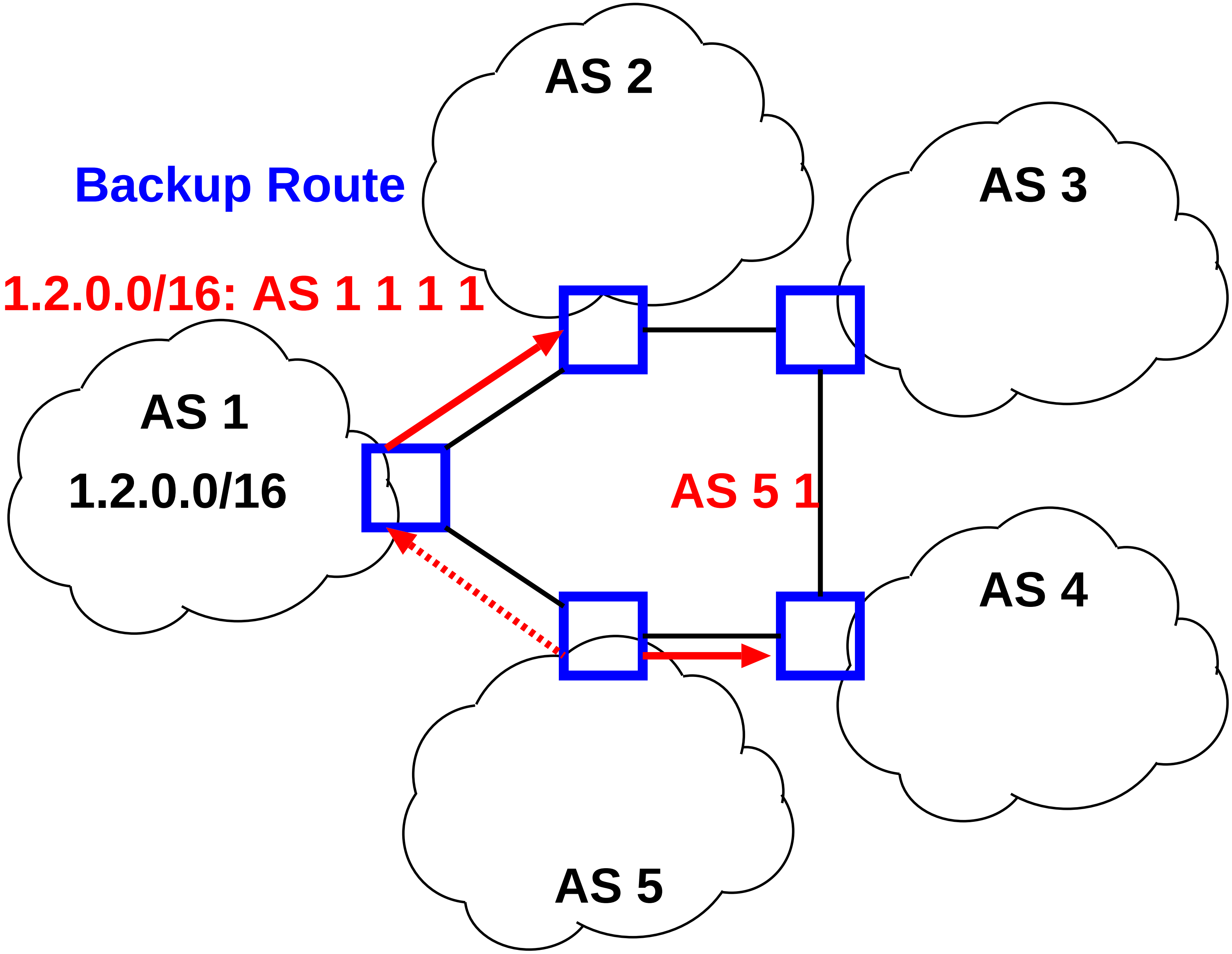

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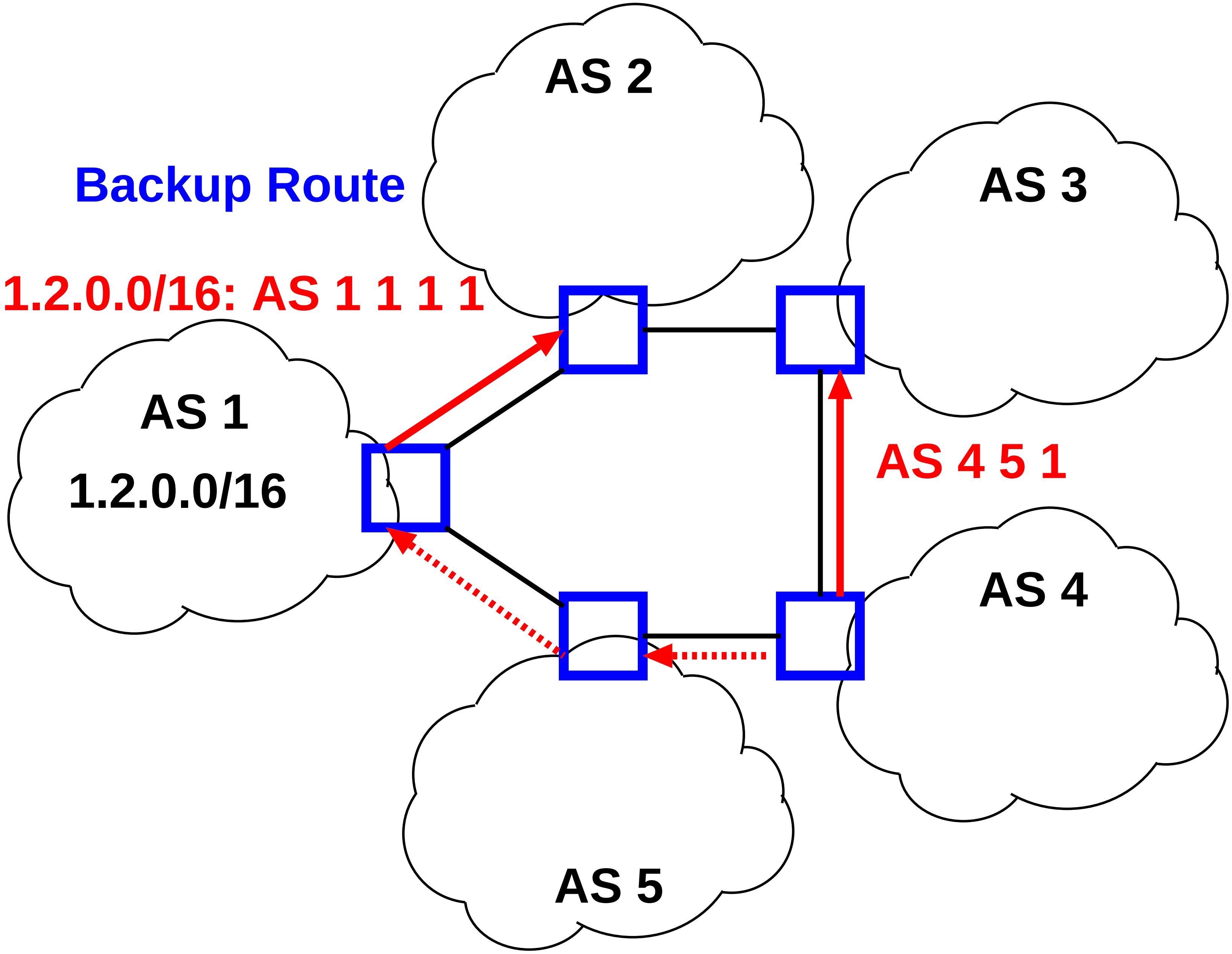

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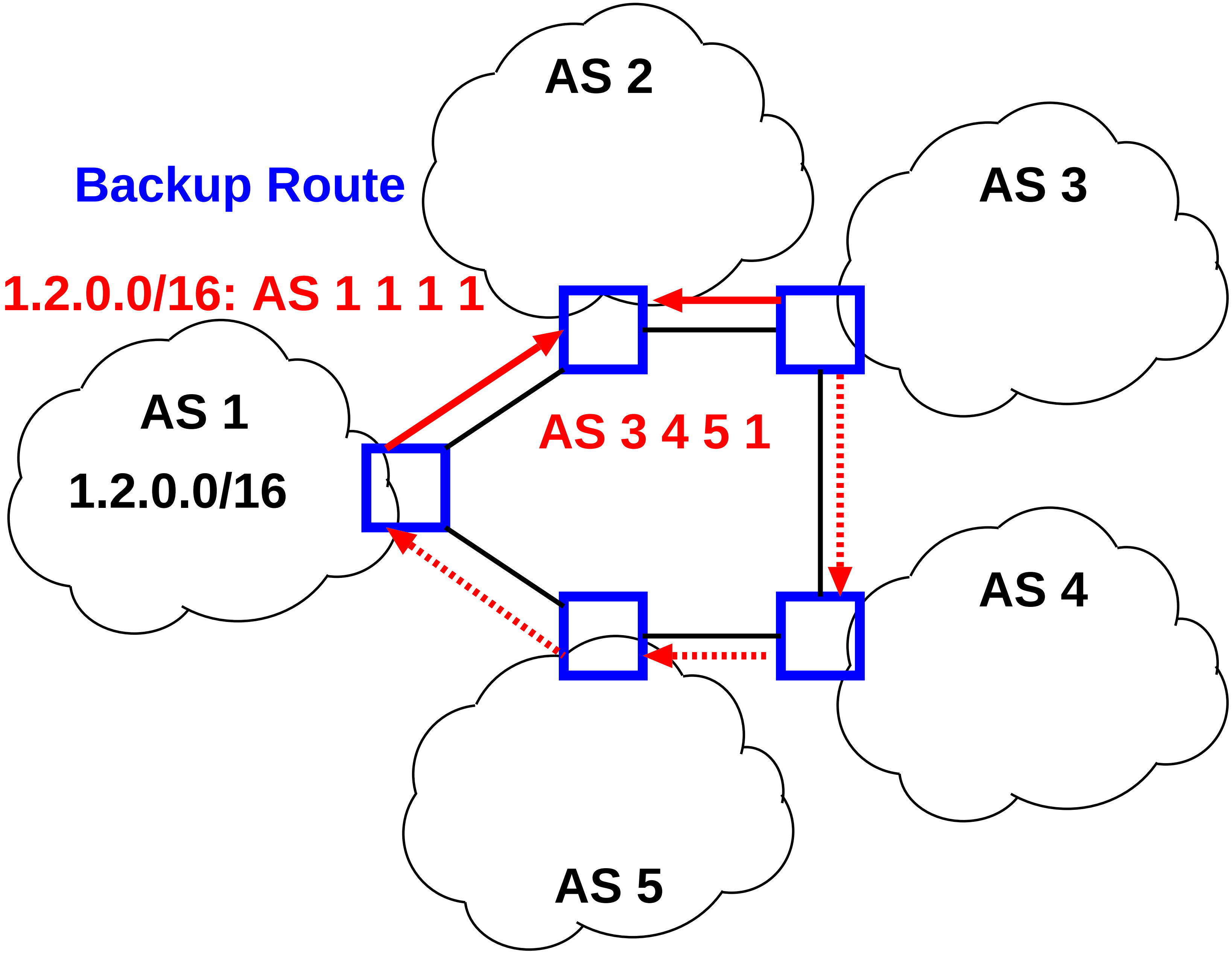

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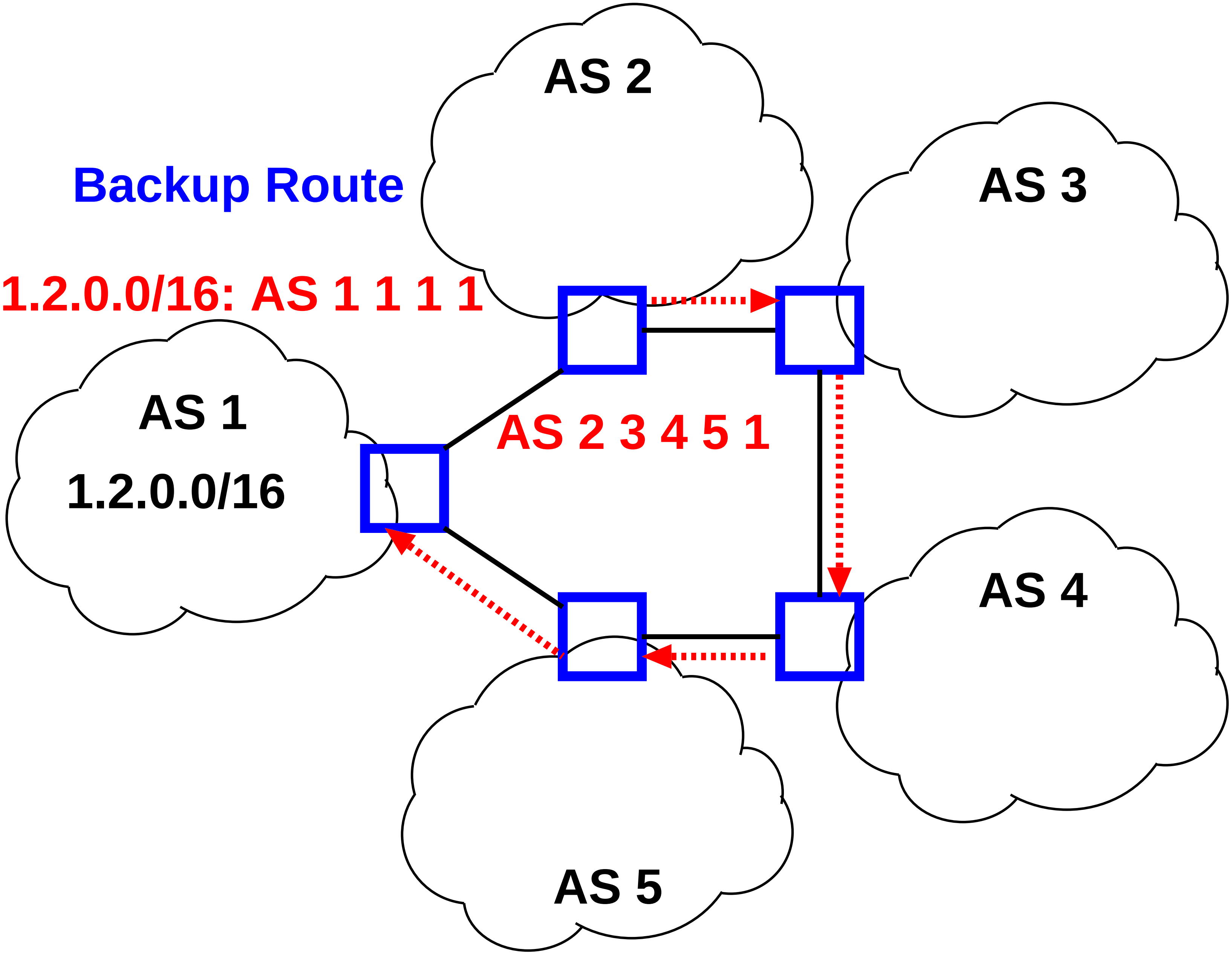

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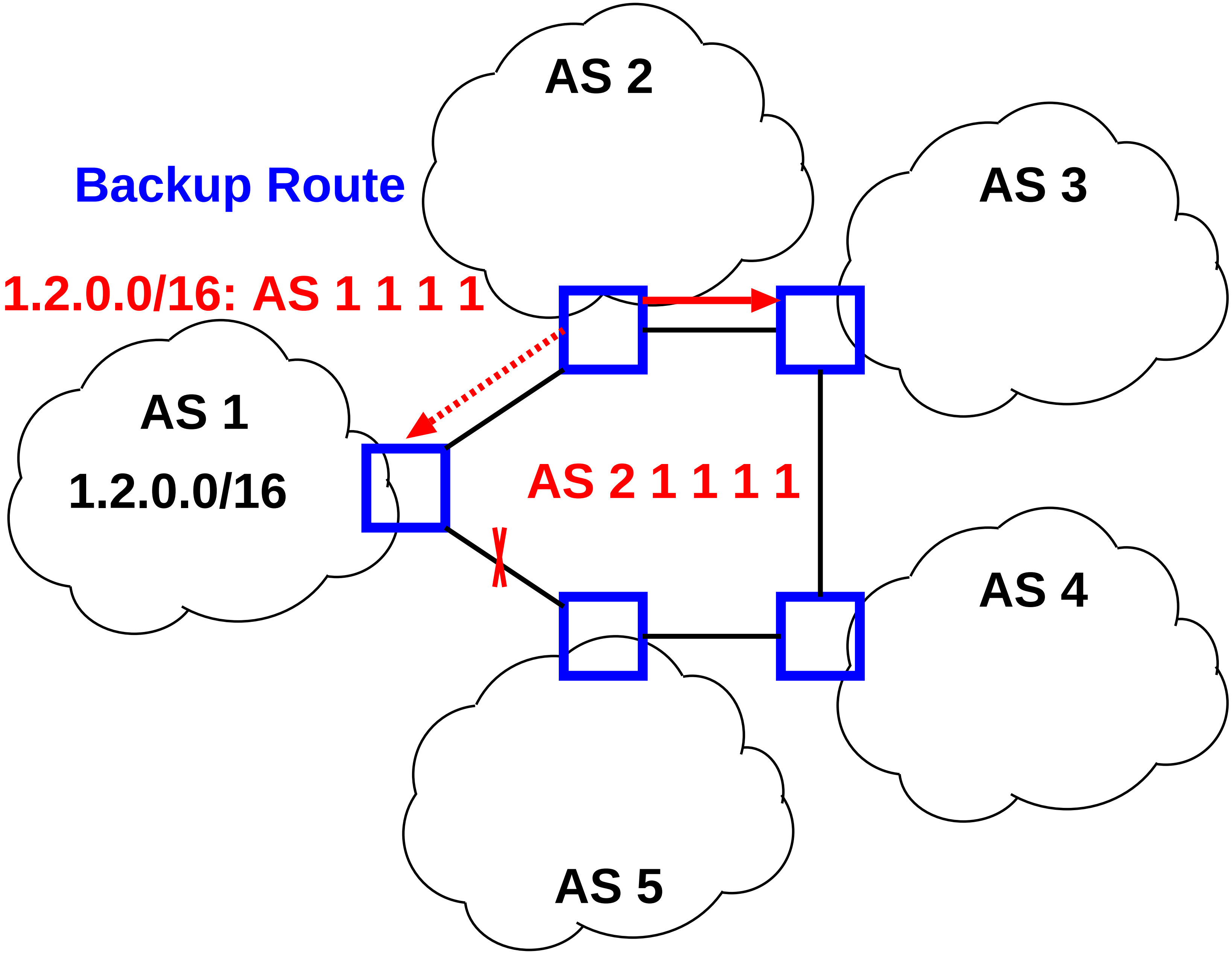

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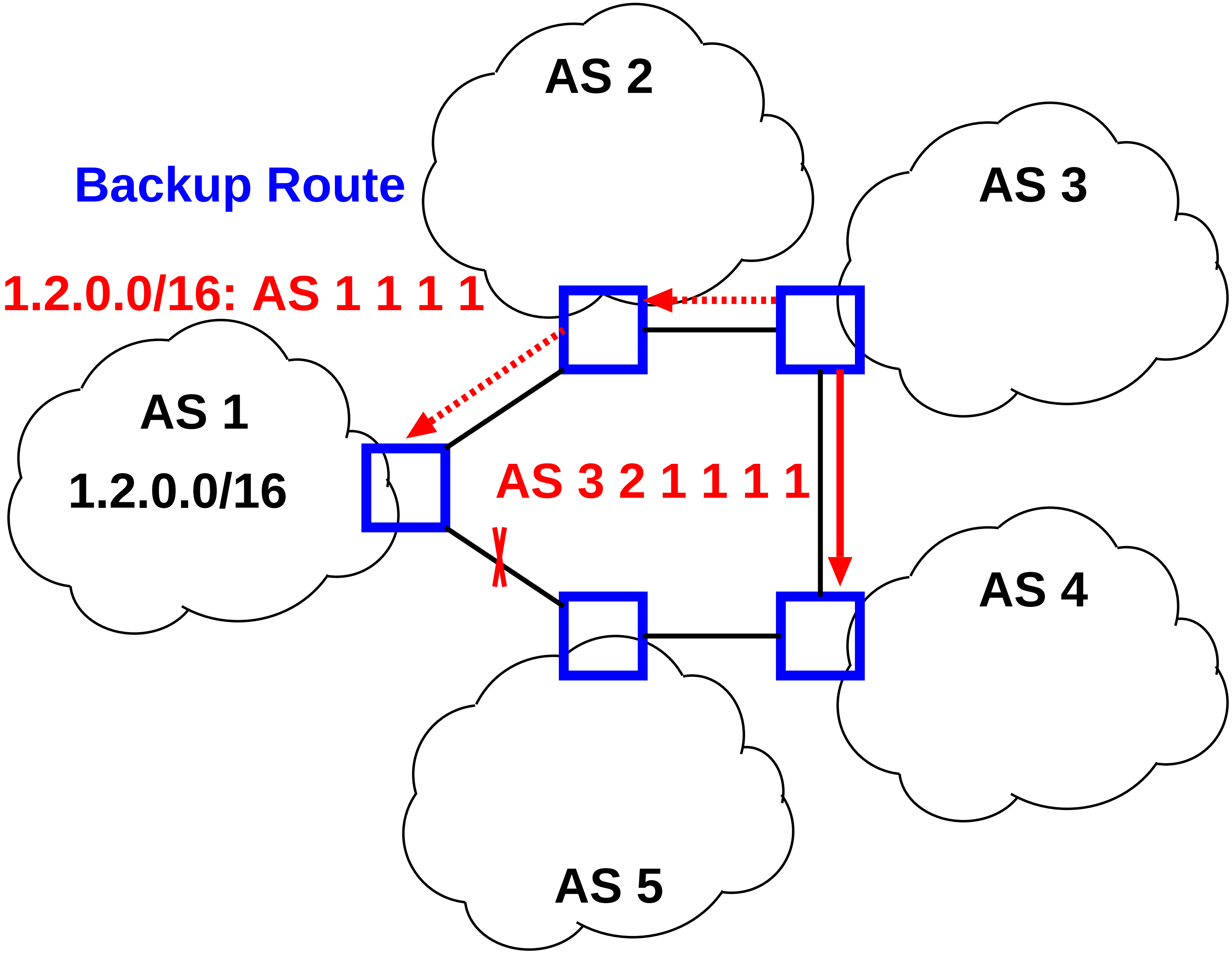

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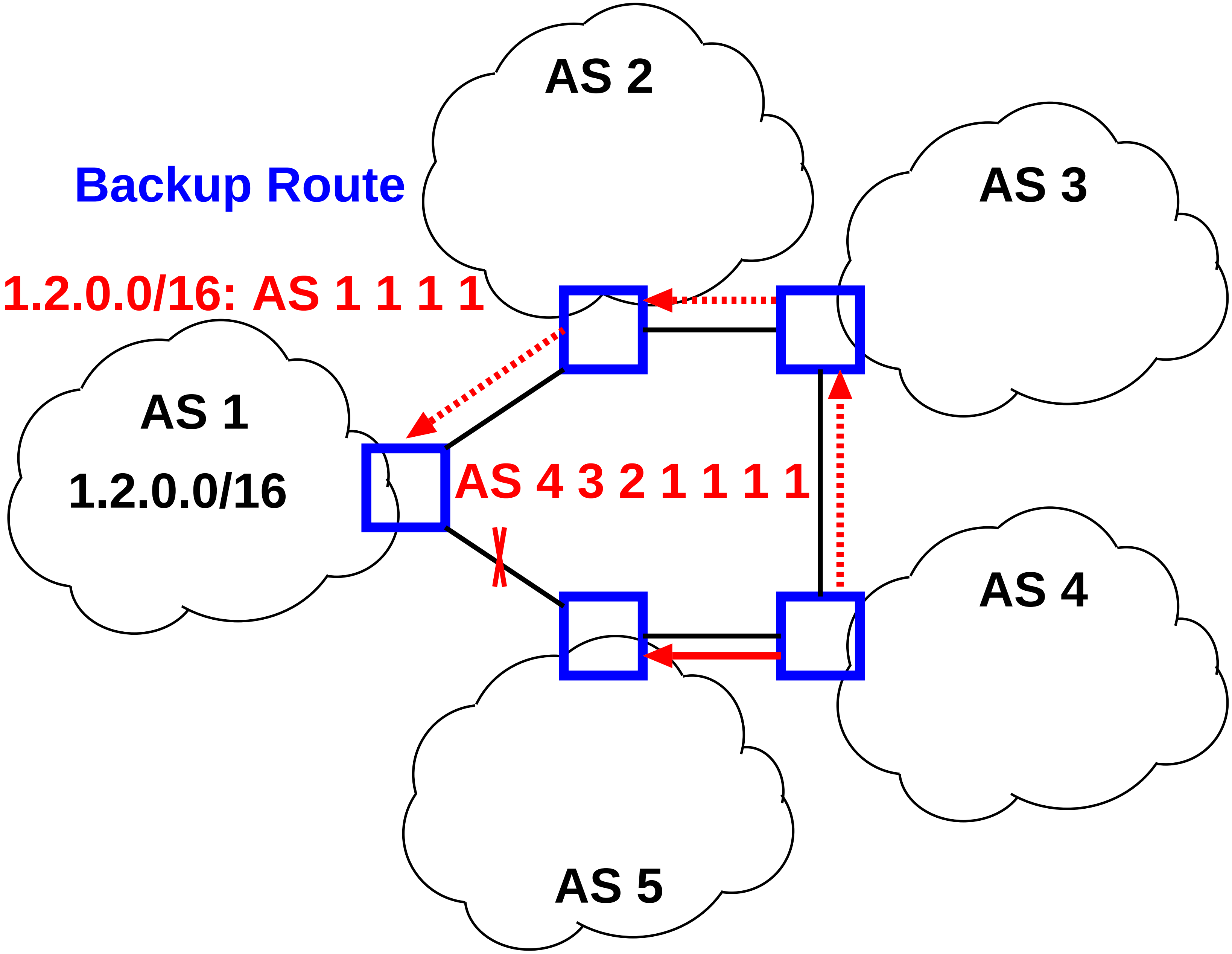

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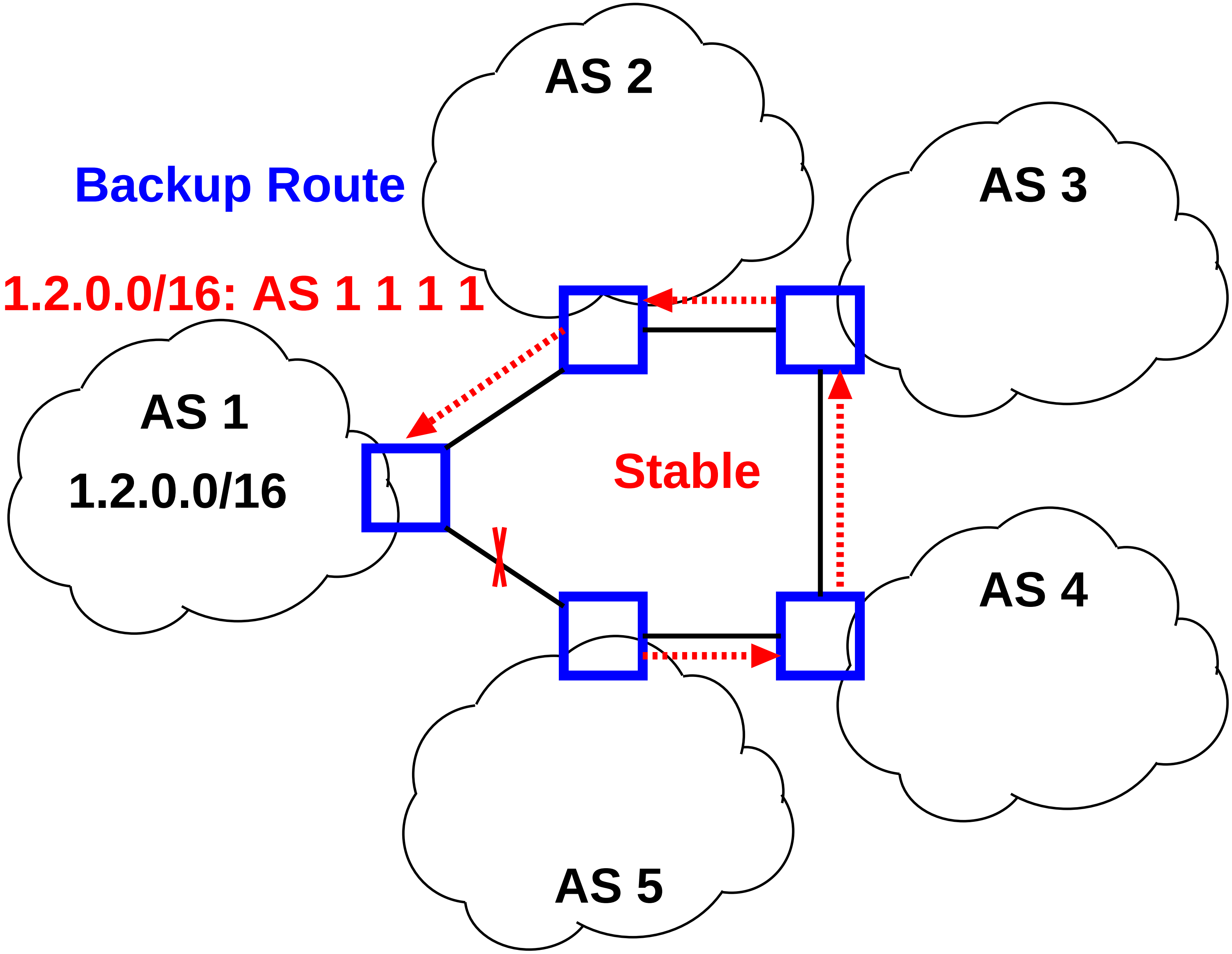

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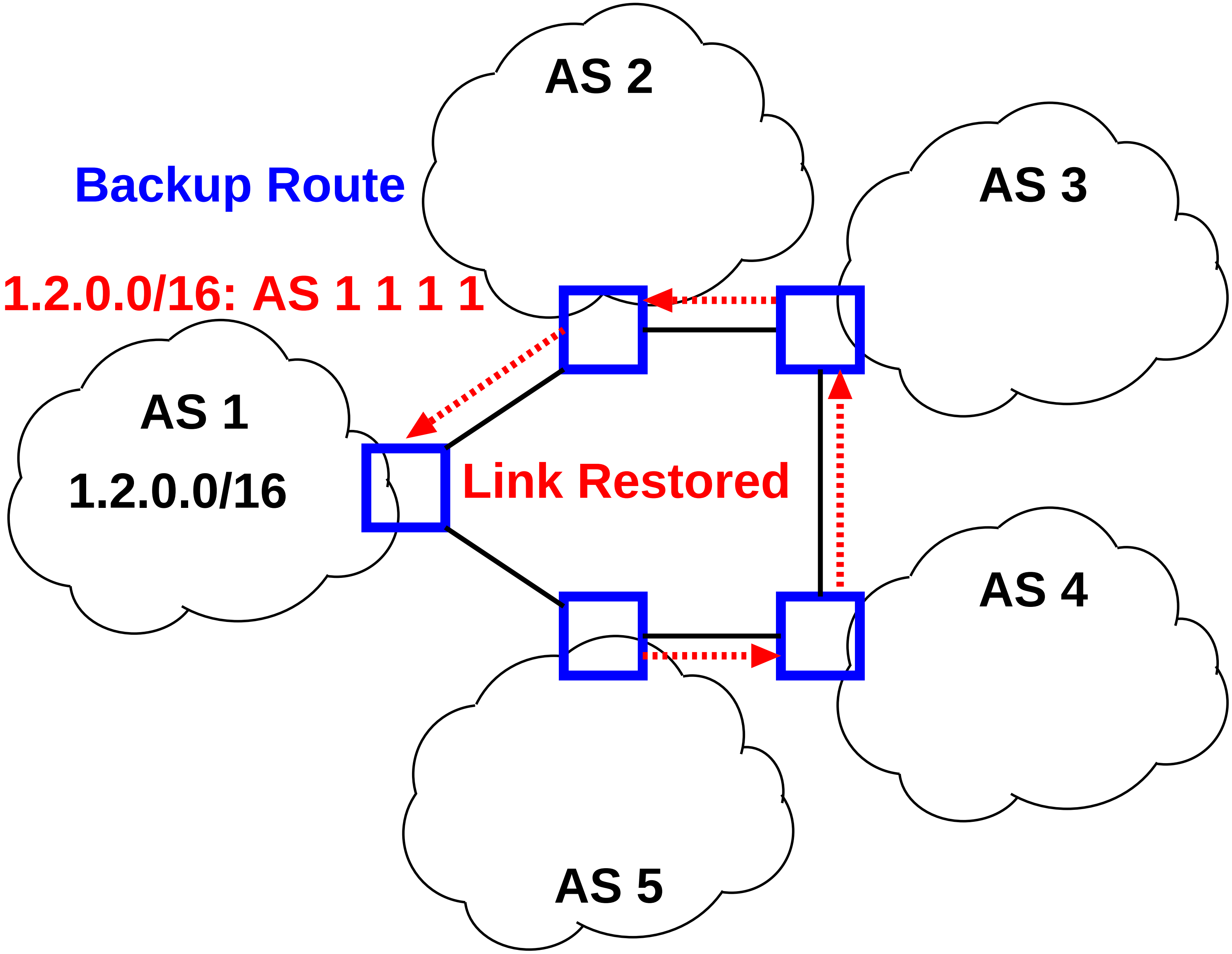

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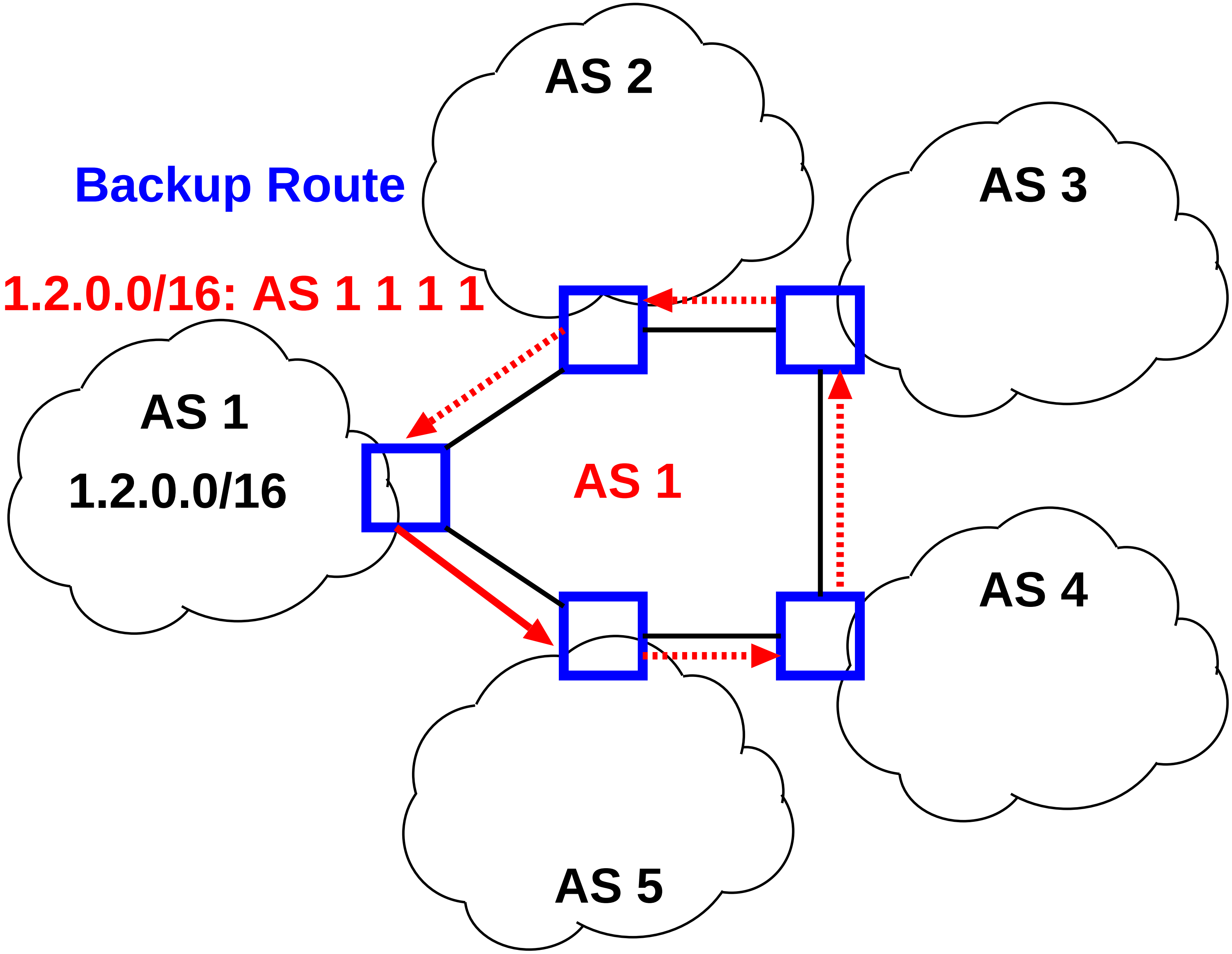

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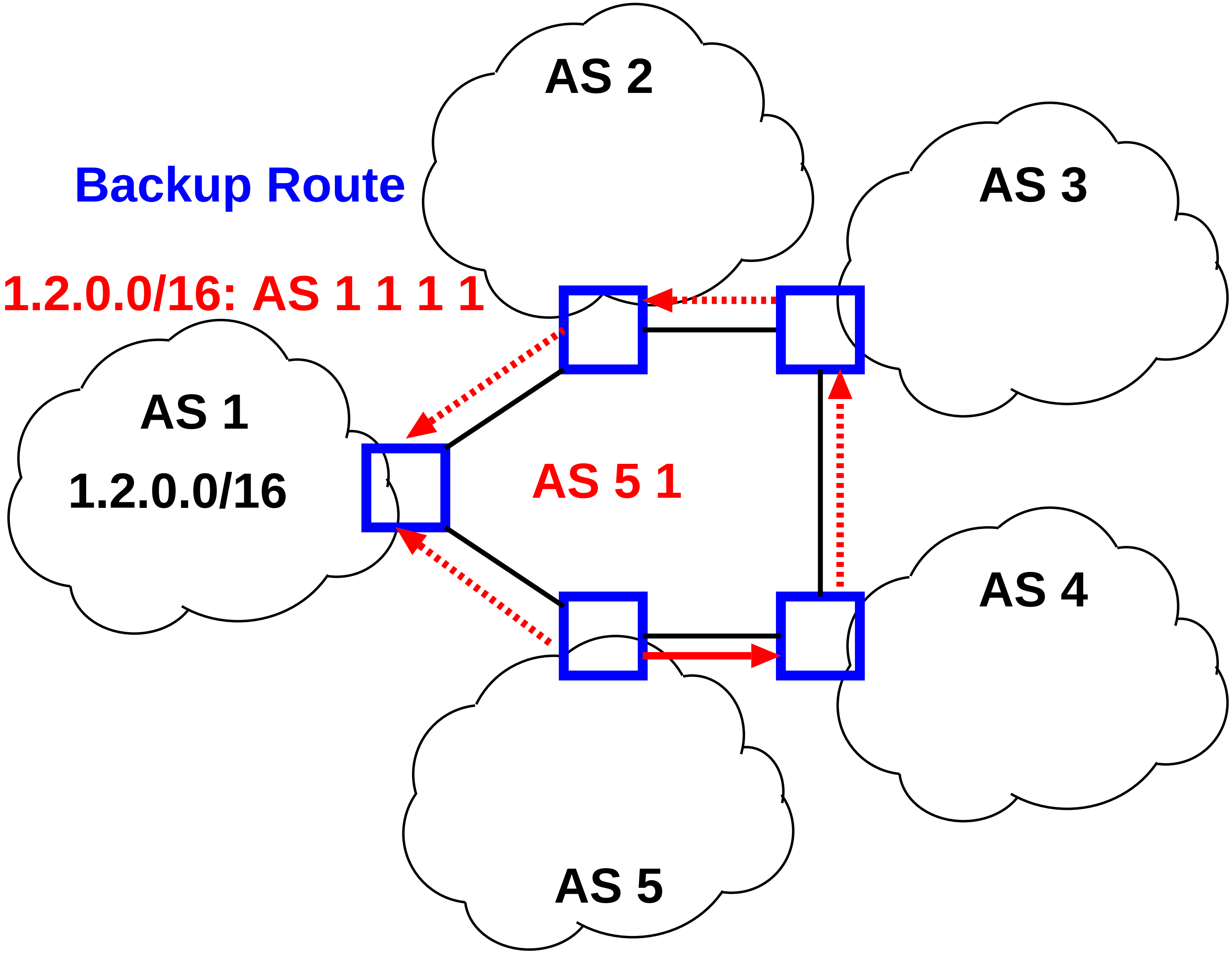

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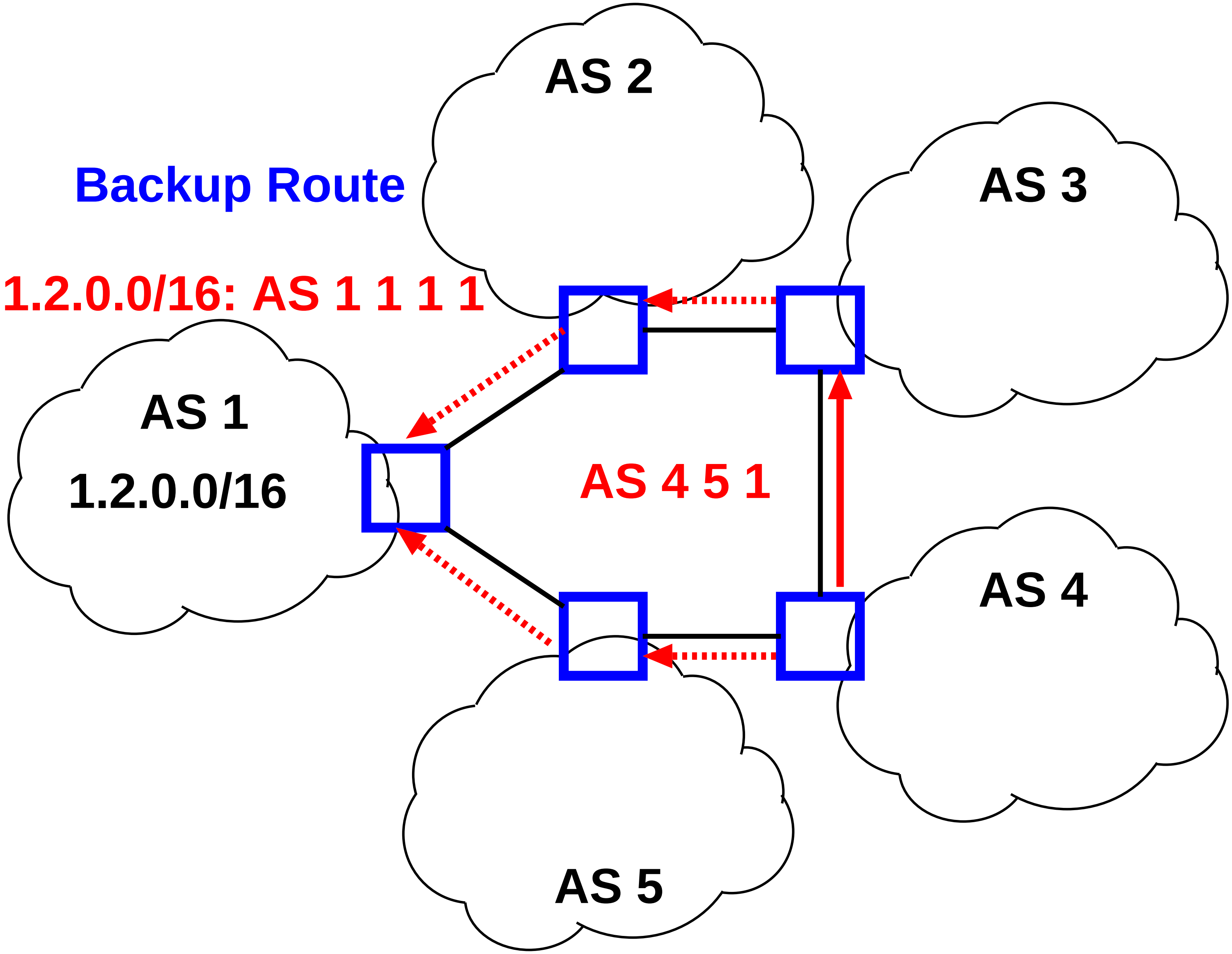

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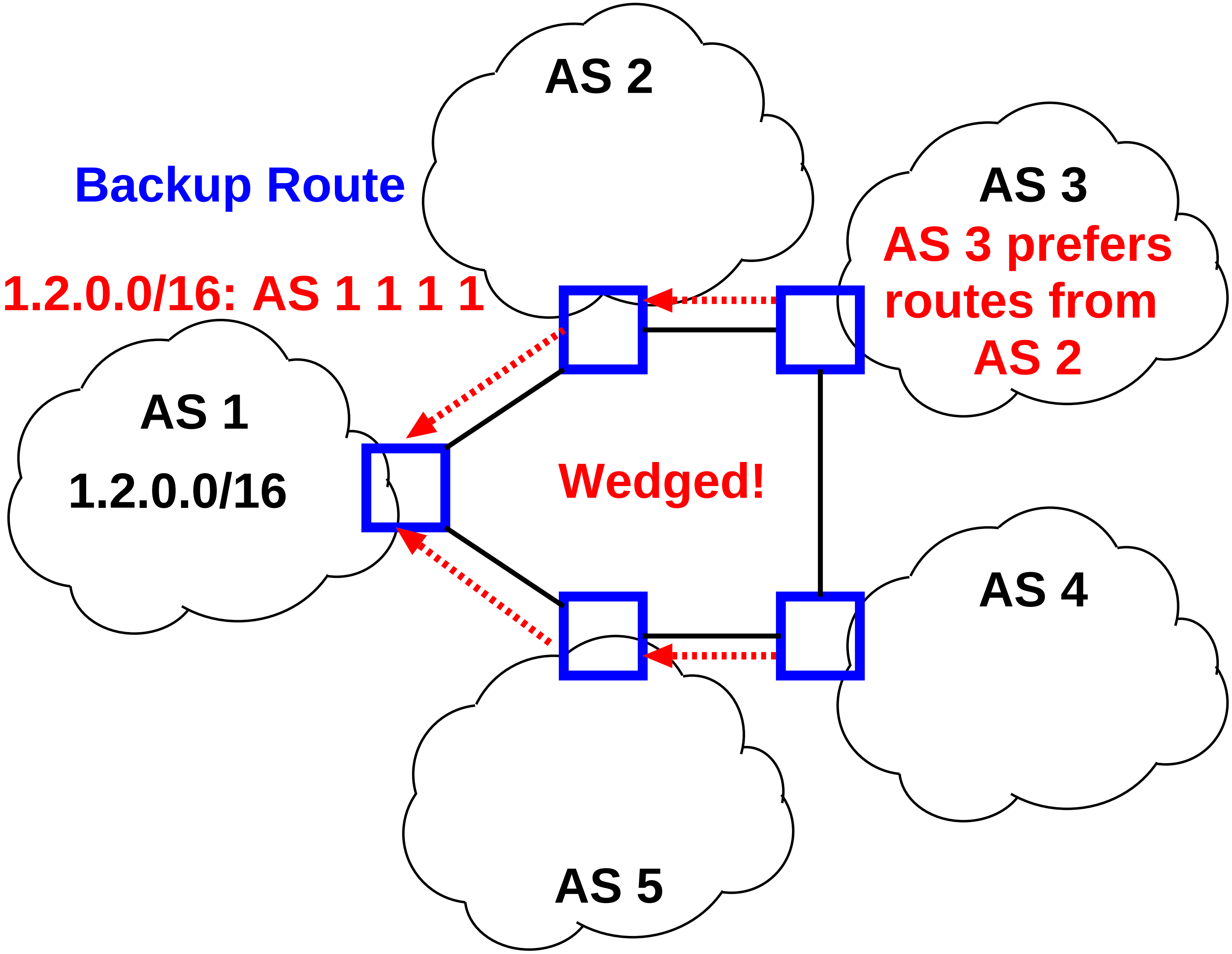
AS 2
Backup Route
AS 3
AS 3 prefers routes from AS 2
1.2.0.0/16: AS 1 1 1 1
AS 1
1.2.0.0/16
Wedged!
AS 4
AS 5