

Advanced Computer Networking (ACN)

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Autonomous Systems

BGP

- BGP Overview

- BGP Peering

- Business and Policy Routing

- k-core Algorithm

Bibliography

BGP Peering

Public Peering

Public peering is done, by meeting at peering locations

- “A room full of switches that many providers connect to”
- Configure L2 (VLAN) connections in switch, instead of having to put in $\mathcal{O}(n^2)$ separate wires
- Payment per “switch port”, priced by connection speed

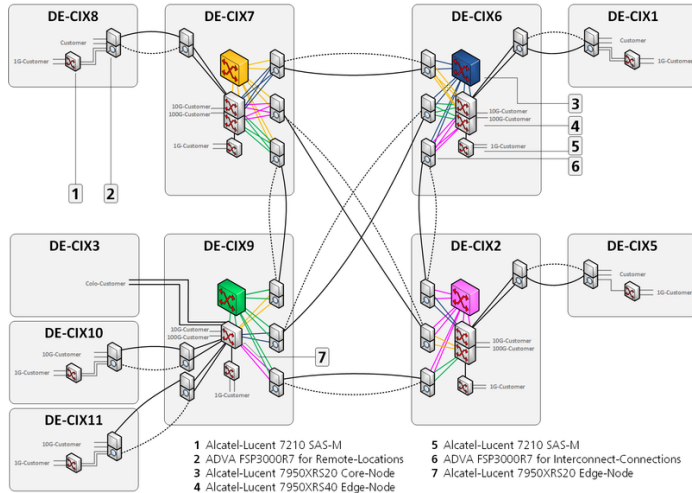
Examples:

- DE-CIX, Frankfurt (by peak traffic largest in world), and other locations
- AMS-IX, Amsterdam
- LINX, London
- MSK-IX, Moscow

Public peering use cases:

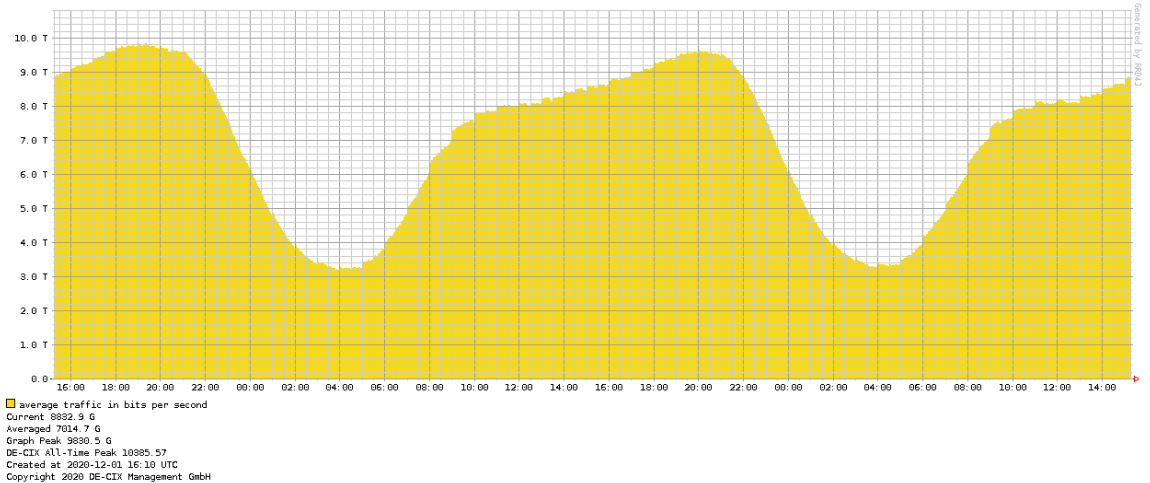
- Peer with as many ASes as possible
- Reduce the traffic you send to your upstream provider

BGP Peering DE-CIX Topology



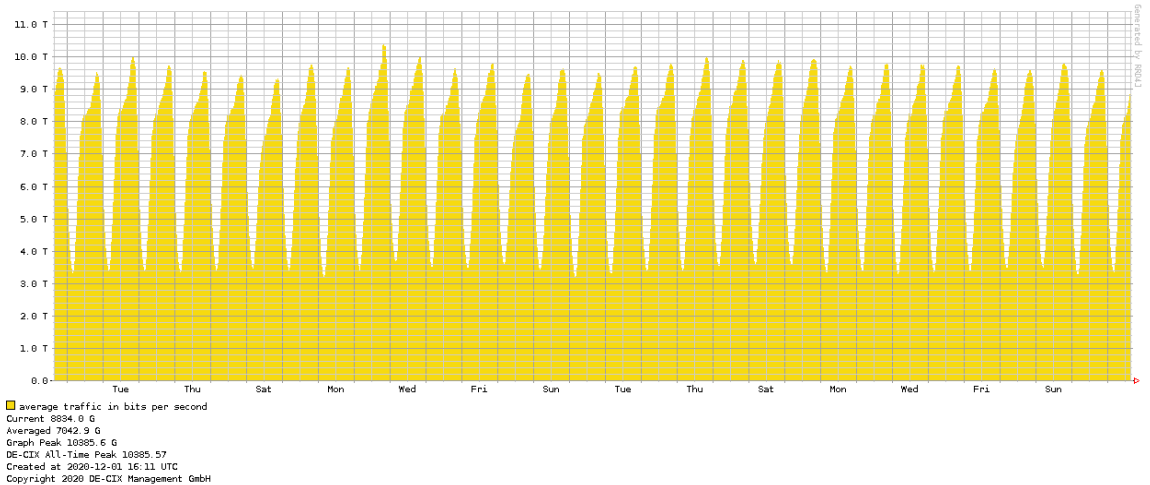
Source: <https://de-cix.net/about/topology/> (2015)

BGP Peering DE-CIX Statistics - 2 Days



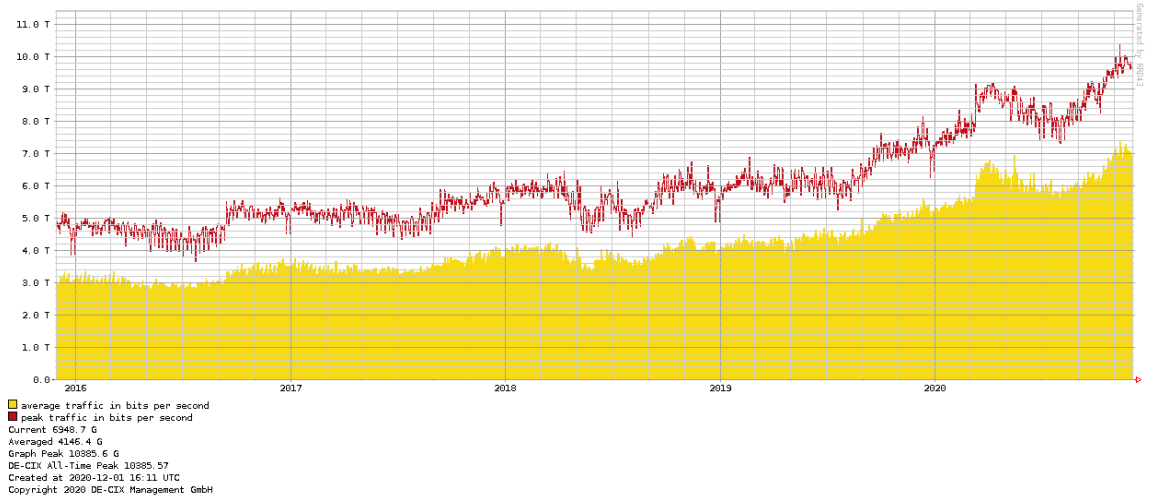
Source: <https://www.de-cix.net/en/locations/germany/frankfurt/statistics>

BGP Peering DE-CIX Statistics - 1 Month



Source: <https://www.de-cix.net/en/locations/germany/frankfurt/statistics>

BGP Peering DE-CIX Statistics - 5 Years



Source: <https://www.de-cix.net/en/locations/germany/frankfurt/statistics>

Business and Policy Routing

Basic Principles

Routing: Prefer routes that incur financial gain

1. Route via a customer (financial gain)
2. Route via a peer (no financial gain or loss)
3. Route via a provider (financial loss)

Route Announcement

- Announce routes that incur financial gain if others use them
 - Others = customers
- Announce routes that reduce costs if others use them
 - Others = peers
- Do not announce routes that incur financial loss
(... as long as alternative paths exist)

Business and Policy Routing

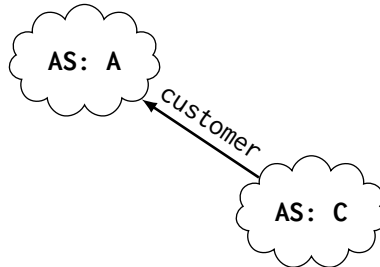
Situation: Stub ASes

Remember:

- Stub ASes have exactly one BGP relationship (with their provider)

Rules

- Provider AS announces routes for reaching the whole internet to customer AS
- Customer AS announces routes for reaching its prefixes to provider AS
- The more traffic the customer sends to the provider or receives from the provider, the more money the provider makes



Business and Policy Routing

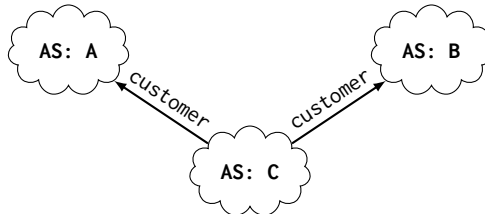
Situation: Multi-Homed ASes

Remember:

- Multi-Homed ASes have multiple providers

Rules

- Several provider ASes announce routes for reaching the whole internet to customer AS
- Customer AS announces routes for reaching its prefixes to several provider ASes
- The more traffic the customer exchanges with one provider, the more money that provider makes
- Customer chooses the cheapest / best-quality provider
- Customer only announces its own prefixes to the providers
 - In case customer (by mistake) announces other prefixes, providers would exchange traffic over the customer network: No benefit for the customer, but financial loss
- Customer may use AS path prepending, by adding his AS number several time to path in BGP announcement, to discourage the use of expensive providers for incoming traffic



Business and Policy Routing

Path Prepending

Trying to influence other peoples routing decisions

- Router of the source AS may use “Shortest AS-PATH” as criterion for choosing where to hand over the packet to the destination AS

Example:

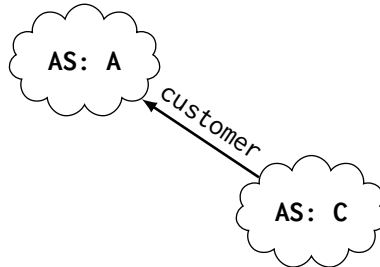
- The destination AS has one router in Munich, and one router in London
- The destination datacenter is also in Munich
- The source AS can choose to hand over the packet in London or Munich
- It is cheaper for the destination AS if the source chooses the Munich router
- The destination AS includes its own ASN multiple times in the BGP updates it sends in London
- The AS-path to Munich is shorter than the AS-path to London
- This may (or may not) convince a source AS to hand over traffic in Munich

Business and Policy Routing

Business Routing Example (1)

A tells C routes to all reachable prefixes

- The more traffic comes from C or vice versa, the more money A makes

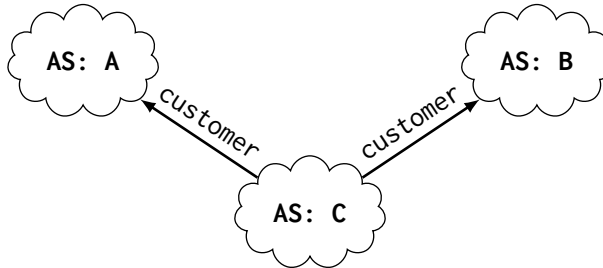


Business and Policy Routing

Business Routing Example (2)

A and B tell C routes to all reachable prefixes

- The more traffic flows from C to A or vice versa, the more money A makes
- The more traffic flows from C to B or vice versa, the more money B makes
- C will pick the one with the cheaper offer / better quality / ...



Business and Policy Routing

Business Routing Example (3)

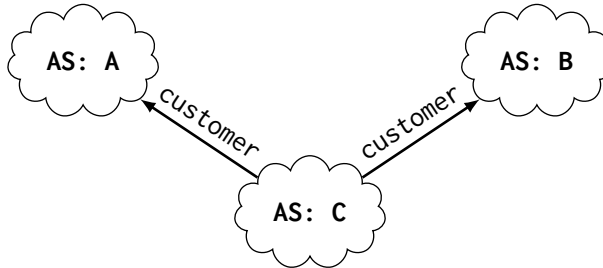
C tells A its own prefixes, C tells B its own prefixes

- C wants to be reachable from outside

C does not tell A routes learned from/via B

C does not tell B routes learned from/via A

- C does not want to pay money for traffic $\dots \leftarrow A \leftarrow C \leftarrow B \leftarrow \dots$



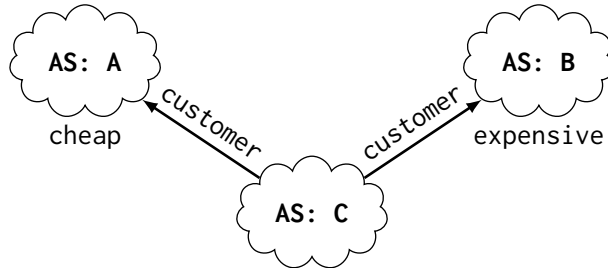
Business and Policy Routing

Business Routing Example (4)

C tells A its own prefixes

C may tell B its own prefixes

- ... but inserts "C" multiple times into AS path (Path Prepending)
- Result: Route available, but longer path = less attractive

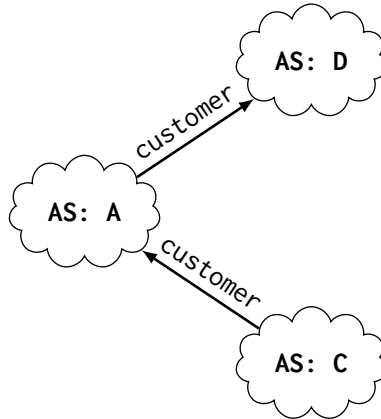


Business and Policy Routing

Business Routing Example (5)

What should A announce here

- C tells A about its own prefixes
- A tells D about its route to C's prefixes: pays money to D, but gains money from C

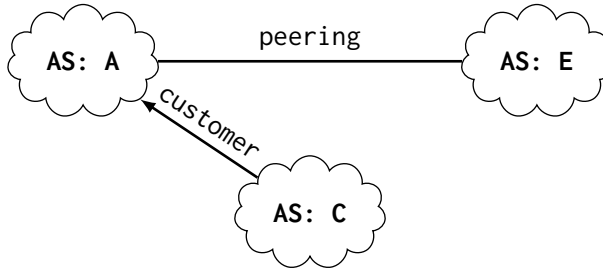


Business and Policy Routing

Business Routing Example (6)

What should A announce to E

- A tells peering partner E about its own prefixes and route to C's prefixes
- no cost on link to E, but gains money from C

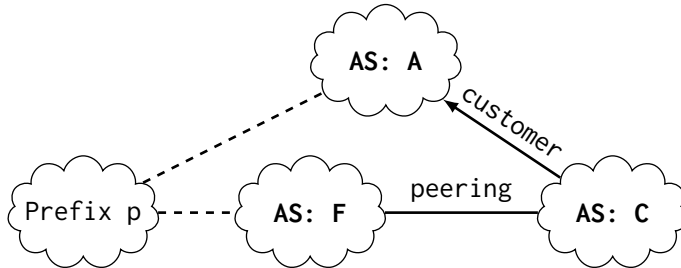


Business and Policy Routing

Business Routing Example (7)

Which route to prefix p does C receive, which should C select?

- A tells C about route to prefix p (C loses money)
- F tells C about route to prefix p (no cost involved)
- C prefers route via F

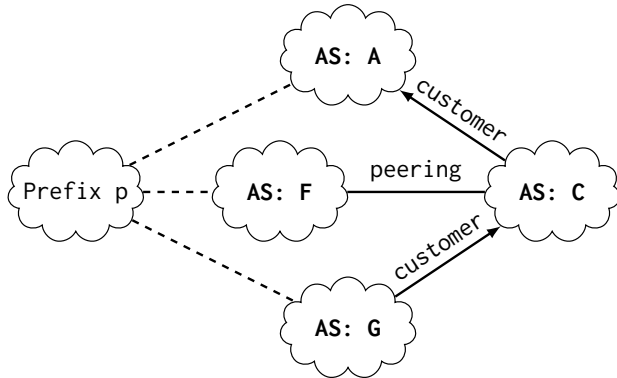


Business and Policy Routing

Business Routing Example (8)

Which route to prefix p does C receive, which should C select?

- A tells C about route to prefix p (C loses money)
- F tells C about route to prefix p (no cost involved)
- G tells C about route to prefix p (C gains money)
- C prefers route via G

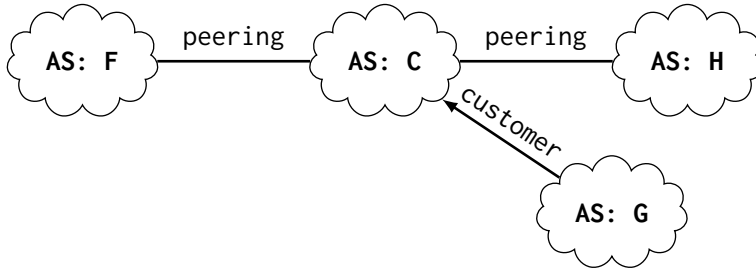


Business and Policy Routing

Business Routing Example (9)

What should C announce here?

- C announces to F and H: its own prefixes and G's prefixes
- C does **not** announce to H: routes to prefixes it learned from F
 - Otherwise: H could send traffic towards F but would not pay anything. F would not pay either. C's network would be loaded with additional traffic.
- C does **not** announce to F: routes to prefixes it learned from H
 - Same reason

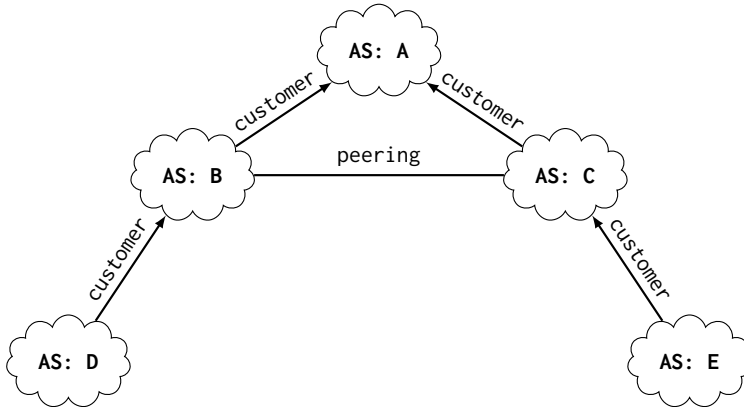


Business and Policy Routing

Policy Routing: Valley-Free Routing (Idealized)

Result: Packets always travel ...

1. upstream: sequence of Customer $\rightarrow$ Provider links (possibly length = 0)
2. then possibly one **peering** link
3. the downstream: sequence of Provider $\rightarrow$ Customer links (possibly length = 0)



Business and Policy Routing Siblings

Not everything is provider/customer or peering

Sibling = mutual transit agreement

- Provide connectivity to the rest of the Internet for each other
- $\approx$ very extensive peering

Examples

- Two small ASes close to each other that cannot / do not want to afford additional Internet services
- Merging of two companies
 - Merging two ASes into one = difficult
 - Keeping two ASes and exchanging everything for free = easier
- Example AT&T has five different ASNs (7018, 7132, 2685, 2686, 2687)

Business and Policy Routing

Tier-1, Tier-2, Tier-3, etc...

Providers can be categorized into Tiers

- Tier-1 / Default-Free-Zone: only peerings, no providers
- Tier-2: only peerings, and one or more Tier-1 provider
- Tier-3: at least one Tier-2 as a provider
- Tier-n: at least one Tier-(n-1) provider
 - defined recursively
 - $n \leq 4$: Rare in Western Europe, North America, East Asia
- “Tier-1.5”: almost a Tier-1, but pays money for some links
 - Example: “Deutsche Telekom” used to pay money to Sprint, but is now Tier-1
 - Marketing effect: Tier-1 sounds better

Business and Policy Routing

Tier-1 Providers

1. Arelion (formerly Telia Carrier) - SE
2. AT&T - US
3. Deutsche Telekom Global Carrier - DE
4. Global Telecom & Technology (GTT) Communications (formerly Tinet & nLayer) - US
5. Liberty Global - NL
6. Lumen Technologies (formerly CenturyLink formerly Level 3 and Global Crossing) - US
7. NTT Communications (formerly Verio) - JP
8. Orange (OpenTransit) - FR
9. PCCW Global - CN
10. Tata Communications (Acquired Teleglobe) - IN
11. Telecom Italia Sparkle (Seabone) - IT
12. Telxius (subsidiary of Telefonica) - ES
13. Verizon Enterprise Solutions (formerly UUNET and XO Communications) - US
14. Zayo Group (formerly AboveNet) - US

1. Receive BGP update
2. Apply import policies
 - Filter routes
 - Tweak attributes (advanced topic ...)
3. Best route selection based on attribute values
 - Policy: Local preference settings and other attributes
 - Install forwarding tables entries for best routes
 - Possibly transfer to Route Reflector RR as alternative to logical full mesh of iBGP sessions
4. Apply export policies
 - Filter routes
 - Tweak attributes
5. Transmit BGP updates

Business and Policy Routing

BGP Business Relationship Summary

Import Policy: Which routes to use

- Select path that incurs most money
- Special/political considerations (e.g. Iranian AS does not want traffic to cross Israeli AS, other kinds of censorship)

Export Policy: Which routes to propagate to other ASes

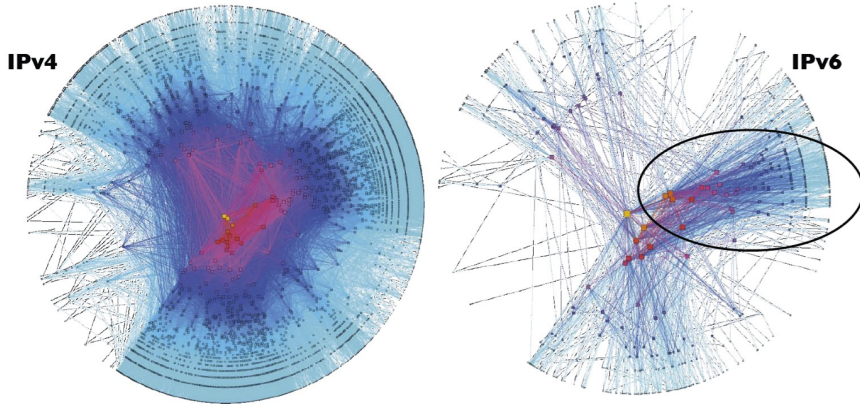
- Not all known routes are advertised
- Export only, ...
 1. ... if it incurs revenue
 2. ... if it reduces cost
 3. ... if it is inevitable

Policy routing: Money, Money, Money, ...

- Route import and export driven by business considerations
- But **not** driven by technical considerations
 - Example: Slower route via peer may be preferred over faster route via provider

k-core Algorithm

IPv4 vs. IPv6 AS Graphs



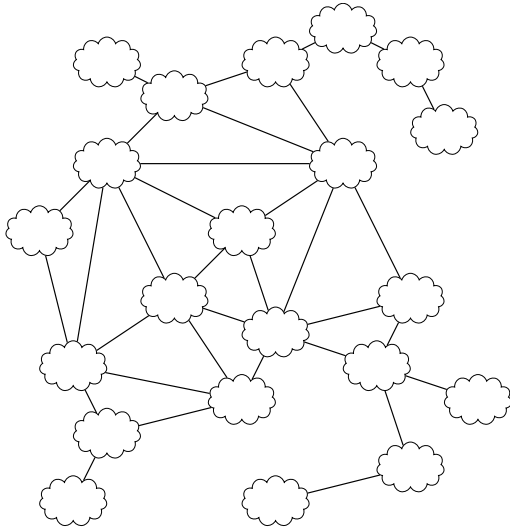
Source: http://www.caida.org/research/topology/as_core_network/

ASes are ranked here by their customer cone size (number of their direct and indirect customers)

Alternative ranking approach: k-core algorithm

k-core Algorithm

k-core Algorithm



Input: Full Graph (if all vertices are connected its a 1-core)

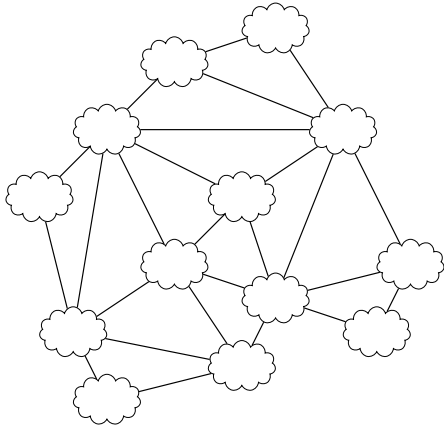
Algorithm steps:

1. Remove all nodes of degree ≤ 1 recursively
2. Did you remove any node?
 - YES: goto step 1
 - NO: return

Result: 2-core subgraph

k-core Algorithm

k-core Algorithm



Input: 2-core subgraph

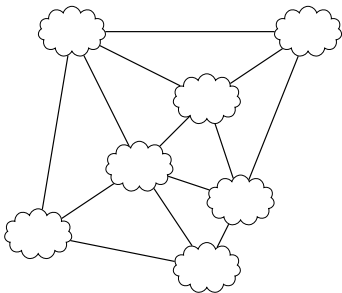
Algorithm steps:

1. Remove all nodes of degree ≤ 2 recursively
2. Did you remove any node?
 - YES: goto step 1
 - NO: return

Result: 3-core subgraph

k-core Algorithm

k-core Algorithm



Input: 3-core subgraph

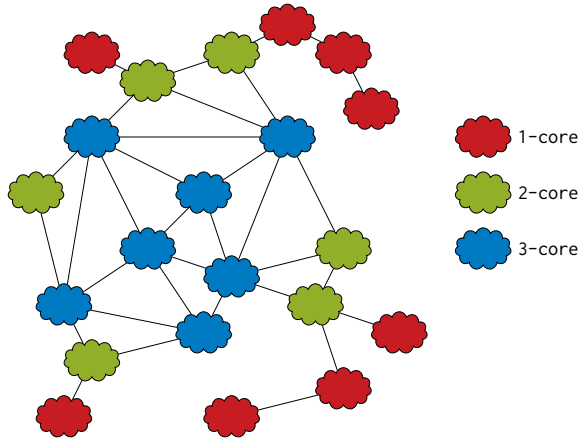
Algorithm steps:

1. Remove all nodes of degree ≤ 3 recursively
2. Did you remove any node?
 - YES: goto step 1
 - NO: return

In this example, this would remove all remaining nodes. Therefore, the constellation on the left is the core of this example network.

k-core Algorithm

k-core Algorithm



Autonomous Systems

BGP

Bibliography

- [1] Y. Rekhter, T. Li, and S. Hares, A Border Gateway Protocol 4 (BGP-4), <https://tools.ietf.org/html/rfc4271>, 2006.