Westfälische Hochschule
Gelsenkirchen Bocholt Recklinghausen
University of Applied Sciences

Structure of the Internet → A view

Prof. Dr. (TU NN)
Norbert Pohlmann

Institute for Internet Security - if(is)
University of Applied Sciences Gelsenkirchen
http://www.internet-sicherheit.de

if(is) internet security.

Content

- Aim and outcomes of this lecture
- Internet Infrastructure
- Autonomous Systems
- Country Internet / CDN
- Basic Internet Model
- Summary

Content

- **Aim and outcomes of this lecture**
- Internet Infrastructure
- Autonomous Systems
- Country Internet / CDN
- Basic Internet Model
- Summary

Structure of the Internet
→ Aims and outcomes of this lecture

Aims

- To introduce the idea of the Internet
- To explore the structure of the Internet
- To analyze the connectivity of the Internet
- To discuss the role of the players of the internet structure
- To introduce a basic Internet model

At the end of this lecture you will be able to:

- Understand what the Internet is from the communication point of view.
- Know basic information about the structure of the Internet.
- Understand how the processes between providers works.
- Understand the motivation of different players and aspects of the Internet.

Content

- Aim and outcomes of this lecture
- **Internet Infrastructure**
- Autonomous Systems
- Country Internet / CDN
- Basic Internet Model
- Summary

Internet Infrastructure (1/3)
→ Networks

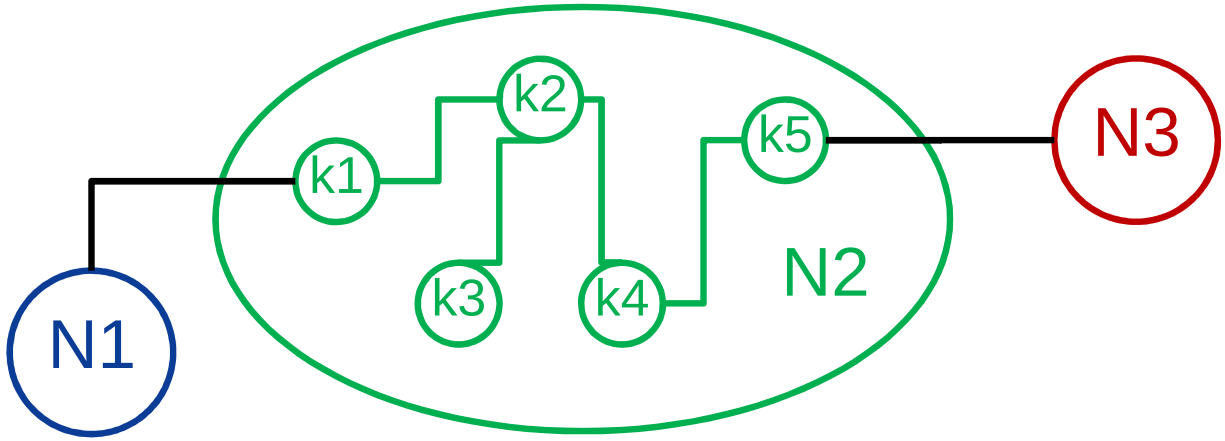
- A **network (N)** is an interconnected group of nodes (K), such as computers, hubs, switches, routers, and so on.

$$N =< K, L >$$

  - K := Number of nodes (k)

$$K = \{k_1, k_2, \ldots, k_n\}$$

  - L := Connection (links) between nodes (k)



Internet Infrastructure (2/3)
→ Autonomous Systems (AS)

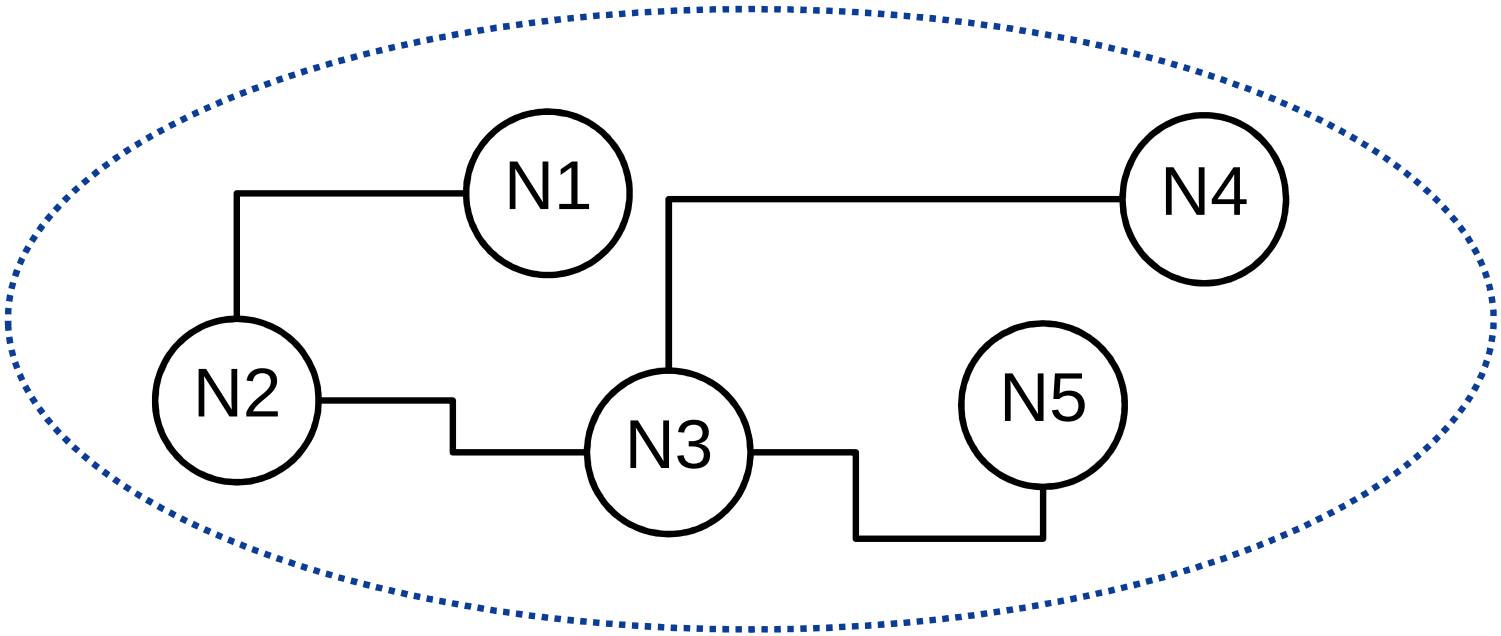
- „An **Autonomous Systems (AS)** is a connected group of one or more IP prefixes run by one or more network (N) operators, which has a SINGLE and CLEARLY DEFINED routing policy.“ [1]

$$AS =< N, L >$$

  - N := Number of networks (n)

$$N = \{n_1, n_2, \ldots, n_m\}$$

  - L := Connection (links) between networks (n)



Internet Infrastructure (3/3)
→ Interconnected networks

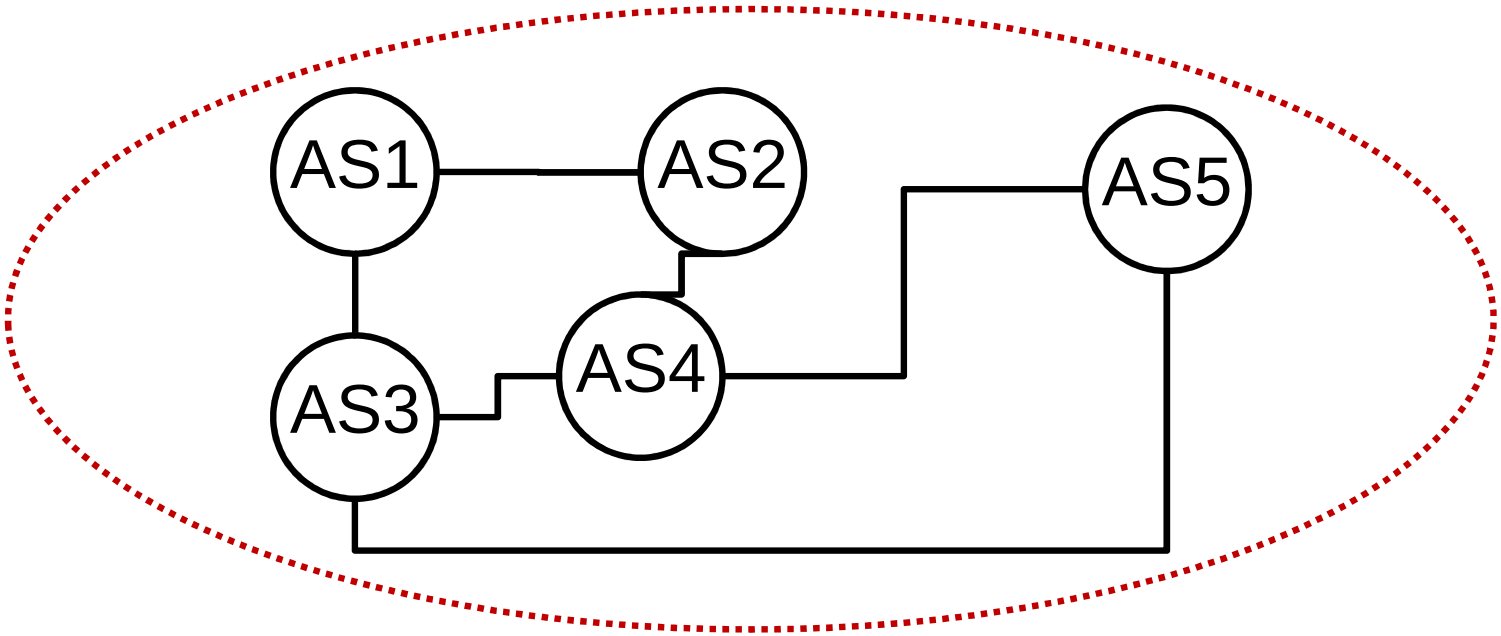
- The **Internet (I)** consists of independent networks, the Autonomous Systems (AS) which are connected.

$$I =< AS, L >$$

  - AS := Number of Autonomous Systems (AS)

$$AS = \{as_1, as_2, \ldots, as_N\}$$

  - L := Connection (links) between Autonomous System (AS)



Content

- Aim and outcomes of this lecture
- Internet Infrastructure
- **Autonomous Systems**
- Country Internet / CDN
- Basic Internet Model
- Summary

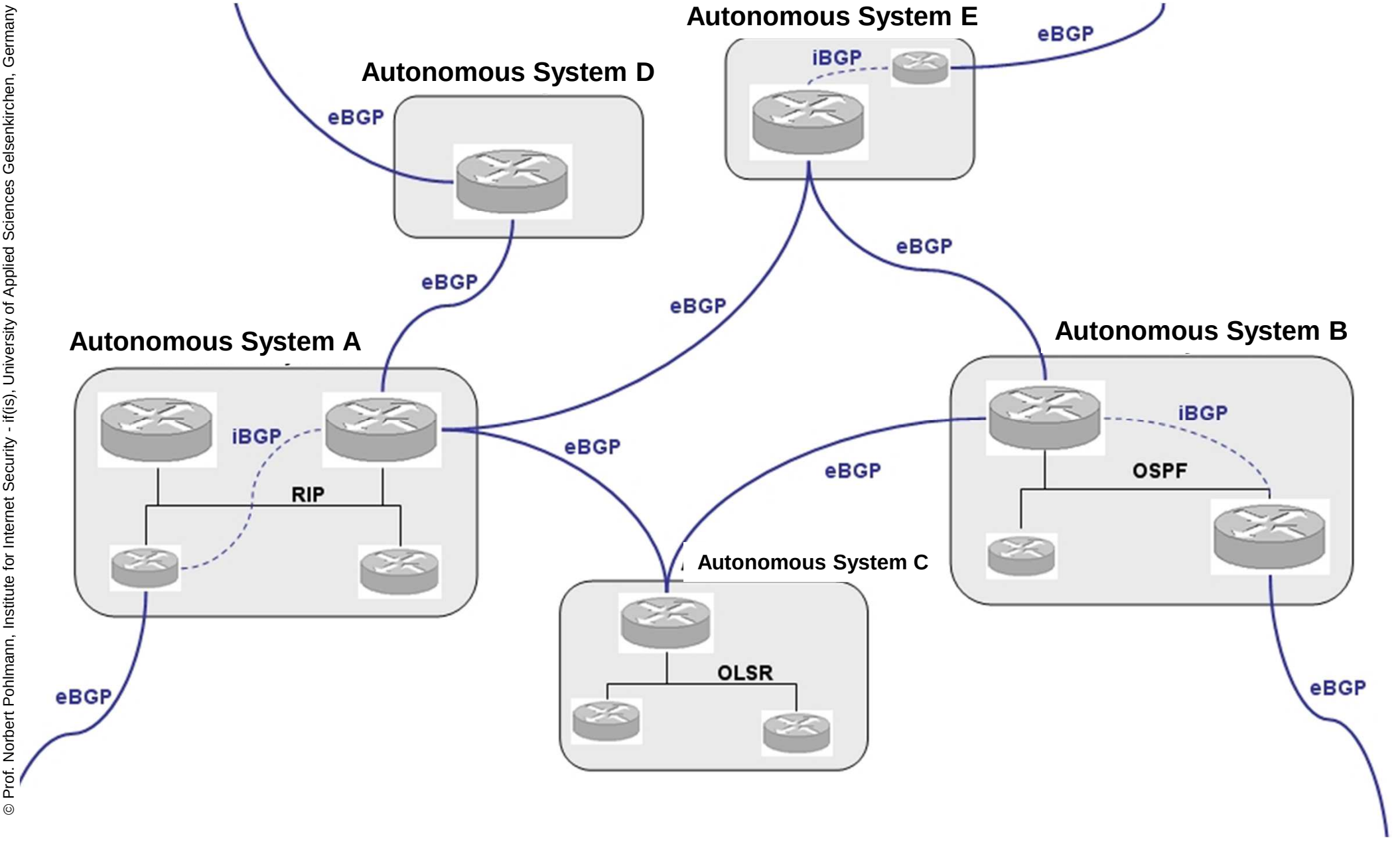
Internet
→ Characteristics

- The Internet is
  - a network of networks
  - services and application neutral
  - multi-functional and multi-medial
- The end points of the networks decide on the manner of communications.
- There is only one non-fragmented, global Internet, which has public IP addresses.
- Every AS is free to negotiate with every other ASs about a connection
- The sending of IP packet via alternate routes is always possible and makes the Internet failsafe
- The Internet is self-governing and therefore it unites all stakeholders.

Structure of the Internet
→Autonomous Systems (AS)

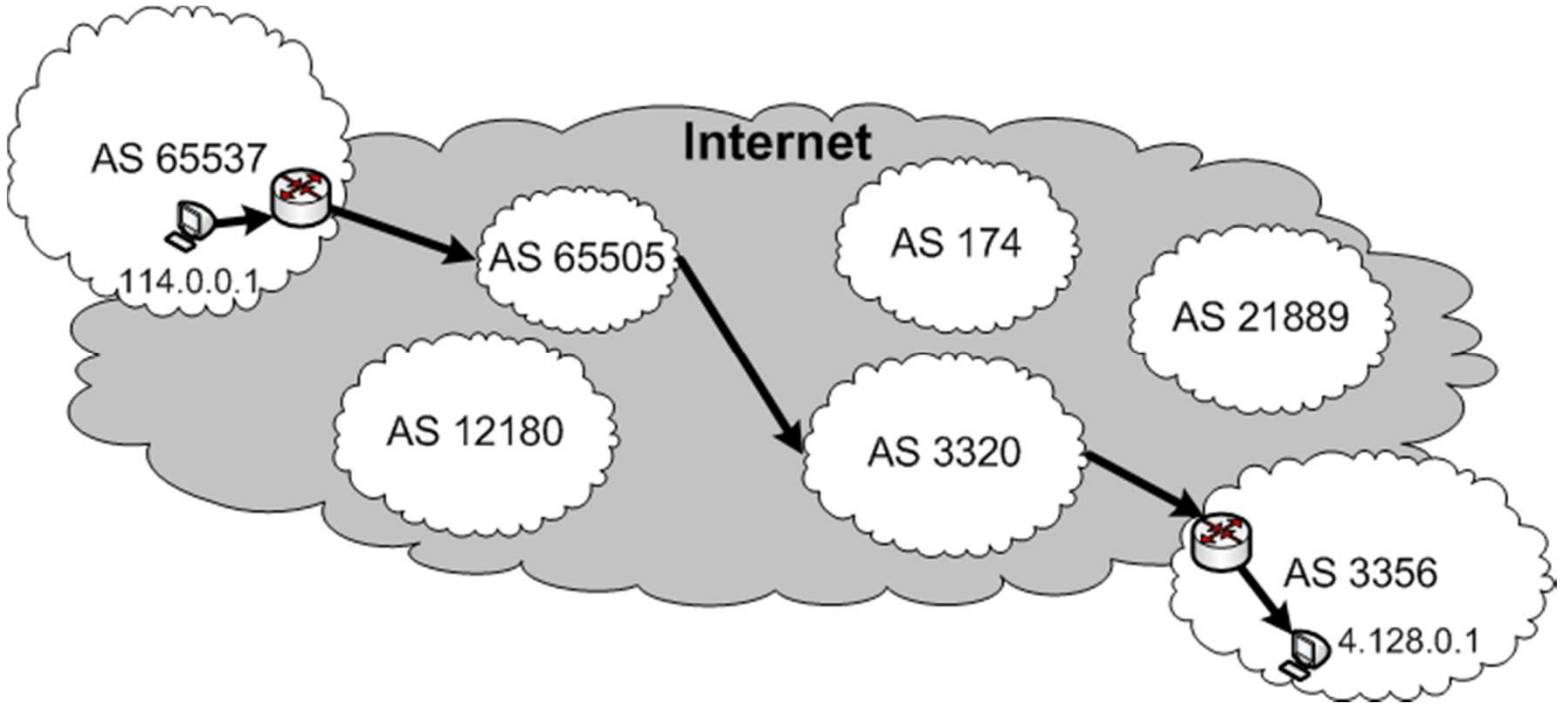
- The global Internet consists of thousands of independent networks, the Autonomous Systems (AS)
- Currently there are more than 50.000 different ASs advertised in the global routing
- **The AS operators have different policies for the size and expansion of their network**
- **An AS needs a strategy to connect with other ASs using transits and private or public peerings**
- There are more than 500,000 logical connections between ASs at the moment

Autonomous Systems
→ Router view



Autonomous Systems
→ AS-Path view

Communication between IP address 114.0.0.1 and 4.128.0.1



The IP packet must go through the AS **65505 3320 3356** (AS-Path) to reach the destination IP address (4.128.0.1)

→ Depending on the kind and the location of the AS, a border router stores up to **500,000 paths** (2014) in its routing information base (RIB).

Structure of the Internet
→ Connection with other ASs

- **Transit (Upstream)**
  - For transit (upstream) the **smaller AS** has to **pay** to the **bigger AS**
    - AP / CP / BP to TP

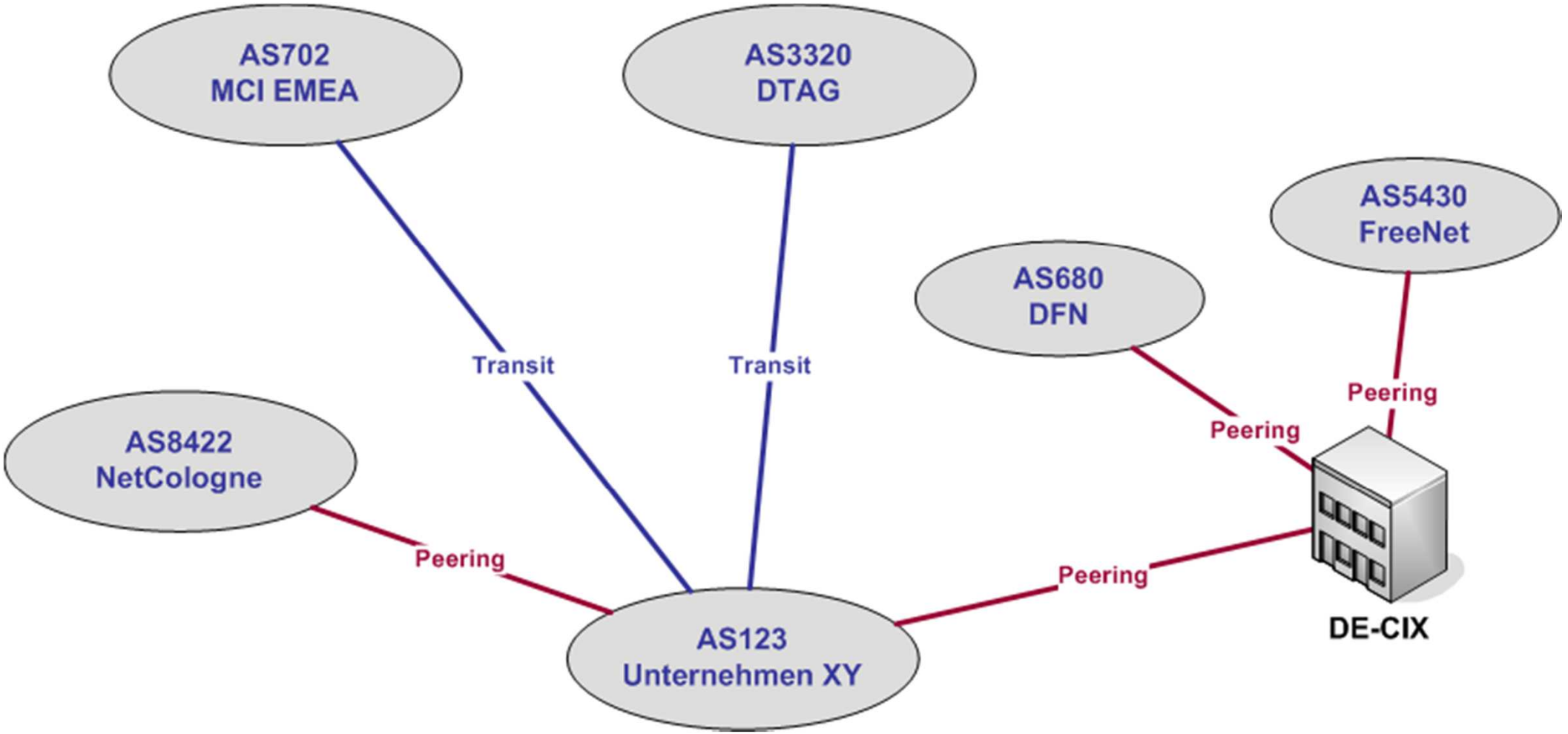
- **Private peering**
  - Private peering is a **connection between ASs of the same level**
  - Normally there is **no payment** for the exchanged data

- **Public peering**
  - Public peering takes place at a central point, so called Internet Exchange Point (IXP)
  - An IXP consists of e.g. switches where up to a few hundred AS can be connected.

Number of connections (AS)

```
      >1000 -->     21 AS
   100-1000 -->    631 AS
    10- 100 --> 3,339 AS
     3-  10 --> 7,316 AS
        <=3 --> 32,743 AS
```

Autonomous Systems
→ Strategy of the Provider

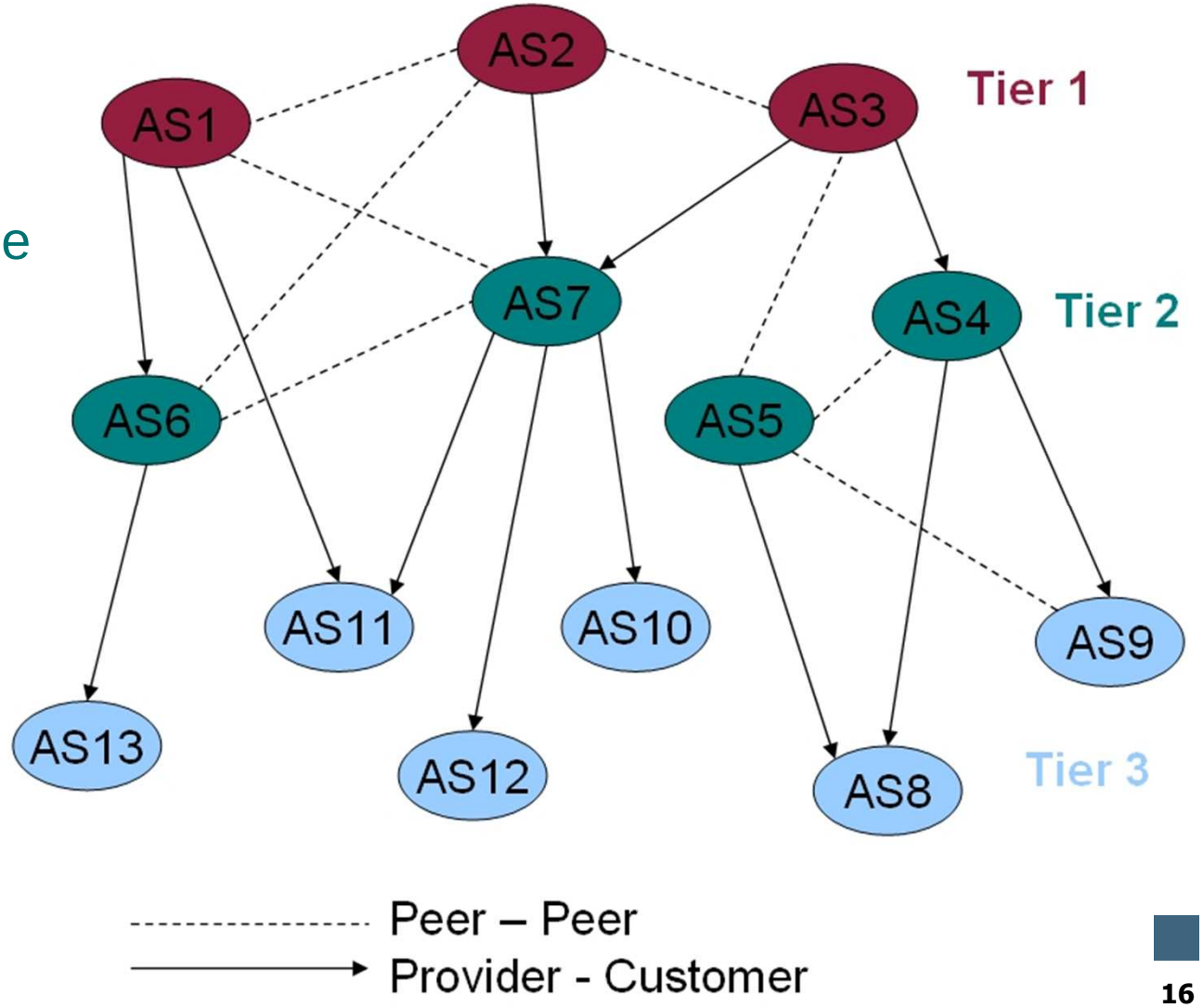


Structure of the Internet
→Tier Model (network view)

Tier 1
A network that reaches every other network in the Internet without transit paying.

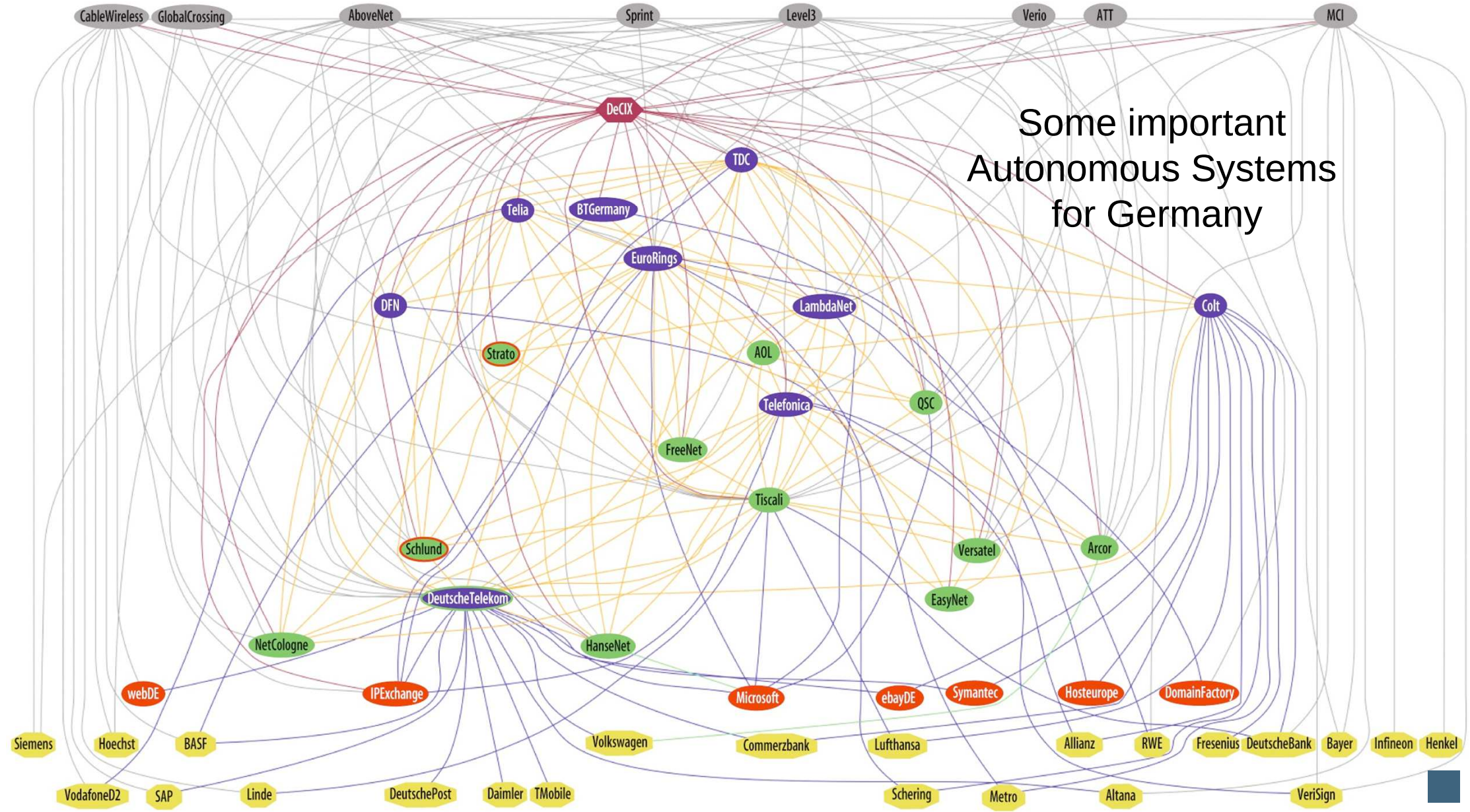
Tier 2
A network that peers with some networks, but still purchases transit or pays settlements to reach at least some portion of the Internet.

Tier 3
A network that purchases transit from other networks to reach the Internet.



Structure of the Internet

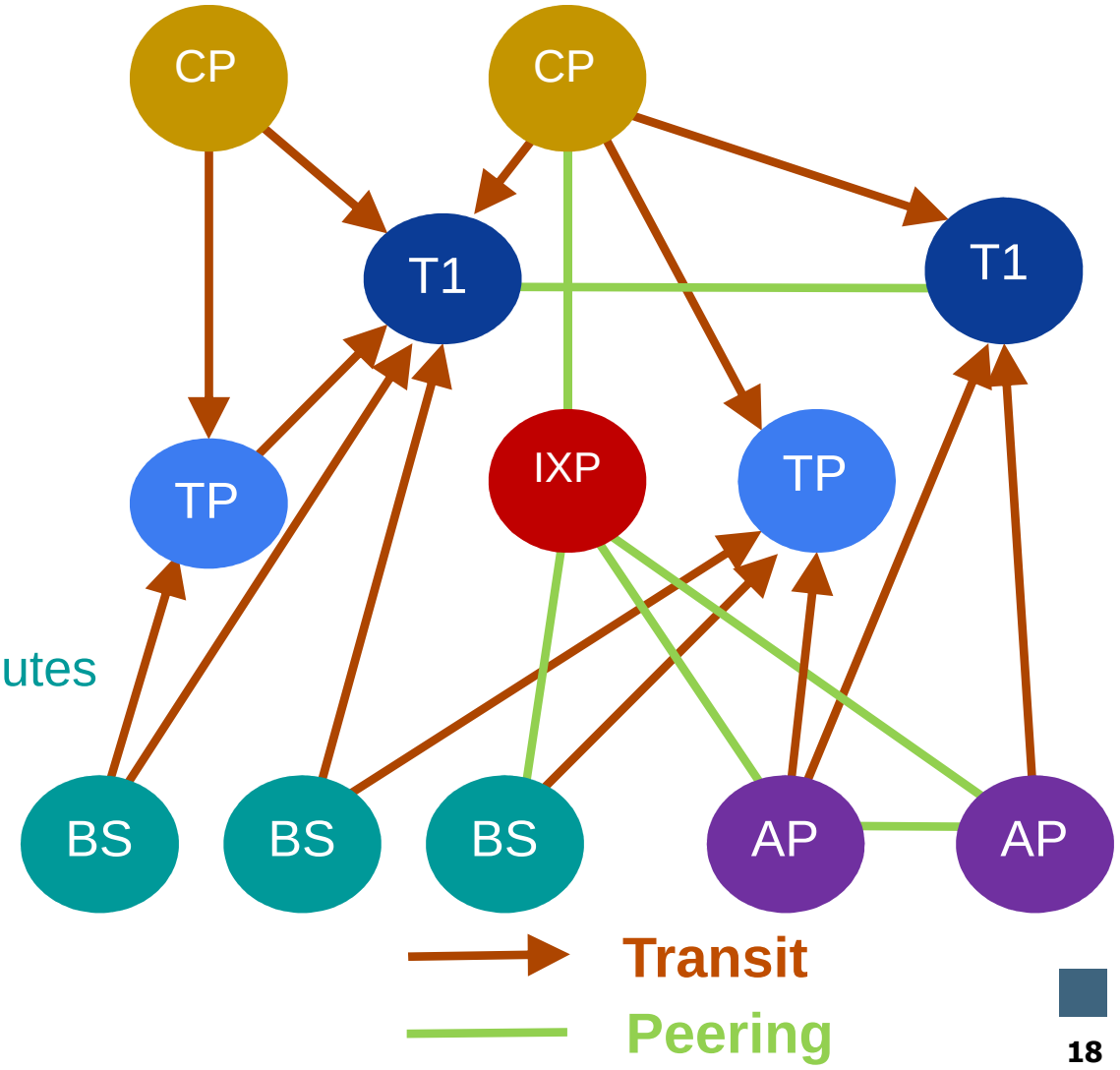
→ if(is) model: „Internet Germany“



Some important Autonomous Systems for Germany

Structure of the Internet
→ if(is) model: Types of AS

- **Tier 1 Network (T1)**
  AS that reaches every other AS in the Internet without transit paying.
- **Transit Provider (TP)**
  AS that routes traffic through for at least 10 ASs
- **Content Provider (CP)**
  AS that hosts at least 75 Websites in the Internet
- **Access Provider (AP)**
  AS that has at least 50,000 IPv4 addresses advertised
- **Business Customers AS (BS)**
  AS can only be found at the end of routes and has less than 4 connection to other AS
- **Internet Exchange Points (IXP)**
  A physical infrastructure where ASs exchange Internet Traffic
  (not necessary an AS)



Different types of AS
→ Types of AS: Tier 1 Network (1/2)

- **Definition:**
  - A Tier 1 Network (T1) is one that can reach every other network (IP address) in the Internet without purchasing IP transit or paying settlements.
    → **necessary to reach every IP address in the Internet!**
  - A transit-free network that peers with every other tier-1 network.

- **Statistic:**
  - There are twelve networks, which are believed to be Tier 1 networks.

Different types of AS
→ Types of AS: Tier 1 Network (2/2)

if(is) internet security.

List of Tier 1 networks [3]:

Name	HQ	ASN(s)
Level 3 Communications	USA	1, 3356, 3549
Centurylink	USA	209, 3561
Verizon Business	USA	701
Srint	USA	1239
TeliaSonera	Sweden	1299
XO Communications	USA	2828
NTT Communications	Japan	2914
Inteliquent	USA	3257
Deutsche Telekom AG	Germany	3320
Tata Communications	India	6453
Telecom Italia	Italy	6762
AT&T	USA	7018

Different types of AS
→ Types of AS: Transit Provider (1/2)

- **Definition:**
  - A Transit Provider (TP) is usually present at many points of presences (PoPs) in different countries where the ASs of its customers are connected.
  - The customers are paying fee to their Transit Providers in order to be connected with the rest of the Internet and to be advertised in routing tables.
  - TP are usually Tier-2 or Tier-1
  - if(is) defines every AS that **routes traffic through** for at least 10 ASs as an Transit Provider (source and destination IP address is not part of the AS)

- **Statistic:**
  - There are 227 Transit Providers in Germany and 3,081 worldwide.

Different types of AS
→ Types of AS: Transit Provider (2/2)

ASN	Name	Country	Connected AS
174	COGENT Cogent/PSI	US	4,039
3356	LEVEL3 Level 3 Communications	US	3,397
6939	HURRICANE - Hurricane Electric, Inc.	US	2,854
7018	ATT-INTERNET4 - AT&T Services, Inc.	US	2,427
9002	RETN-AS ReTN.net Autonomous System	GB	1,835
701	UUNET - MCI Communications Services, Inc. d/b/a Verizon Business	US	1,811
4323	TWTC - tw telecom holdings, inc.	US	1,547
3549	GBLX Global Crossing Ltd.	US	1,533
209	ASN-QWEST - Qwest Communications Company, LLC	US	1,388
34695	E4A-AS E4A s.r.l.	IT	1,351
8359	MTS MTS OJSC	RU	1,287
13237	LAMBDANET-AS Lambdanet Communications Deutschland GmbH	DE	1,280
39792	ANDERS-AS Anders Telecom Ltd.	RU	1,265
5580	ATRATO Atrato IP Networks	NL	1,238
3257	TINET-BACKBONE Tinet SpA	US	1,174
12389	ROSTELECOM-AS OJSC Rostelecom	RU	1,174
8492	OBIT-AS Obit Telecommunications, St.Petersburg, Russia	RU	1,137
702	AS702 Verizon Business EMEA - Commercial IP service provider in Europe	DE	1,078
19151	WVFIBER-1 - WV FIBER	US	1,039
6461	MFNX MFN - Metromedia Fiber Network	US	1,033

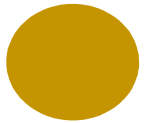
Top20 Transit Providers worldwide

Different types of AS
→ Types of AS: Content Provider (1/2)

- **Definition:**
  - Content Providers (CP) are hosting and offering websites as well as other content (music, films, TV, …) on servers in their AS.
  - The CP send much more data out of the AS than received from other ASs
    - For example typical ratio receive/sent
      - Website: 1 / 12
      - TV: ???
  - CP are usually Tier-3
  - **if(is)** defines every AS that hosts at least 75 websites as a Content Provider.

- **Statistic:**
  - There are 247 content providers in Germany, 2,800 in the G20 states and worldwide 3,815

Different types of AS
→ Types of AS: Content Provider (2/2)



Top20 Content Provider in Germany

ASN	Name	Websites
8560	ONEANDONE-AS 1&1 Internet AG	316,229
24940	HETZNER-AS Hetzner Online AG RZ	214,409
25074	INETBONE-AS MESH GmbH	88,910
6724	STRATO STRATO AG	86,794
8972	PLUSSERVER-AS intergenia AG	41,097
20773	HOSTEUROPE-AS Host Europe GmbH	40,808
47846	SEDO-AS Sedo GmbH	38,376
15598	IP-EXCHANGE IP Exchange GmbH	30,244
34011	DOMAINFACTORY domainfactory GmbH	30,060
34788	NMM-AS Neue Medien Muennich GmbH	28,484
28753	LEASEWEB-DE Leaseweb Germany GmbH	22,174
15456	INTERNETX-AS InterNetX GmbH	15,284
3320	DTAG Deutsche Telekom AG	14,822
13237	LAMBDANET-AS Lambdanet Communications Deutschland GmbH	11,064
29671	SERVAGE Servage GmbH	9,370
24989	IXEUROPE-DE-FRANKFURT-ASN Equinix Germany (Previously IX Europe Germany AS)	7,343
16097	HLKOMM HL komm Telekommunikations GmbH	7,218
12306	PLUSLINE Plus.Line AG	6,930
24961	FIBREONE-AS myLoc managed IT AG	6,758
51167	GIGA-HOSTING Giga-Hosting GmbH	6,570

Different types of AS
→ Types of AS: Access Provider (1/3)

- **Definition:**
  - Access Providers (AP) are providing access to the internet for their customers (also called: eyeball or ISP)
  - An Access Provider needs traditionally a huge amount of official IPv4 addresses for its customers
  - Mobile network operators often run their mobile Networks behind a NAT (using private IP addresses)
  - AP are mostly Tier-3 *(e.g. German Telekom is AP, CP, TP and Tier 1)*
  - **if(is)** defines every AS that has at least 50,000 IPv4 addresses advertised as an Access Provider
- **Statistic:**
  - There are 124 access providers in Germany and 4,026 worldwide

Different types of AS
→ Types of AS: Access Provider (2/3)

Top20 Access Provider in Germany (IP address definition)

ASN	Name	Country	ipv4 DE
3320	DTAG Deutsche Telekom AG	DE	31,440,796
31399	DAIMLER-AS Daimler Autonomous System (BS and not AP)	DE	16,834,559
680	DFN Verein zur Foerderung eines Deutschen Forschungsnetzes e.V.	DE	8,157,462
3209	VODANET Vodafone D2 GmbH	DE	7,235,584
6805	TDDE-ASN1 Telefonica Germany GmbH & Co.OHG	DE	4,740,970
44178	TMD-CORE-AS Telekom Deutschland GmbH	DE	2,953,472
20676	QSC-1 QSC AG	DE	2,721,732
553	BELWUE Landeshochschulnetz Baden-Wuerttemberg (BelWue)	DE	2,111,232
702	AS702 Verizon Business EMEA - Commercial IP service provider in Europe	DE	1,881,016
31334	KABELDEUTSCHLAND-AS Kabel Deutschland Vertrieb und Service GmbH	DE	1,851,392
13184	HANSENET Telefonica Germany GmbH & Co.OHG	DE	1,700,096
12638	AS12638 E-Plus Mobilfunk GmbH & Co. KG	DE	1,459,456
5430	FREENETDE freenet Datenkommunikations GmbH	DE	1,261,503
20825	UNITYMEDIA Unitymedia NRW GmbH	DE	1,163,520
8881	VERSATEL Versatel Deutschland GmbH	DE	1,150,960
12312	ECOTEL ecotel communication ag	DE	1,125,992
29562	KABELBW-ASN Kabel BW GmbH	DE	790,528
1668	AOL-ATDN - AOL Transit Data Network	US	732,712
24940	HETZNER-AS Hetzner Online AG RZ	DE	569,669
8422	NETCOLOGNE NETCOLOGNE AS	DE	558,592

Different types of AS
→ Types of AS: Access Provider (3/3)

ASN	Name	Country	ipv4
4134	CHINANET-BACKBONE No.31,Jin-rong Street	CN	101,560,064
7922	COMCAST-7922 - Comcast Cable Communications, Inc.	US	70,829,696
721	DNIC-ASBLK-00721-00726 - DoD Network Information Center	US	65,796,576
4837	CHINA169-BACKBONE CNCGROUP China169 Backbone	CN	51,733,760
4766	KIXS-AS-KR Korea Telecom	KR	44,862,464
17676	GIGAINFRA Softbank BB Corp.	JP	44,285,952
3356	LEVEL3 Level 3 Communications	US	42,741,884
7018	ATT-INTERNET4 - AT&T Services, Inc.	US	38,695,136
71	HP-INTERNET-AS Hewlett-Packard Company	US	32,481,280
3320	DTAG Deutsche Telekom AG	DE	31,626,748
7132	SBIS-AS - AT&T Internet Services	US	29,547,520
4713	OCN NTT Communications Corporation	JP	29,013,248
174	COGENT Cogent/PSI	US	27,535,000
701	UUNET - MCI Communications Services, Inc. d/b/a Verizon Business	US	23,880,448
22394	CELLCO - Cellco Partnership DBA Verizon Wireless	US	22,726,528
9394	CRNET CHINA RAILWAY Internet(CRNET)	CN	19,305,472
19262	VZGNI-TRANSIT - Verizon Online LLC	US	19,229,440
3269	ASN-IBSNAZ Telecom Italia S.p.a.	IT	18,605,824
2516	KDDI KDDI CORPORATION	JP	18,246,912
237	MERIT-AS-14 - Merit Network Inc.	US	18,163,968

Top20 AS with most IP adds. worldwide

Different types of AS
→ Types of AS: Business Customer

- **Definition:**
  - A Business Customer AS (BS) does not provide internet services to other ASs
  - Business Customers are usually big companies which operate their own AS (always Tier-3)
  - They use various Transit Providers to achieve trustworthy connectivity and competition
  - The ASN of such AS can only be found at the end of routes (source and destination IP address is part of the AS)

- **Examples: (Germany)**
  - Bayer AG, BASF, Volkswagen...

- **Statistic:**
  - 866 in Germany; 31,572 worldwide

Internet Exchange Points
→ Important Internet component

- **Definition:**
  - An Internet exchange Point (IXP) is a physical infrastructure where ASs exchange Internet Traffic
  - The biggest IXP is the DE-CIX in Frankfurt [4]
  - An IXP physically consists of one ore more hierarchically structured switches where the Edge-Routers of the participating AS are connected
  - An optional route server handles the BGP traffic and makes it possible to manage connectivity between ASs from a central point

- **Statistic:**
  - There are over 350 IXP listed at PeeringDB [5], the biggest platform for finding peering Partners in the web

Content

- Aim and outcomes of this lecture
- Internet Infrastructure
- Autonomous Systems
- **Country Internet / CDN**
- Basic Internet Model
- Summary

Country Internet
→ if(is) approach: Definition

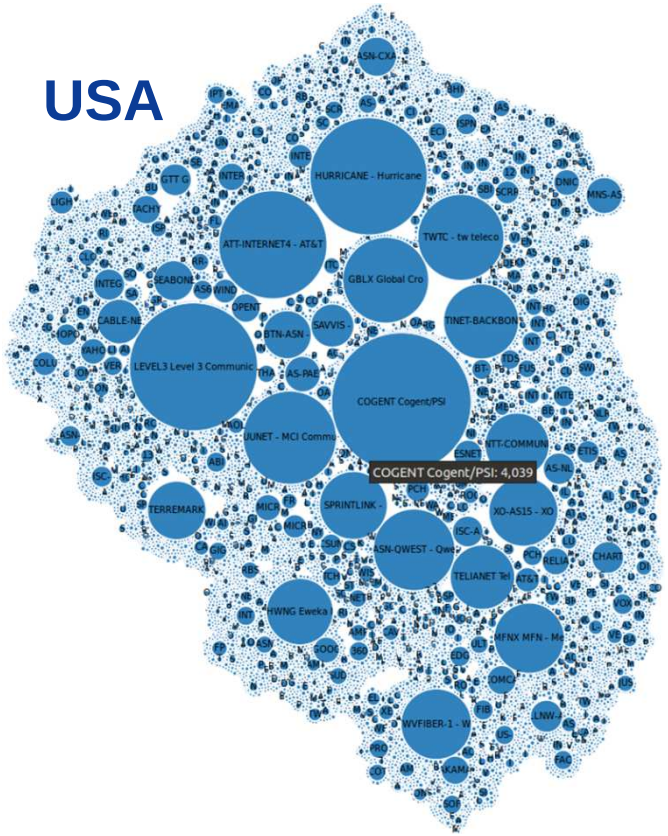
- **Core definition:**
  - An AS is one of the defined country, where most of the IP addresses of the AS are used in this country.
  - Tools: Maxmind's geolocation and ip2asn databases [6]
    - Statistic:
      - Germany: 1,385
      - Great Britain: 1,435
      - France: 828
      - USA: 14,614

- **Extended Definition:**
  - All ASs that use IP addresses within this country.
    - Statistic:
      - Germany: 1,749
      - Great Britain: 2,115
      - France: 1,079
      - USA: 15,438

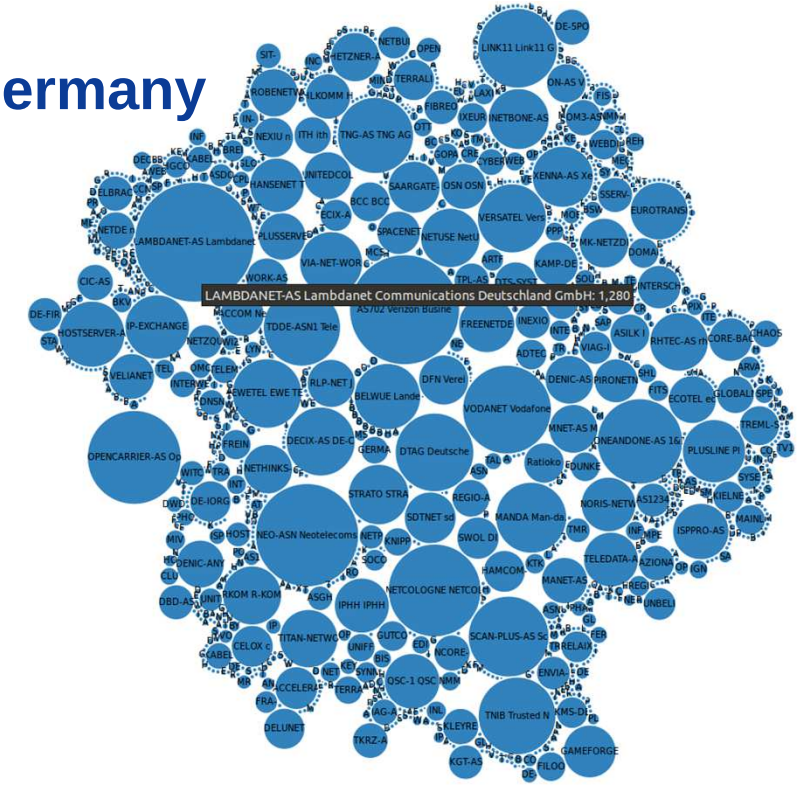
Country Internet
→ if(is) approach: Spirit and purpose

- We are able to compare special aspects of different countries
- We can identify which AS has what kind of relevance for a country
- National comparison of malware distribution of different AS (CP, AP, BP, …)
- …

USA



Germany

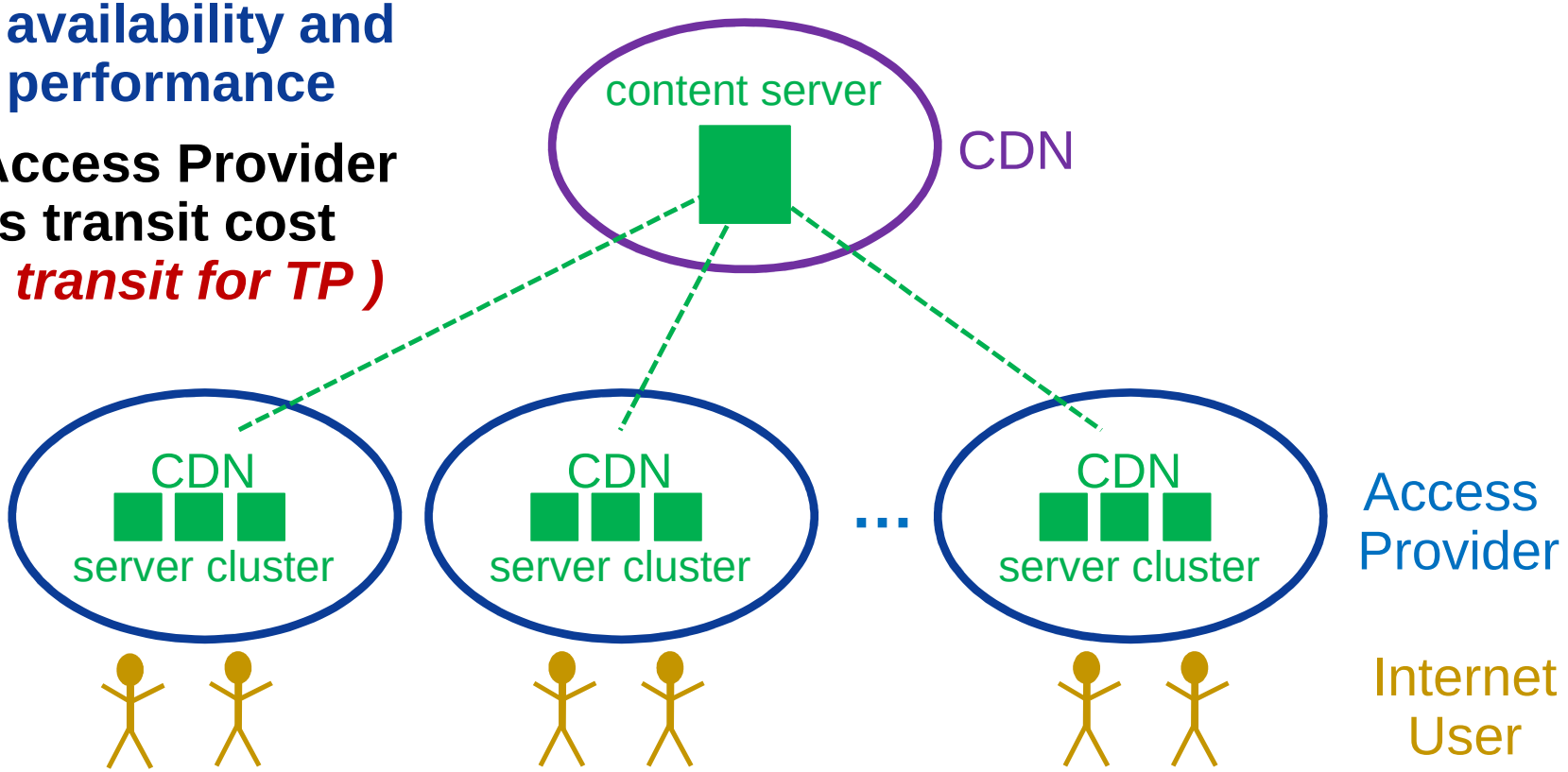


Size of the circles is calculated from the number of connections.

Content Delivery Networks (CDN) → Approach (1/2)

- A CDN consists of one or more ASs and server clusters, which are distributed in many places within different AS (Access Provider).
- The server clusters synchronize their content with a main content server.

- **Advantages and motivation**
  - **closer to the end user (~5 hops instead ~12 hops)**
  - **high availability and high performance**
  - **the Access Provider saves transit cost *(less transit for TP)***



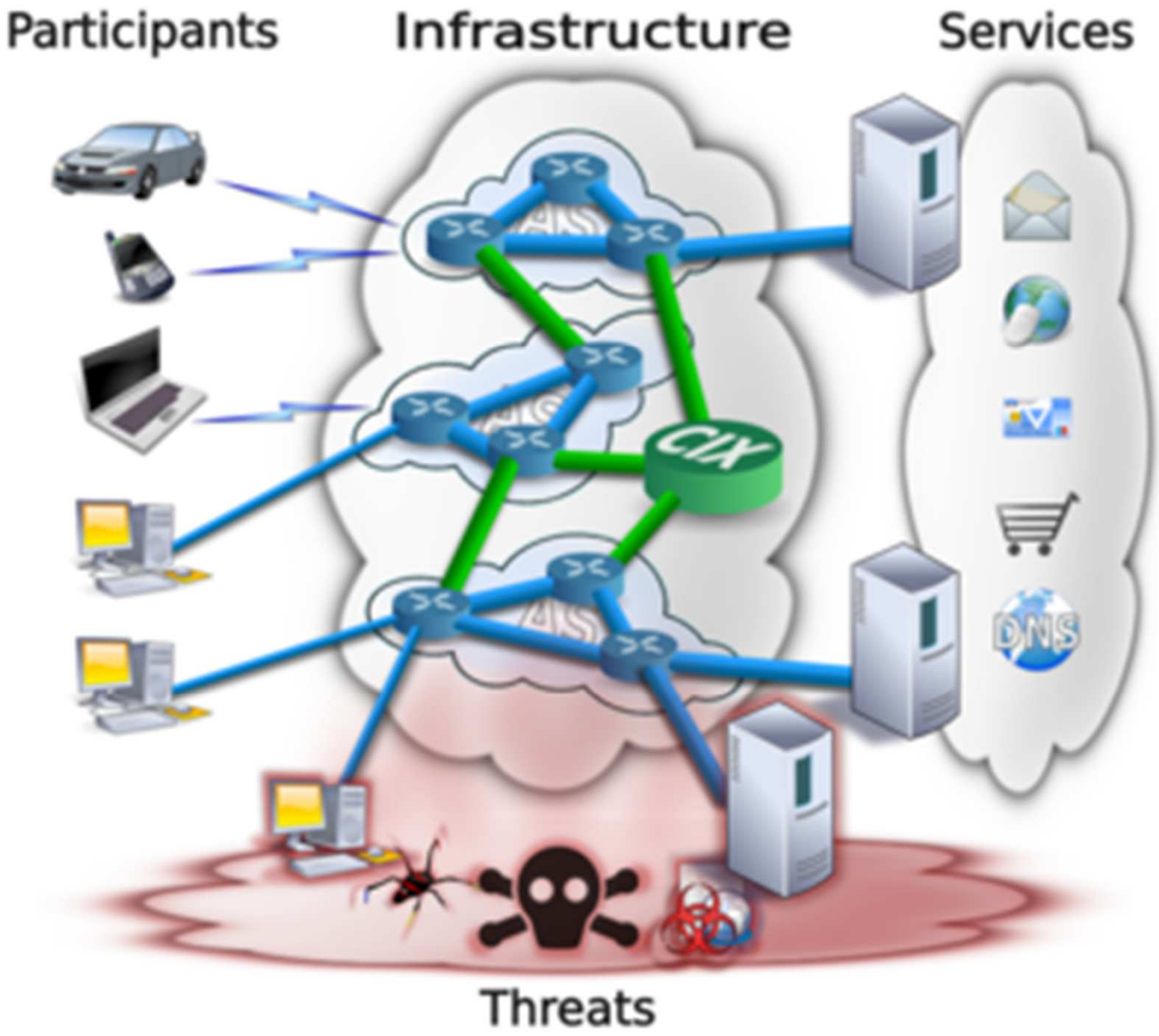
Content Delivery Networks (CDN) → Approach (2/2)

- Some well known CDNs:
  - **Akamai**
  - Amazon Web Services (CloudFront)
  - Coral
  - Level 3 Communications
  - NTT Europe Online (NTTEO)
  - TV1.EU
  - Host Europe
  - Google Page Speed

Content

- Aim and outcomes of this lecture
- Internet Infrastructure
- Autonomous Systems
- Country Internet / CDN
- **Basic Internet Model**
- Summary

Basic Internet Model
→ Overview



Basic Internet Model
→ Infrastructure

- Links (copper cable, fiber optics, wireless, …)
- Routers, switches, hubs, …
- Networks
- Autonomous Systems
- IXP
- …

Basic Internet Model
→ Participants

- Mainframe, server, …
- PCs, notebooks, …
- Smartphones, PADs, …
- Cars
- Industrial components
- Critical Infrastructure components
- Internet of Things → everything
- …

Basic Internet Model
→ Services

- DNS
- e-mail
- Websites
- Social networks
- VoIP, streaming, …
- Online shopping, banking, gambling, …
- …

Basic Internet Model
→ Threats

- Malware
- DDoS
- Spamming
- Phishing
- …

Content

- Aim and outcomes of this lecture
- Internet Infrastructure
- Autonomous Systems
- Country Internet / CDN
- Basic Internet Model
- **Summary**

Structure of the Internet
→ Summary

- Structure of the Internet is self regulated.
- Only few organisations really know what happens in the Internet.
- For the Cyber Situation Awareness it is important to know and understand the structure and the development of the Internet!
- …

Westfälische Hochschule
Gelsenkirchen Bocholt Recklinghausen
University of Applied Sciences

Structure of the Internet → A view

Thank you for your attention!
Questions?

Prof. Dr. (TU NN)
Norbert Pohlmann

Institute for Internet Security - if(is)
University of Applied Sciences Gelsenkirchen
http://www.internet-sicherheit.de

if(is) internet security.

Structure of the Internet
→ Literature

- [1] http://en.wikipedia.org/wiki/Autonomous_system_(Internet)
- [2] N. Pohlmann: “Wie verlässlich ist das Internet?“ http://www.internet-sicherheit.de/fileadmin/docs/publikationen/IP-Sicherheit-Verlaesslichkeit-12-02-08.pdf
- [3] http://en.wikipedia.org/wiki/Tier_1_network#List_of_tier_1_networks
- [4] http://www.de-cix.net/
- [5] https://www.peeringdb.com
- [6] http://www.maxmind.com/app/ip-location

Links:

AiconViewer: http://www.internet-sicherheit.de/aiconviewer/
IKS:http://www.internet-sicherheit.de/institut/forschung/aktuelle-forschungsprojekte/internetkennzahlen/uebersicht/