emnify

SRECON AMERICAS

Please give me back my Network Cables!

On Networking Limits in AWS

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What’s this?

- ”100G network cable”

100G Ethernet
Throughput Limits

- 148,809,524pps!
  @64 bytes/frame
- Per direction!

Cloudy
Throughput Limits

EC2 Instance Types
Throughput Limits

General Purpose m7g

Instance Size	vCPU	Memory (GiB)	Instance Storage (GB)	Network Bandwidth (Gbps)	EBS Bandwidth (Gbps)
m7g.medium	1	4	EBS-Only	Up to 12.5	Up to 10
m7g.large	2	8	EBS-Only	Up to 12.5	Up to 10
m7g.xlarge	4	16	EBS-Only	Up to 12.5	Up to 10
m7g.2xlarge	8	32	EBS-Only	Up to 15	Up to 10
m7g.4xlarge	16	64	EBS-Only	Up to 15	Up to 10
m7g.8xlarge	32	128	EBS-Only	15	10
m7g.12xlarge	48	192	EBS-Only	22.5	15
m7g.16xlarge	64	256	EBS-Only	30	20
m7g.metal	64	256	EBS-Only	30	20

$950/mo

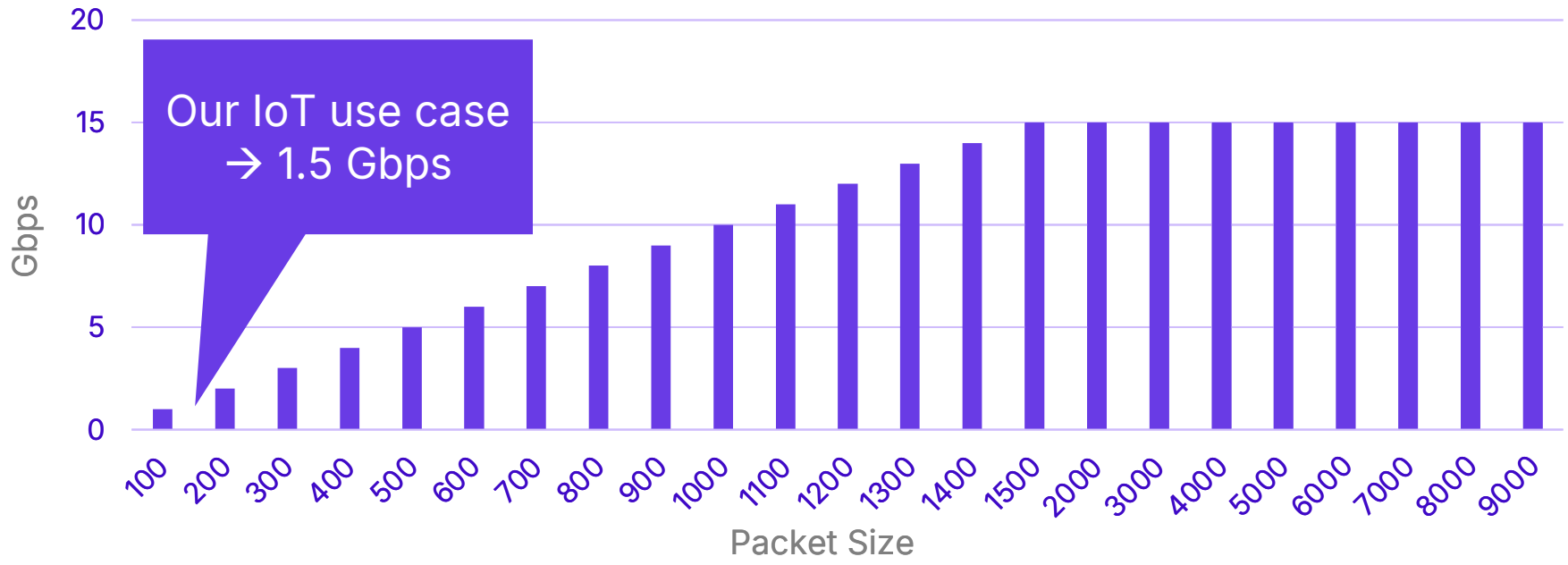
Compute-optimized + network-enhanced c7gn

Instance Size	vCPU	Memory (GiB)	Instance Storage (GB)	Network Bandwidth (Gbps)***	EBS Bandwidth (Gbps)
c7gn.medium	1	2	EBS-Only	Up to 25	Up to 10
c7gn.large	2	4	EBS-Only	Up to 30	Up to 10
c7gn.xlarge	4	8	EBS-Only	Up to 40	Up to 10
c7gn.2xlarge	8	16	EBS-Only	Up to 50	Up to 10
c7gn.4xlarge	16	32	EBS-Only	50	Up to 10
c7gn.8xlarge	32	64	EBS-Only	100	Up to 20
c7gn.12xlarge	48	96	EBS-Only	150	Up to 30
c7gn.16xlarge	64	128	EBS-Only	200	Up to 40
c7gn.metal	64	128	EBS-Only	200	Up to 40

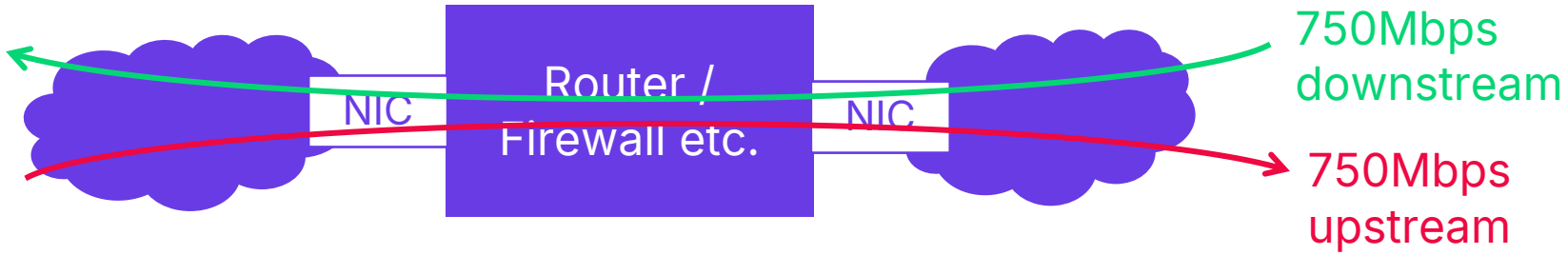
$1450/mo

Real 15 Gbps – or again “up to”?
Throughput Limits

- AWS limits throughput based on
  - Bandwidth (data rate): 15 Gbps regardless of packet size (default MTU is 9001 byte)
  - Packets per Second (PPS), i.e., rate of 1500 byte packets to reach 15 Gbps: 1.25Mpps



Network Functions
Throughput Limits



With a 15 Gbps instance, we can transfer bi-directional 750 Mbps - peak!

One Note...

Disclaimer

- We like working with AWS, it makes our life so much easier!
- But we want to share our journeys through sleepless nights etc.

Thanks to..

- Our colleagues, who went with us through this
- AWS account team and network specialists

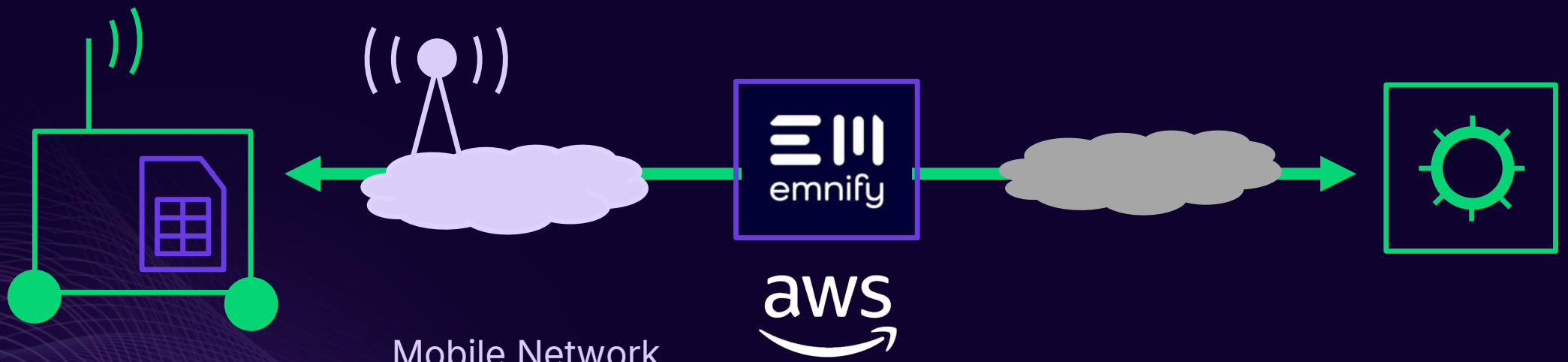
Limits are critical in multi-tenant environments – they protect (also us) from noisy neighbors!

emnify IoT SuperNetwork

- Cellular connectivity for the Internet of Things (IoT)
- Global IoT SIM card
- 🇩🇪 Headquartered in Germany
  🇪🇺 Engineering EU remote

- Deployed in 7 breakout regions
- IoT-specific security features
- Integration into customer networks

Why are AWS limits so relevant for us?



- Unpredictable traffic
- Customer pays for the traffic
- EC2 instance type economics

customer-owned | emnify-contracted | emnify-owned | nobody owns it

Burstable Instance Types (“up to X Gbps”) Throughput Limits

- Documentation is clear about baseline / burst bandwidth
- Credits-based mechanism
- On a best effort basis

Network specifications

Note

C8g instance types support configurable bandwidth weightings. With these instance types, you can optimize an instance's bandwidth for either networking performance or Amazon EBS performance. The following table shows the default networking bandwidth performance for these instance types. For the supported configurable weightings, see Configurable bandwidth weighting preferences.

Instance type	Baseline / Burst bandwidth (Gbps)	EFA	ENA	ENA Express	Network cards	Max. network interfaces	IP addresses per interface	IPv6
			C7g					
c7g.medium [1]	0.52 / 12.5	✗	✓	✗	1	2	4	✓
c7g.large [1]	0.937 / 12.5	✗	✓	✗	1	3	10	✓
c7g.xlarge [1]	1.876 / 12.5	✗	✓	✗	1	4	15	✓
c7g.2xlarge [1]	3.75 / 15.0	✗	✓	✗	1	4	15	✓
c7g.4xlarge [1]	7.5 / 15.0	✗	✓	✗	1	8	30	✓
c7g.8xlarge	15 Gigabit	✗	✓	✗	1	8	30	✓
c7g.12xlarge	22.5 Gigabit	✗	✓	✓	1	8	30	✓
c7g.16xlarge	30 Gigabit	✓	✓	✓	1	15	50	✓

Note

[1] These instances have a baseline bandwidth and can use a network I/O credit mechanism to burst beyond their baseline bandwidth on a best effort basis. Other instances types can sustain their maximum performance indefinitely. For more information, see instance network bandwidth.

For `32xlarge` and `metal` instance types that support 200 Gbps, at least 2 ENIs, each attached to a different network card, are required on the instance to achieve 200 Gbps throughput. Each ENI attached to a network card can achieve a max of 170 Gbps.

Monitoring
Throughput Limits

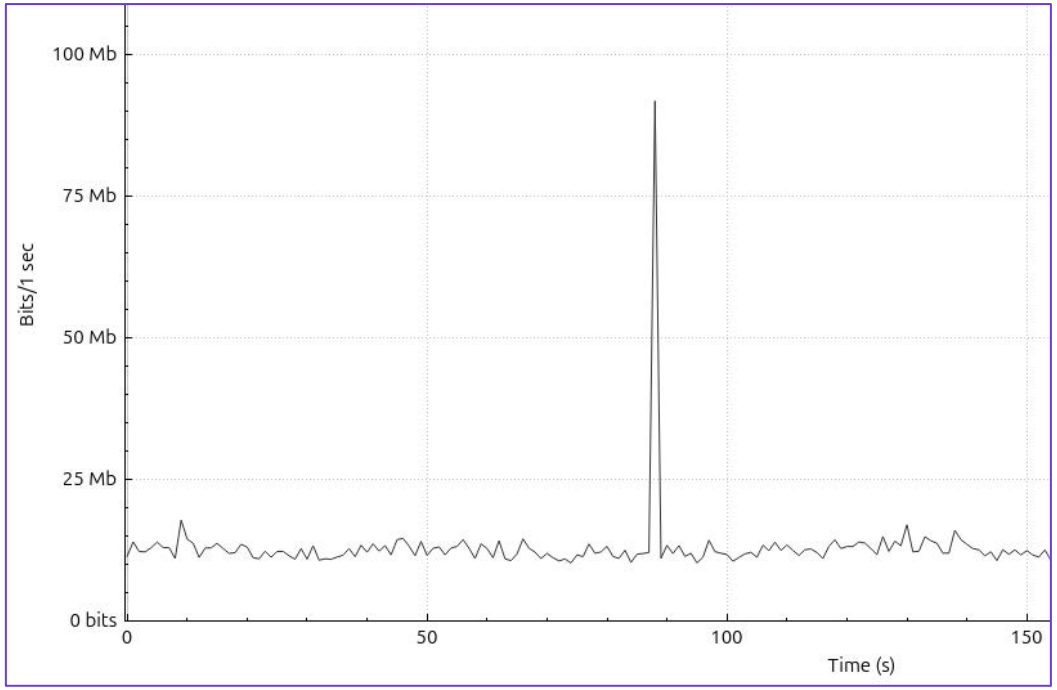
- Metrics
  - `bw_in_allowance_exceeded`
  - `bw_out_allowance_exceeded`
  - `pps_allowance_exceeded`
- Indicate queuing (and potential packet drops)

- ~~Amazon CloudWatch~~
- `ethtool -S ens5` to read from NIC driver (ENA)
  - CloudWatch Agent install + configuration
  - Prometheus *node_exporter*, with *ethtool* collector (disabled by default)
- Monitoring interval: Beware of bursts

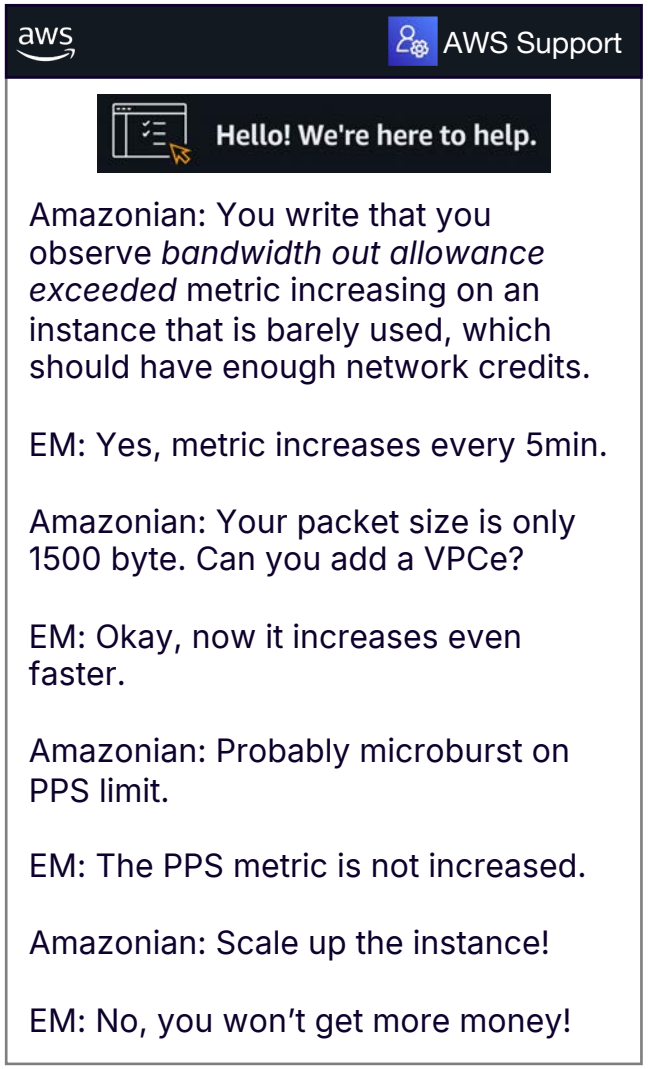
Microbursts
Throughput Limits

- Packet drops on a c6i.xlarge with very low traffic
  - Bandwidth utilization is 15 Mbps
  - `bw_out_allowance_exceeded` increases every 5 min
- File upload to S3 every 5 min
  - File size: 9 MB
  - Data transmit completes within 26 ms
  - → 9 MB/26 ms = 2.7 Gbps peak

Instance type	Baseline / Burst bandwidth (Gbps)
c6i.xlarge [1]	1.562 / 12.5



Microbursts
Throughput Limits



- Limits are implemented much more granular than per second.
- `bw_out_allowance_exceeded` does not always mean dropped packets, only enqueued.
- Make sure you monitor your application behavior.
- "Bandwidth is a shared resource"
  Instance burst is on a best effort basis, even when the instance has credits available, as burst bandwidth is a shared resource.

Countermeasures
Throughput Limits

Increasing Limits

- ~~Add more network interfaces?~~
- Change the instance type
  - Scale up! 💸
  - Use network-enhanced types 💸
  - Use newer generation (7th gen increased limits)
- EC2 instance bandwidth weighting: 25% more network capacity (requires. 8th gen instance)
- Use jumbo frames inside AWS or via DX

Avoid Microbursts

- AWS-CLI S3: `default.s3.max_bandwidth`
- SO_MAX_PACING_RATE socket option for own applications
- Limit bandwidth using `tc`
- Increase the Tx ring size with `ethtool`

https://repost.aws/knowledge-center/ec2-instance-exceeding-network-limits

Issues
Fragmented Packets

- `pps_allowance_exceeded` increased, while far away from the PPS limit

aws AWS Support

Hello! We're here to help.

Amazonian: You write that everything is fine but you have packet loss metrics increasing.

EM: Yes, totally.

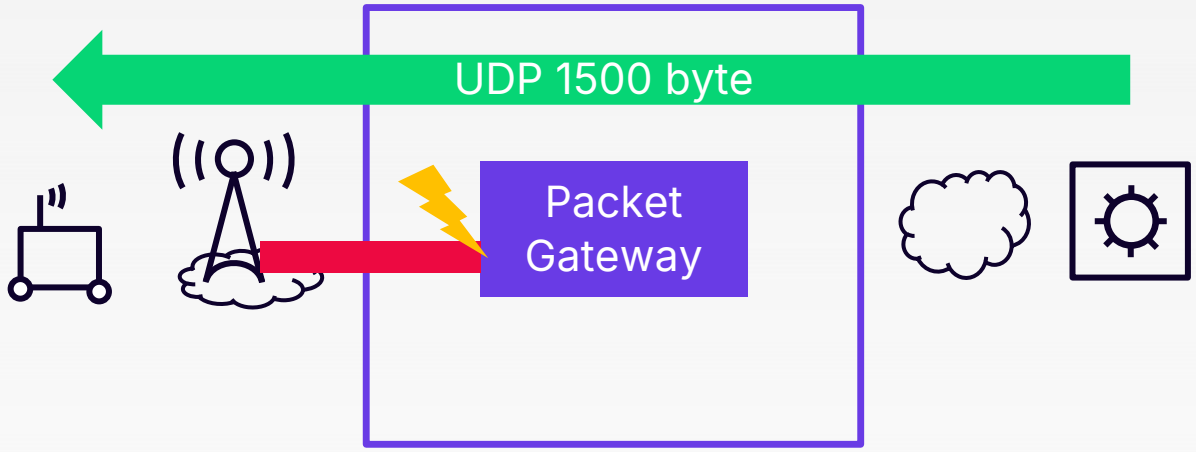
Amazonian: Fragmented packets?

EM: Oh, yes! How many can I?

Amazonian: Can't tell ya

EM: Hold my beer. Like 1000?

Amazonian: Exactly. And btw. you won't get more when you scale up.



https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ena-nitro-perf.html#ena-nitro-perf-exceptions

Understanding
Fragmented Packets

- Not using Nitro's hardware acceleration (fast path)

- Differs between
  - Ingress: Nitro standard rate (slow path)*
  - Egress: 1024 pps (intentionally slow path)

- Same limit (1024pps) as link-local traffic, but different bucket.

Application design considerations

There are aspects of application design and configuration that can affect your processing efficiency. The following list includes some important considerations.

Packet size

Larger packet sizes can increase throughput for the data that an instance can send and receive on the network. Amazon EC2 supports jumbo frames of 9001 bytes, however other services may enforce different limits. Smaller packet sizes can increase the packet process rate, but this can reduce the maximum achieved bandwidth when the number of packets exceed PPS allowances.

If the size of a packet exceeds the Maximum Transmission Unit (MTU) of a network hop, a router along the path might fragment it. The resulting packet fragments are considered exceptions, and are normally processed at the standard rate (not accelerated). This can cause variations in your performance. However, you can override the standard behavior for outbound fragmented packets with the fragment proxy mode setting. For more information, see Maximize network performance on your Nitro system. We recommended that you evaluate your topology when you configure MTU.

* UNDOCUMENTED LIMIT, BUT GROWS WITH INSTANCE SIZE

Monitoring
Fragmented Packets

- `pps_allowance_exceeded` increased, while far away from the PPS limit
- Running `tcpdump 'ip[6] = 32'`
- Ask AWS support!

Countermeasures
Fragmented Packets

Avoid Fragmentation

- Don’t fragment!
- VPN / encapsulation use cases
  - Lower MTU of tunnel interfaces: Fragment the inner packets (hide them from AWS)
  - Make sure path MTU discovery works
  - TCP MSS clamping

Increase Throughput

- Move fragmentation to TGW, if applicable
- Use ENA’s fragment bypass support (v2.13.3, released last week)
  - `enable_frag_bypass`
  - Increases egress throughput from 1024 pps to the “standard rate” (not accelerated)
  - Competes for Nitro CPU resources

https://github.com/amzn/amzn-drivers/blob/master/kernel/linux/ena/RELEASENOTES.md#r2133-release-notes

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Conntrack

CONNECTION TRACKING

Introduction
Connection Tracking

State of Connections

- Stateful firewall:
  - Allow the returning flow of a connection
  - Similar to NAT table, but slightly different
- In Linux, mostly using `iptables`

Source IP Address	Source Port	Destination IP Address	Destination Port	Protocol	State
1.2.3.4	54321	5.6.7.8	80	TCP	ESTABLISHED
1.2.3.5	54322	5.6.7.8	80	TCP	SYN_SENT
1.2.3.5	43210	6.7.8.9	123	UDP	SEEN_REPLY

Introduction
Connection Tracking

State of Connections

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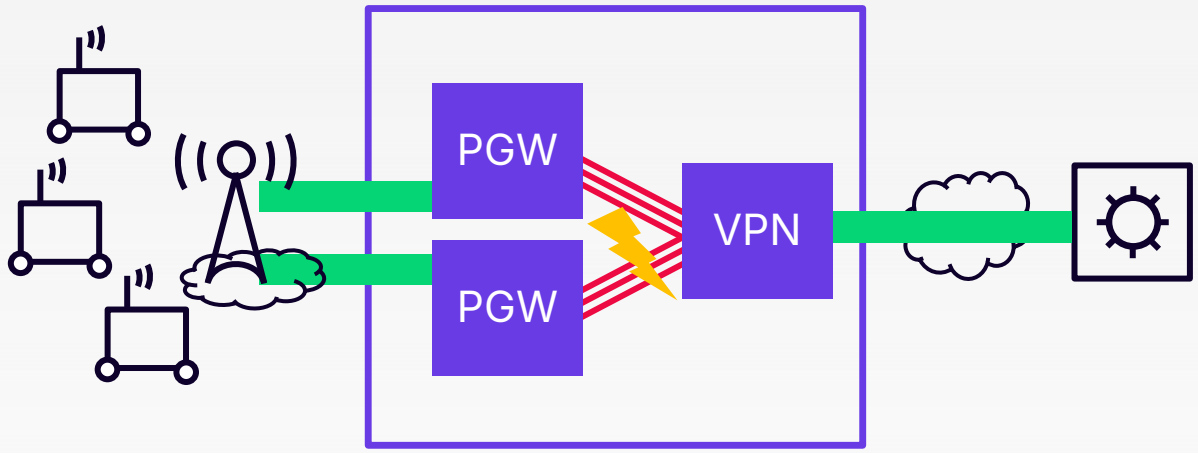
AWS

- Security groups: What makes them *stateful*
- Limited number of entries
  - Varies per EC2 instance type
  - No official documentation of limits

Consequences
Connection Tracking

- New TCP / UDP connections are blocked
  - Incoming connections might fail
  - DNS might (sometimes) not work
  - AWS SSM might (sometimes) not work



Monitoring
Connection Tracking

Capacity Exceeded

- `conntrack_allowance_exceeded`
- since 2021

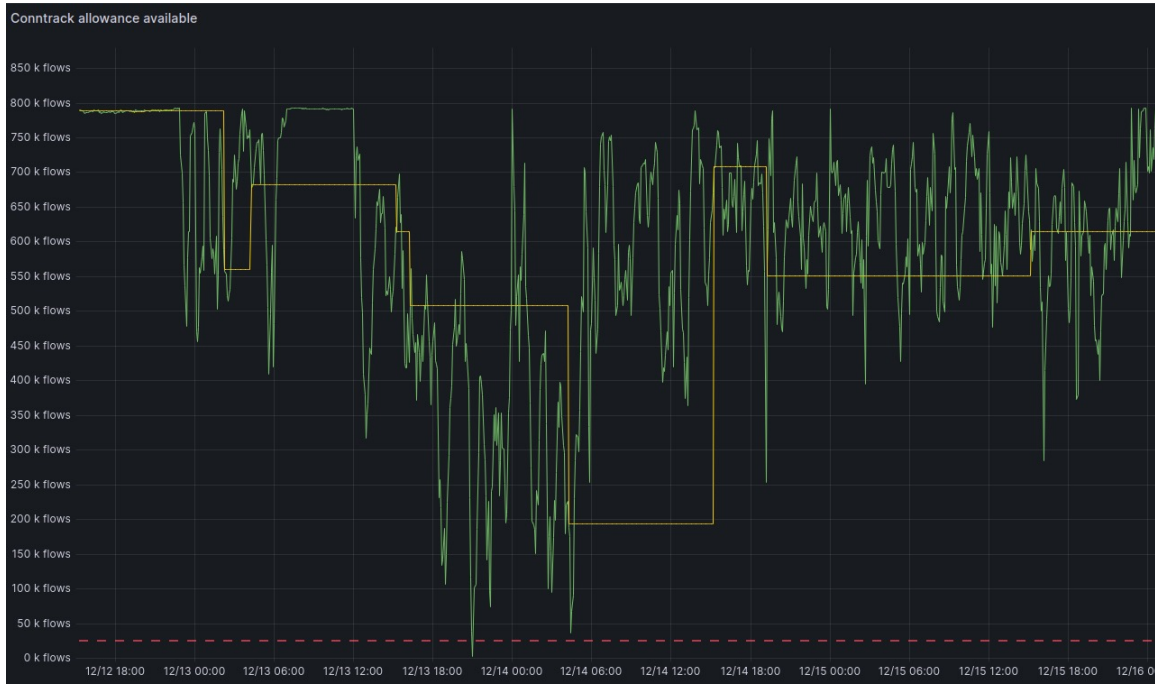
Remaining Capacity

- `conntrack_allowance_available`
- since Jan 2023

	c5	..n	c6g	..n	c7g	..n	c8g	..n
large	136k	136k	153k	153k	153k	205k	153k	N/A
xlarge	273k	273k	307k	307k	307k	410k	307k	N/A
			+12% compared to previous generation			+33%		?

Monitoring Challenges
Connection Tracking

- Requires young enough ENA driver version, not included in Ubuntu 24.04 LTS. We have own version compiled.
- Counters to be interpreted differently
  - *Exceeded* counter: refused connections per interface (use the *sum* of all interfaces)
  - *Available* counter: each interface shows the same value, the remaining for the EC2 instance (use *avg* or pick a single interface)
- Observed different values for the available counter on different interfaces – only 1st interface was up-to-date (bug #291, fixed)
- Flow logs can help, but setup is cumbersome



Countermeasures
Connection Tracking

Disable connection tracking

- Have a rule in the reverse direction allowing traffic from all IP addresses[1]:

Ingress Rules		Egress Rules	
Local Port	Source IP	Destination IP	Remote Port
80	0.0.0.0/0	0.0.0.0/0	*

- Network functions, imagine NAT instance

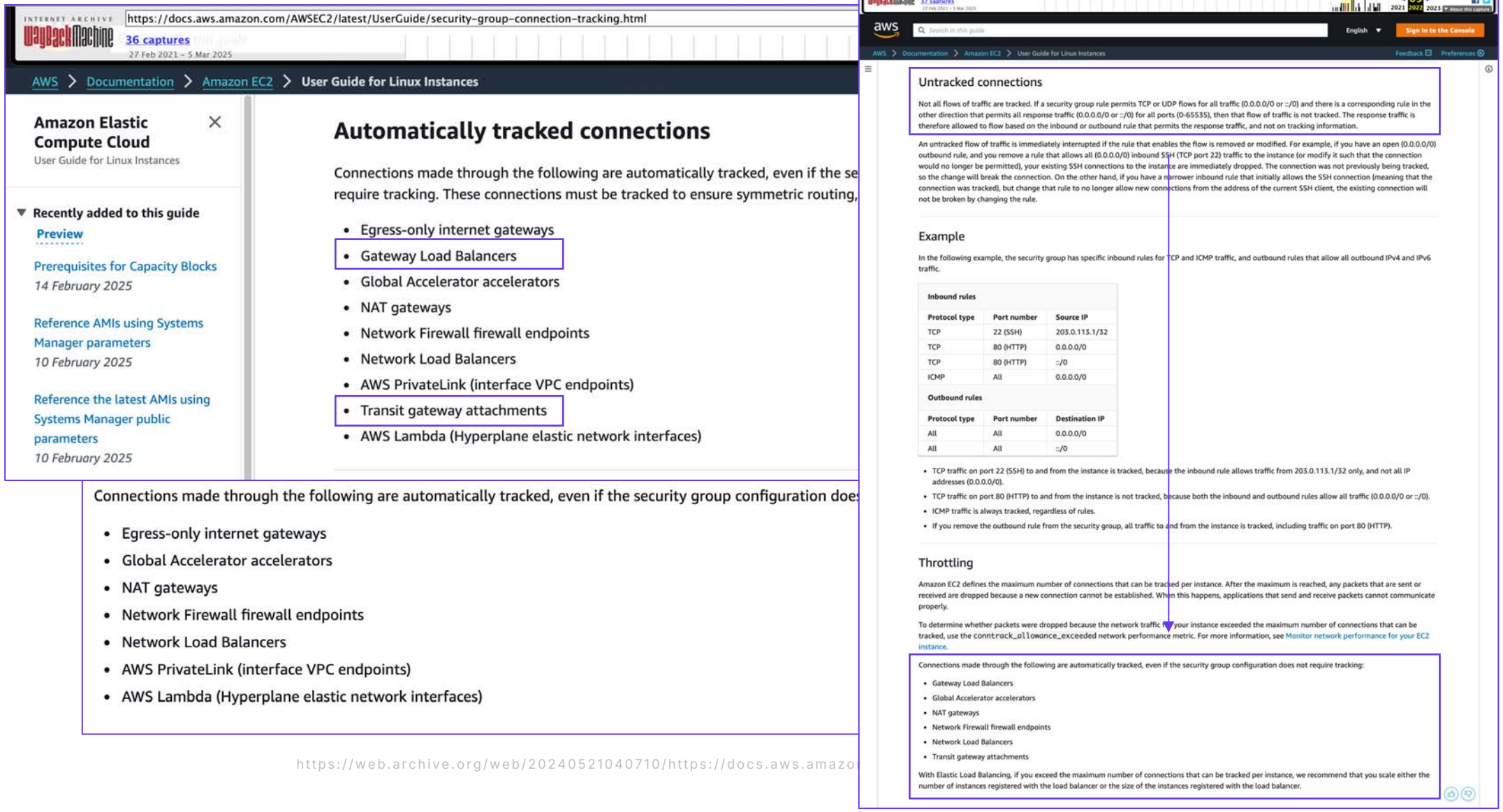
Ingress Rules		Egress Rules	
Local Port	Source IP	Destination IP	Remote Port
*	0.0.0.0/0	0.0.0.0/0	*

- **Beware of the security implications!**

1) EXCEPT "AUTOMATICALLY TRACKED"

https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/security-group-connection-tracking.html

Automatically Tracked Connections



Countermeasures
Connection Tracking

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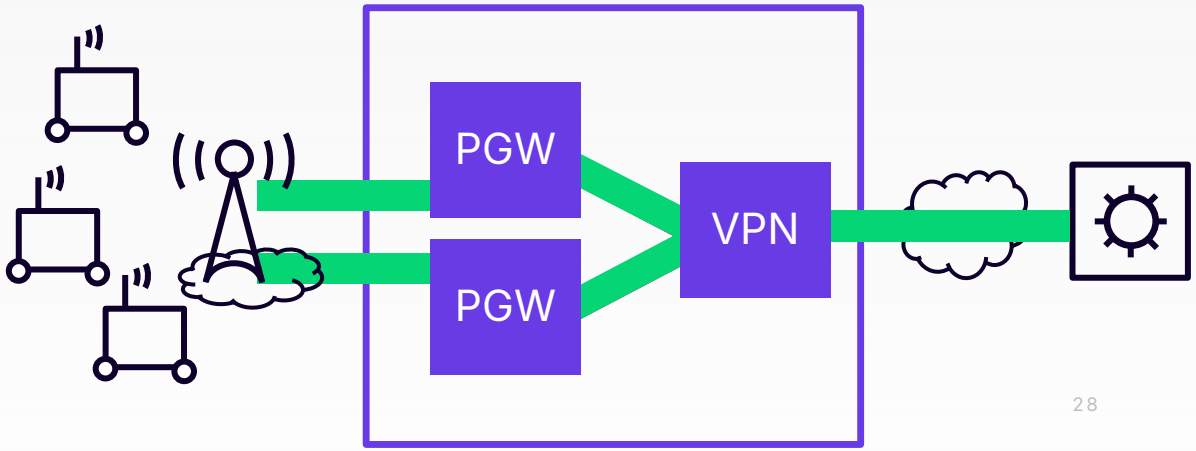
- **Beware of the security implications!**

Live with it

- Change EC2 instance
  - Scale up instance size, as it doubles 💸
  - Change instance type (cf. table before)
- Lower idle timers of network interface
- Lower cardinality (easier said than done)



Summary

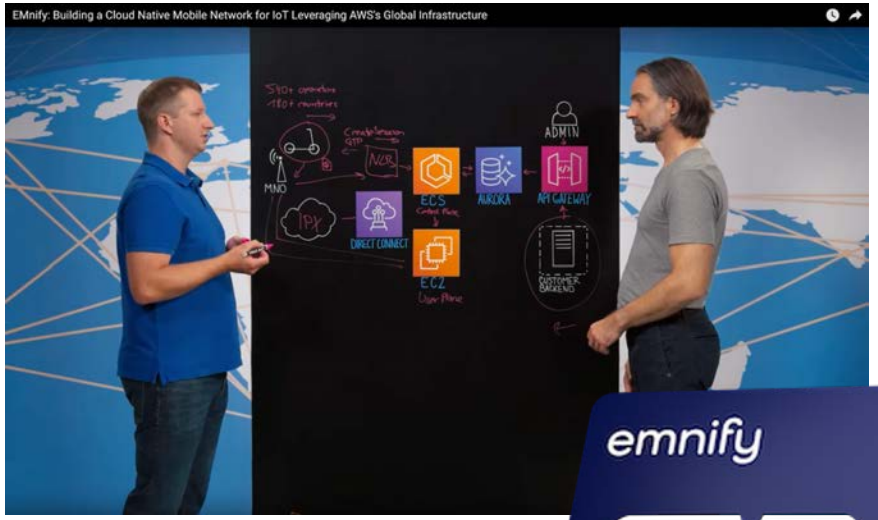
- The cloud has limits to protect from noisy neighbors
  - Often not clear, what the limits are
  - AWS documentation got a lot better (we should read it more often!)

- Monitoring capabilities are helpful
  - We can’t rescue every packet
  - Sometimes still a mystery

- Other clouds?

Resources

- This is My Architecture: emnify



- Evaluation SIM Cards

- AWS re:Invent 2024 - EC2 Nitro networking under the hood (NET402)
- EC2 User Guide – Instance network bandwidth
- AWS Blogs - Amazon EC2 instance-level network performance metrics uncover new insights
- AWS re:post - Why does my Amazon EC2 instance exceed its network limits when average utilization is low?