

P4EC: Enabling Terabit Edge Computing in Enterprise 4G LTE

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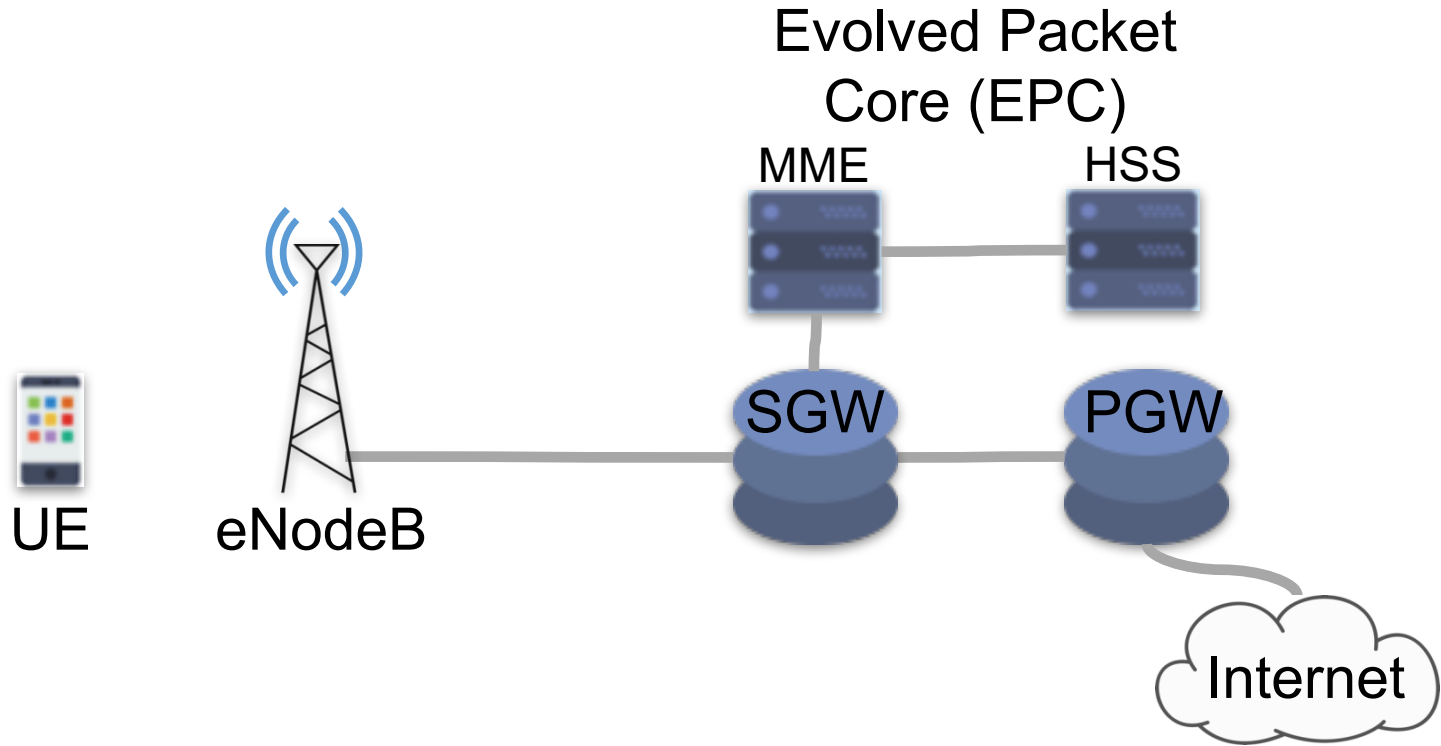
University of Colorado
Boulder

From Few MNOs to Many

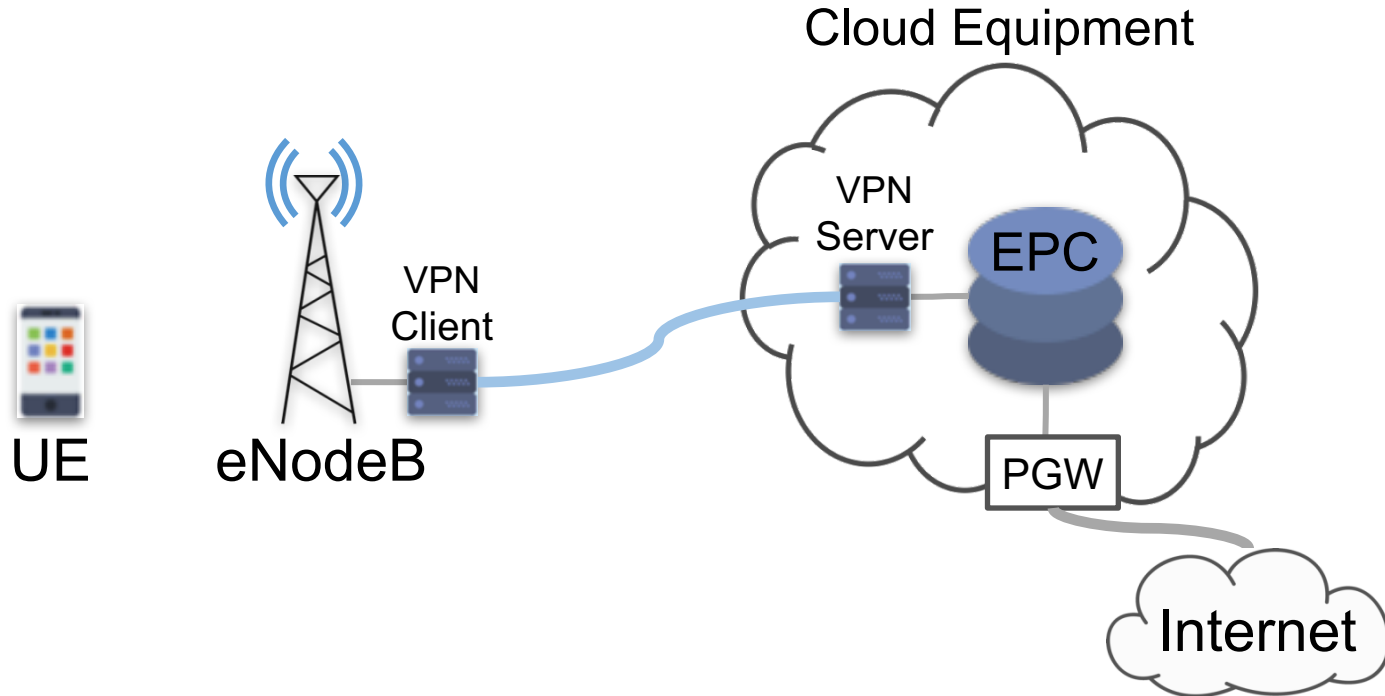
- 2012 FCC. “Amendment of the Commission’s Rules with Regard to Commercial Operations in the 3550-3650 MHz Band.”
- 2019 FCC. “WTB and OET Approve Initial Commercial Deployments in 3.5 GHz Band.”



LTE Network Structure



LTE Network Structure with Cloud-EPC

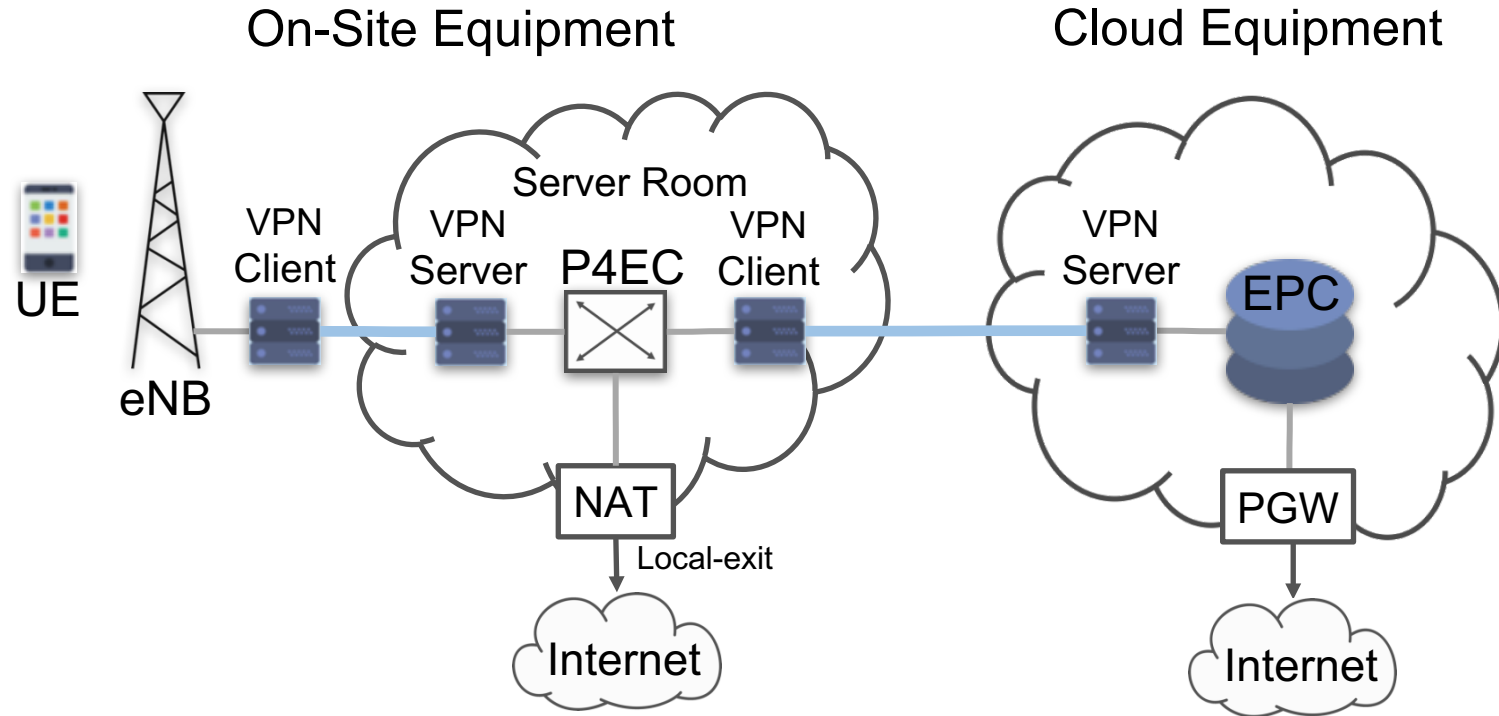


Time Sensitive Applications

- Wearable Cognitive Assistants
- Augmented Reality
- IoT Devices



Solution: P4EC “Local-exit”



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Stordis P4 Programmable Switch:

- Barefoot Tofino chipset.
- 100 GbE ports.
- Line-rate packet processing.
- 2.0 Tbps aggregate throughput.
- ~\$9,000 in cost.
- Handles traffic from over 7,300 eNBs.

Stordis BF2556x-1T



LTE Testbed

LTE Phones
in Shield Box



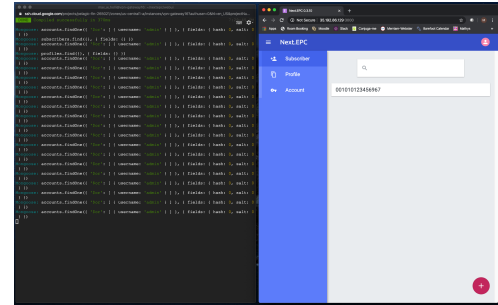
Client VPN and eNB



P4EC



Cloud-Based
Open-Source EPC



UEs
45.45.0.0/16

eNB
192.168.1.2

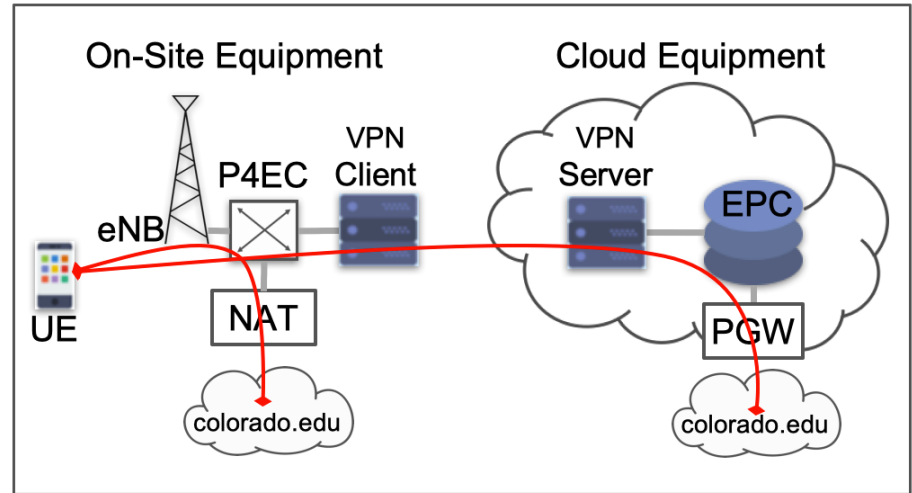
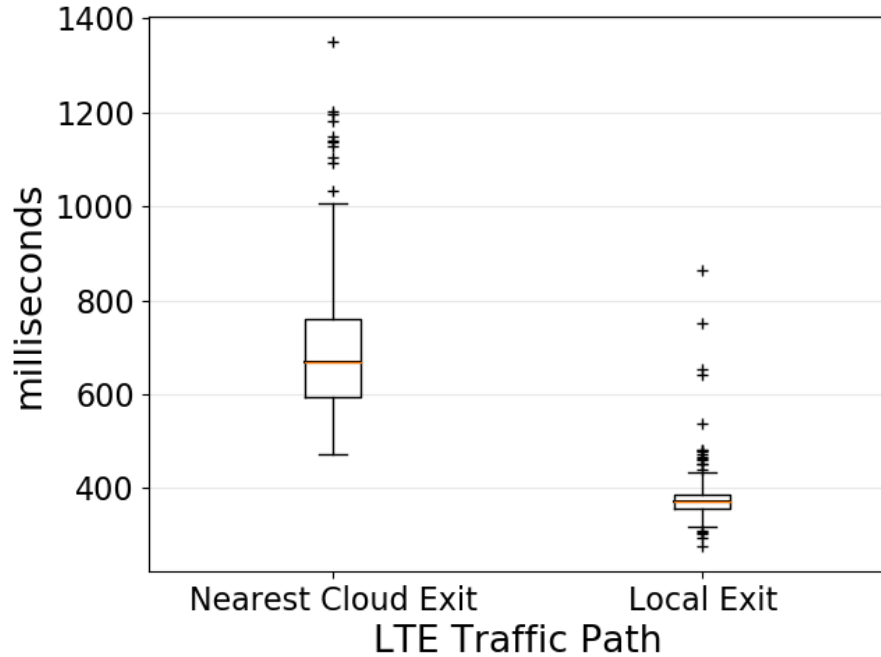
P4 Switch

EPC
192.168.1.254
45.45.0.1

Local-Exit

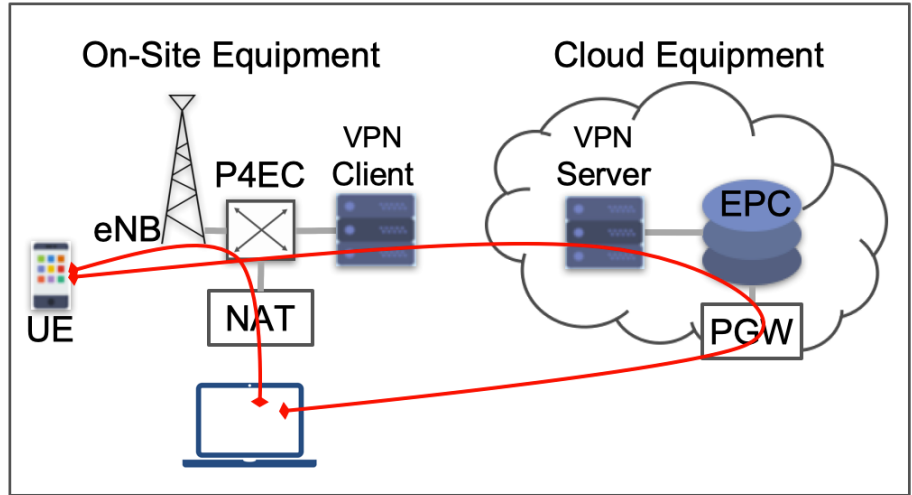
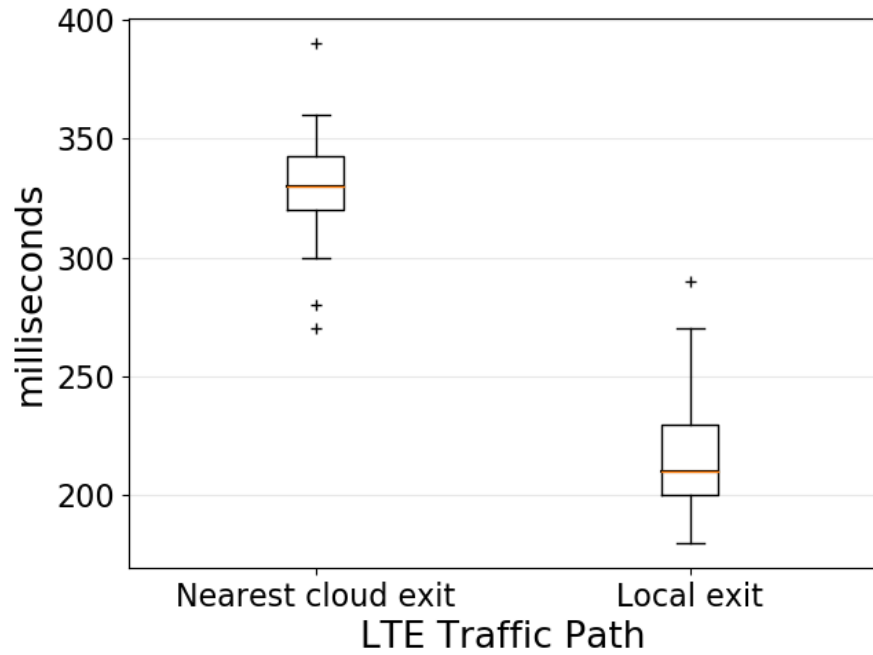
Results

Webpage Download Test Local Exit vs Cloud Exit



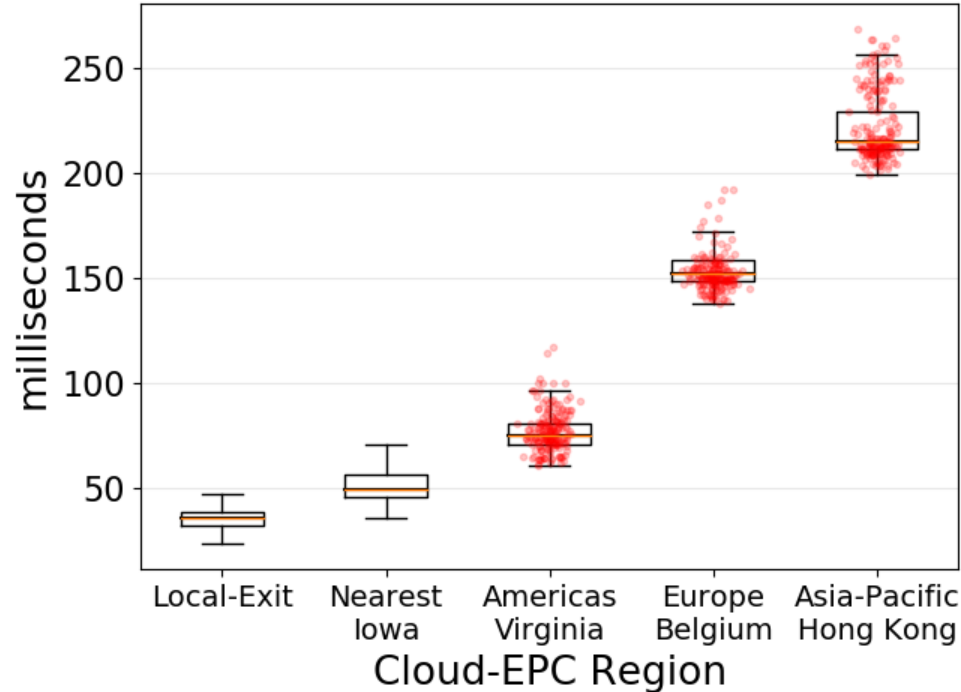
Results

Video Call End-to-end Delay Test Local Exit vs Cloud Exit



Results

Ping Round-Trip-Time
UE to the Gateway of increasingly distant datacenters



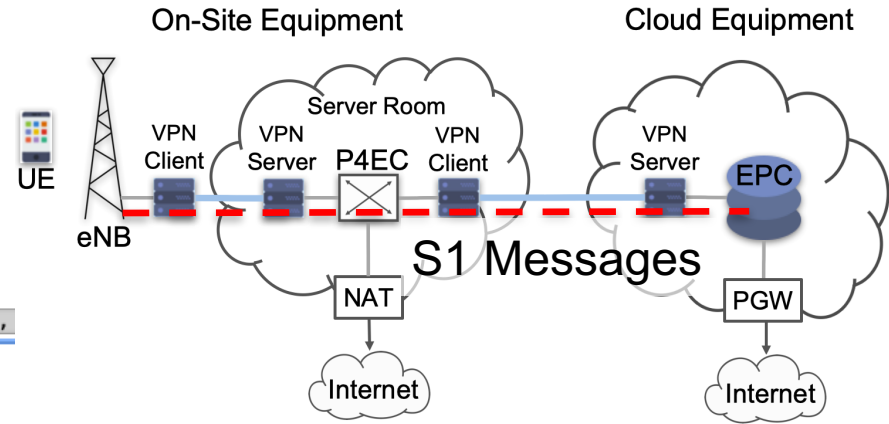
Identifying an Authorized UE

UE → EPC Attach Request Message

S1AP...	220	id-initialUEMessage, Attach request, PDN connectivity request
0000	58 8a 5a 14 6f 74 64 a8 37 26 01 99 08 00 45 a0	X.Z.otd. 7&....E.
0010	00 cc 3e 96 00 00 40 84 b6 27 c0 a8 01 02 c0 a8	...>...@. '.....
0020	01 fe 8e 3c 8e 3c 05 b6 fa 44 36 23 f4 3a 00 03	...<.<.. .D6#...:
0030	00 ab 78 2d ee 97 00 02 00 14 00 00 00 12 00 0c	...x-.....
0040	40 80 96 00 00 07 00 08 00 02 00 0e 00 1a 00 5e	@.....^
0050	5d 17 0a 34 1b 29 08 07 41 02 0b f6 00 f1 10 00	]..4.).. A.....
0060	02 01 f6 00 e4 8e 05 02 08	 p.@..'
0070	d0 11 d1 27 20 80 80 06 00	!
0080	00 00 00 83 06 00 00 00 00	
0090	05 00 00 10 00 52 00 f1 10 20 25 5c 00 00 31 02	

EPC → UE Attach Accept Message

S1AP...	452	SACK id-InitialContextSetup, InitialContextSetupRequest , Attach accept,
0000	64 a8 37 26 01 99 58 8a 5a 14 6f 74 08 00 45 02	d.7&..X. Z.ot..E.
0010	01 b4 32 25 40 00 40 84 82 4e c0 a8 01 fe c0 a8	..2%@.@. .N.....
0020	01 02 8e 3c 8e 3c 78 2d ee 70 f9 03 25 21 03 00	...<.<x- .p.%!..
0030	00 10 78 2d ee 98 00 01 a0 00 00 00 00 00 00 03	...x-.....
0040	01 82 a8 63 d1 8e 00 03 00 0e 00 00 00 12 00 09	...c.....
0050	00 81 6d 00 00 07 00 00 00 02 00 0e 00 08 00 02	...m.....
0060	00 0e 00 42 00 0a 18 00 00 00 00 00 00 00 00	...B...> ...>...
0070	00 18 00 69 00 00 34 00 00 00 00 00 00 00 00	...i..4. dE.
0080	a8 01 fe 00 00 00 05 00 00 00 00 00 00 00 00 00	U 'pe4B..B
0090	02 49 0a 02 00 f1 10 00 01 30 39 30 3a 00 39 52	.I..... .090:..9R
00a0	08 c1 01 09 09 08 69 00 00 00 00 00 00 00 00 00	in ternet..
00b0	2d 2d 00 04 27 22 80 00 00 00 00 00 00 00 00 00	...!.....



Content Redirection

Packet Inspected in 4 Places for Redirection

```

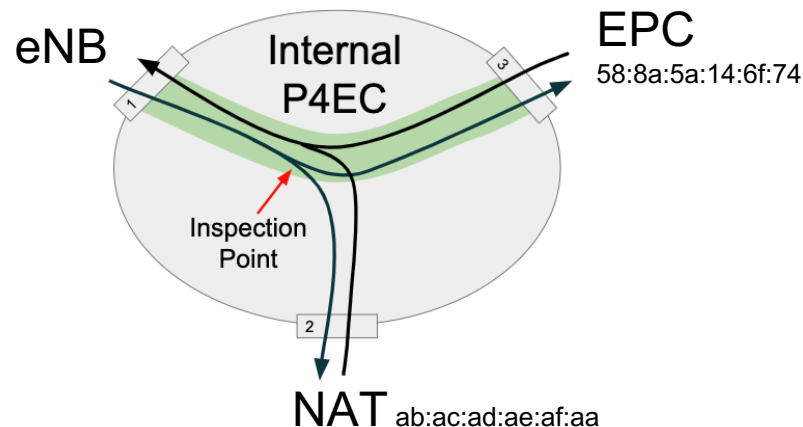
-----START PACKET:-----
MAX:: 1 proto ethernet(dst='58:8a:5a:14:6f:74',ethertype=2048,src='64:a8:37:26:01:99')
MAX:: 2 proto
MAX:: 3 proto udp(csum=46581,dst='192.168.1.2',flags=2,header_length=5,identification=0,offset=0,option=None,proto=17,src='192.168.1.2',tos=56,total_length=91)
MAX:: 4 proto gtp(ext_type=None,flags=0,msg_length=75,msg_type=255,npdu_num=None,proto_type=1,seq_num=None,tid=93,version=48)
MAX:: 5 proto
MAX:: 6 proto ipv4(csum=8520,dst='8.8.8.8',flags=2,header_length=5,identification=56328,offset=0,option=None,proto=17,src='45.45.0.21',tos=0,total_length=75,tid=93,version=48)
MAX:: 7 proto udp(dst_port=53,src_port=41630,total_length=55)
-----END-----
  
```

Labels in the packet dump:

- Dst. MAC**: 58:8a:5a:14:6f:74 (in the Ethernet header)
- UE's IP**: 45.45.0.21 (in the IPv4 header)
- Dst. IP**: 8.8.8.8 (in the UDP header)
- UDP Port**: 53 (in the UDP header)

P4EC Match Action Table Rule

MATCH	ACTION
IP_src=45.45.0.21 IP_dst=8.8.8.8 UDP_dst=53	ETH_dst=ab:ac:ad:ae:af:aa forward_port: 2



GTP Packet Encapsulation and Decapsulation

Encapsulate Header Modifications

Step 1	Step 2	Step 3
TCP/UDP	TCP/UDP	TCP/UDP
IP	IP inner	IP inner
ETH	New GTP	GTP Tunnel ID
	New UDP	UDP
	New IP	IP dst=eNB IP src=EPC IP
	ETH	ETH eNB mac

Decapsulate Header Modifications

Step 1	Step 2	Step 3
TCP/UDP	TCP/UDP	TCP/UDP
IP inner	IP inner	IP inner
GTP	GTP	ETH Edit dst mac
UDP	UDP	
IP	IP	
ETH	ETH	

Thank You

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