



OmniUPF



1. [5G](#)
2. [UPF](#)
3. [PFCP](#) [SMF](#)
4. [5G](#)
5. [5G](#)
6. [5G](#)
7. [5G](#)
8. [5G](#)



OmniUPF eBPF 5G/LTE QoS Linux eBPF OmniUPF 5G SA 5G NSA LTE

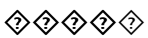


UPF 3GPP 5G LTE

- QoS
-
-
-
-
-

OmniUPF 3GPP TS 23.501 5G TS 23.401 LTE UPF Linux eBPF

OmniUPF



- 3GPP
- eBPF
- GTP-U GPRS
- IPv4 IPv6

- XDP eXpress
-

QoS

- QoS QER
- PDR
- FAR
- SDF
- URR

- PFCP SMF/PGW-C
- RESTful API
-
- eBPF
- Web

- eBPF
-
-
-
-

Web UI

OmniUPF 5G SA 5G NSA 4G LTE/EPC
OmniUPF

- UPF - 5G/NSA N4/PFCP OmniSMF
- PGW-U PDN - 4G EPC Sxc/PFCP
OmniPGW-C
- SGW-U - 4G EPC Sxb/PFCP OmniSGW-C

OmniUPF

- UPF 5G
- PGW-U + SGW-U 4G EPC
- UPF + PGW-U + SGW-U 4G 5G

eBPF PFCP UPF PGW-U
SGW-U

??
?? /map_info
?? /dataplane_config
??
?? API ? ? ? ? ? ? ? ? ? ? [PFCP](#) ? ? ? ? ? ? ? ?

Web ? ? ? ?

Web ? ? ? ? ? ? UPF ? ? ? ? ? ? ? ? ? ? ? ?

?? ?

- ? ? ? ? ? ? ? ? ? ? PFCP ? ? ? ? ? UE IP ? TEID ? ? ? ? ?
- ? PDR ? FAR ? QER ? URR
- ? FAR ? ? ?
- ? XDP ? N3/N6 ? ? ? ? ?
- ? ? ? ? ? ? eBPF ?
- ? ? ? ? ? ? ? ? UPF ? ? ? ? ? ? ? ? ? ?
- ?

?? ? ? ? ? ? UI ? ? ? ? ? ? ? [Web UI](#) ? ? ? ? ?

PFCP ? ? ? SMF ? ?

PFCP ? ?

?? ? ? ? ? ? ? SMF ? ? ? UPF ? ? PFCP ? ? ?

?? ? ? ? ? ? ?

?? ? ? ?

- ? ? SMF ? UPF ? ? ? ? ? ?
- UPF ? ? ? ? ID ? FQDN ? IP ? ? ? ? ? ? ? ?
- ? ? ? ? ? ? ? ? ? ? ? ? ? ?
- ?

?? ? ? ? ? ? ? ? ? ? ? ? ? ? ? [? ? ? ? ? ?](#)

PFCP ? ? ? ?

? UE ? ? PDU ? ? ? 5G ? ? PDP ? ? ? ? LTE ? ? ? SMF ? UPF ? ? ? PFCP ? ? ?

- PDR
- FAR
- QER
- URR
- SMF

OmniUPF Web REST API

PFCP

PFCP UE PDU 5G PDP LTE

- SEID
- PDR
- FAR
- QoS QER
- URR

- UE IP TEID
- IP TEID
- PDR/FAR/QER/URR
- PFCP

PDR

PDR

- PDR N3 TEID
- PDR UE IP IPv4 IPv6
- SDF
- PDR

FAR

FAR

- FAR

- 
-  **FAR** 
- 

QoS **QER**

QER 

- **QoS** MBR GBR
- **QER**
- **5G QoS** **QFI**

◆◆◆◆◆◆◆**URR**◆◆

URR 

- 
- 
-  **URR**

◆ ◆ ◆ ◆

◆◆◆◆◆ **UPF** ◆◆◆◆◆











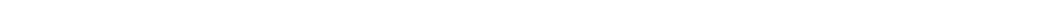








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- **TCP** 
-  Zoom  Teams  WhatsApp 
- 
- **VoIP** 
- 

OmniUPF

OmniUPF

OmniUPF

1. **eBPF** FAR
- 2.

- UDP 22152 eBPF
- FAR ID TEID GTP-U
- FAR ID
- - FAR 10,000
 - FAR 100,000
 - TTL 30 - TTL
- 60

1. SMF PFCP FAR BUFF=1 2
2. eBPF BUFF 22152
3. FAR ID
4. SMF FAR FORW=1 BUFF=0
5. FAR
- 6.

	1-2	
VoIP		
	SSH	

- CDR KPI

- `buffer_packet_ttl 10`
-

- **RX**
- **TX**
-
- **GTP-U**

-
-
- TEID UE IP

XDP

eXpress

- **XDP**
- **XDP**
- **XDP**
- **XDP**

N3/N6

- **N3 RX/TX** RAN gNB/eNodeB
- **N6 RX/TX**
-

eBPF

???

????????????????

?????

??PFCP ????UE ?????

?????

1. PFCP

- SMF ???? ???? UPF PFCP ???? 8805
- ???? PFCP
- ???? ID ???? SMF ? UPF

2. eBPF

- ????>90%?
- UPF eBPF
- ?????

3. PDR/FAR

- UE IP
- TEID
- FAR

4. ?

- N3 IP gNB
- ???? N6
- GTP-U

????? ?????

?????

??UE ?????

?????

1. PDR

- PDR TEID gNB TEID
- PDR UE IP IP
- SDF

2. FAR

- FAR
-
-

3. QoS

- QER MBR
- GBR
-

4. MTU

- GTP-U 40-50
- N3/N6 MTU
- ICMP

1.

- FAR 2
- SMF
-

2. TTL

-
- TTL
-

3.

- FAR
-
- FAR

???

????????????????

??????

1. ?????

- eBPF 64 ?????
- ?????
- ? URR ?????

2. ?????

- ???? eBPF ?????
- ???? eBPF ?
- ? XDP ?????

3. ?????

- ? N3/N6 ?????
- ???? eBPF ?????
- ???? XDP ?

???

??????CPU ??

???

1. ?? **XDP** ???? XDP ?????
2. ?? **eBPF** ?????
3. ?? **CPU** ????eBPF ?????
4. ???? ???? NIC ???? XDP ??

??????

- **XDP** ???? 10M+ ?????
- **PDR** ???? PDR ?????
- ???? UPF ?????
- ???? NIC ?????

?????? ????? ?

???

????

?? UPF ?

???

????

- ?YAML ?CLI ?
- ?UPF/PGW-U/SGW-U ?
- XDP ?
- ?Proxmox?VMware?KVM?Hyper-V?VirtualBox?
- NIC ? XDP ?
- ?
- ?

XDP ?

?? XDP ?

- XDP ?/?/?
- ?
- Proxmox VE ? XDP ?
- ?
- VMware ESXi?KVM ? Hyper-V XDP ?
- XDP ?
- ? XDP ?

???

????

- eBPF ?
- XDP ?
- PFCP ?
- ?GTP-U ? 22152?
- QoS ?5ms ?
- ?3.5μs ?10 Mpps/?

????

PFCP ?

- ?PDR? - ?
- ?FAR? - ?

- QoS 11111 QER1 - 11111 MBR/GBR1
- 11111111 URR1 - 11111111
- 1111111111
- 111111111111

11111

111111111111

- N3/N6 1111111111
- XDP 111111111/111/111/111
- eBPF 1111111111111111
- 1111111111111111111111111111
- 1111111111111111
- 1111111111111111

Web UI 11111

111111111111

- 1111111111
- 111111111/11111111
- 1111111 PDR1 FAR1 QER1 URR 1111111
- 11111111111111111111
- 1111111111
- eBPF 1111111111
- 111111

API 11

111 REST API 11111111

- OpenAPI/Swagger 11111
- PFCP 11111111
- 11111111 PDR1 - IPv4 1 IPv6
- 11111111 FAR1
- QoS 11111111 QER1
- 1111111111 URR1
- 11111111
- 111111111111
- 11111111 FRR 11
- eBPF 111111
- 111111
- 1111111111111111
- 11 API 1111111111

UE

FRR

- FRR
- UE
-
- OSPF BGP
- OSPF
- OSPF LSA
- BGP
- Web UI
-
- Mermaid

-
-
- PFCP
-
- XDP eBPF
-
- Proxmox VMware VirtualBox
- NIC
-

OmniUPF

- 1.
2. [Web UI](#)
- 3.

SGWU+PGWU N9

1. [N9](#) - SGWU+PGWU
2. [N9](#) - PFCP
3. [N9](#) -
4. [N9](#) -

◆◆◆◆

◆◆ API ◆◆

OmniUPF ◆◆ REST API ◆◆◆◆◆◆◆◆

```
# ◆◆◆◆◆
```

```
GET http://localhost:8080/api/v1/upf_status
```

```
# PFCP ◆◆
```

```
GET http://localhost:8080/api/v1/upf_pipeline
```

```
# ◆◆
```

```
GET http://localhost:8080/api/v1/sessions
```

```
# ◆◆
```

```
GET http://localhost:8080/api/v1/packet_stats
```

```
GET http://localhost:8080/api/v1/xdp_stats
```

```
# ◆◆◆◆
```

```
GET http://localhost:8080/api/v1/map_info
```

```
# ◆◆◆◆
```

```
GET http://localhost:8080/api/v1/upf_buffer_info
```

◆◆◆◆◆ API ◆◆◆◆◆◆◆◆ Swagger UI◆◆◆◆◆◆◆◆ http://<upf-ip>:8080/swagger/index.html

◆◆◆◆◆◆◆◆

```
# ◆◆◆◆◆
```

```
interface_name: [eth0]
```

```
xdp_attach_mode: native
```

```
n3_address: 10.100.50.233
```

```
pfcip_address: :8805
```

```
pfcip_node_id: 10.100.50.241
```

```
# N3/N6/N9 ◆◆◆◆◆
```

```
# generic|native|offload
```

```
# N3 ◆◆ IP
```

```
# PFCP ◆◆◆◆◆
```

```
# PFCP ◆◆ ID
```

```
# ◆◆
```

```
max_sessions: 100000
```

```
# ◆◆◆◆◆◆◆◆◆◆
```

```
# API ◆◆◆◆
```

```
api_address: :8080
```

```
metrics_address: :9090
```

```
# REST API ◆◆
```

```
# Prometheus ◆◆◆◆◆
```




OmniUPF



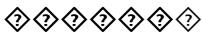
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3. [XDP !\[\]\(62c45eda4bc23efb369f0ef570de9340_img.jpg\) !\[\]\(9999676de84988a10f0d1ae0bb783cb4_img.jpg\)](#)
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5. [eBPF !\[\]\(62c345d2f169e4b7243454a5da758fd4_img.jpg\) !\[\]\(3951078b7853fa01b1487f537a7f7fc3_img.jpg\) !\[\]\(97d23387acdc534d82571a59b9548bff_img.jpg\)](#)
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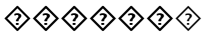
OmniUPF  eBPF                     XDP           5G/LTE  
          Linux           OmniUPF     
                  



-          
-            
-   XDP     



- eBPF     CPU   
-        
-     /   



- XDP     SmartNIC  
-     XDP  
-        

1. XDP

- eBPF SmartNIC
- NIC CPU
- 100 Gbps+
- SmartNIC Netronome Mellanox ConnectX-6

`xdp_attach_mode: offload`

- SmartNIC
- eBPF
- eBPF

2. XDP

- eBPF
- SKB
- 10-40 Gbps
- XDP

`xdp_attach_mode: native`

-
-
- eBPF

- Intel: i40e, ice, ixgbe, igb
 - Mellanox: mlx4, mlx5
 - Broadcom: bnxt
 - Amazon: ena
 - 10G+
-

3. XDP

- eBPF SKB
- XDP
-
-

xdp_attach_mode: generic

-
- SR-IOV
-
-

1-5 Gbps/

XDP

eBPF XDP

			OmniUPF
XDP_PASS			ICMP
XDP_DROP			
XDP_TX			
XDP_REDIRECT			N3 ↔ N6
XDP_ABORTED		eBPF	

OmniUPF eBPF

- eBPF eBPF
-
-
- 33


```
orig_packet_len = ntohs(ip->tot_len); // ?? IP ?
```

2. ? ? ? ? ? ? ?

```
// ? ? ? ? IP + UDP + GTP-U ? ? ? ?  
gtp_encap_size = sizeof(struct iphdr) + sizeof(struct udphdr) +  
sizeof(struct gtpuhdr);  
bpf_xdp_adjust_head(ctx, -gtp_encap_size);
```

3. ? ? ? ? IP ? ?

```
ip->saddr = original_sender_ip; // ? ? ? ? ? ? ? ? ? ?  
ip->daddr = local_upf_ip; // ? ? ? ? ? ? ? ? ? ? ? ? IP  
ip->protocol = IPPROTO_UDP;  
ip->ttl = 64;
```

4. ? ? UDP ? ?

```
udp->source = htons(22152); // BUFFER_UDP_PORT  
udp->dest = htons(22152);  
udp->len = htons(sizeof(udphdr) + sizeof(gtpuhdr) +  
orig_packet_len);
```

5. ? ? GTP-U ? ?

```
gtp->version = 1;  
gtp->message_type = GTPU_G_PDU;  
gtp->teid = htonl(far_id | (direction << 24)); // ? ? FAR ID ?  
? ?  
gtp->message_length = htons(orig_packet_len);
```

6. ? ? XDP_PASS ?

- ? ? ? ? ? ? ? ? ? ? UDP ? ? ? ? ? ? 22152
- ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

? ? ? ? ? ? ?

? ? ? ? ? ? SMF ? ? FAR ? ? ? BUFFER ? ? ? ? ? ? ? ? ? ? ? ?

? ? ? ? ? ? ?

	? ?	? ? ?		? ?
? FAR	? ? 10,000	? ? ?	? ? FAR	? ? ? ? ? ? ? ? ? ?
? ? ?	100,000	? ? ?	? ? ? ? ? ? ? ? ? ?	
? ? ? TTL	30	?	? ? ? ? ? ? ? ? ? ?	
? ? ? ?	22152		? ? ? ? ? ? ? UDP	? ?
? ? ? ? ? ?	60	?	? ? ? ? ? ? ? ? ? ?	

QoS

OmniUPF QoS

qer.h

```
static __always_inline enum xdp_action limit_rate_sliding_window(
    const __u64 packet_size,
    volatile __u64 *window_start,
    const __u64 rate)
{
    static const __u64 NSEC_PER_SEC = 1000000000ULL;
    static const __u64 window_size = 5000000ULL; // 5ms

    // = 0
    if (rate == 0)
        return XDP_PASS;

    //
    __u64 tx_time = packet_size * 8 * (NSEC_PER_SEC / rate);
    __u64 now = bpf_ktime_get_ns();

    //
    __u64 start = *window_start;
    if (start + tx_time > now)
        return XDP_DROP; //

    //
    if (start + window_size < now) {
        *window_start = now - window_size + tx_time;
        return XDP_PASS;
    }

    //
    *window_start = start + tx_time;
    return XDP_PASS;
}
```

- 5ms 5,000,000
-
-
- **MBR = 0**

QoS

MBR = 100 Mbps = 1500

1.

```
tx_time = 1500 * 8 / 1000000000 * (1000000000 ns/sec ÷ 100000000 bps)
tx_time = 1500 * 8 * 10 = 120000 ns = 120 µs
```

2.

- t=0 t=120µs
- t=100µs
- t=150µs

3.

```
Max PPS = (100 Mbps ÷ 8) ÷ 1500 = 8333 / 120 µs
```

XDP	SmartNIC	100 Gbps	148 Mpps	< 1 µs
XDP	10G NIC	10 Gbps	8 Mpps	2-5 µs
XDP	10G NIC	40 Gbps	32 Mpps	2-5 µs
XDP		1-5 Gbps	0.8-4 Mpps	50-100 µs

XDP

NIC RX	0.5 µs	0.5 µs
XDP	0.1 µs	0.6 µs
PDR	0.3 µs	0.9 µs
QER	0.1 µs	1.0 µs
FAR	0.5 µs	1.5 µs
URR	0.2 µs	1.7 µs
GTP-U	0.8 µs	2.5 µs
XDP_REDIRECT	0.5 µs	3.0 µs
NIC TX	0.5 µs	3.5 µs

~3.5 μs XDP 10G NIC

CPU

- 8-10 Mpps XDP
- 12-15 Mpps
- 8

CPU

CPU % ≈ (/ 10,000,000) × 100%

2 Mpps ~20%

eBPF

- ~100 ns
- ~300 ns
- ~50 ns

= × (+ × 64)

10 Mpps × (1500 B + 3 × 64 B) ≈ 160 Gbps

UPF

- SMF UPF
- UPF UE
- UPF

CPU

1. XDP CPU

- [illegible]

NIC

- [illegible]

◆ ◆ ◆ ◆ ◆

```
#   eBPF         
ulimit -l unlimited
```

```
#   IRQ      XDP    
systemctl stop irqbalance
```

```
# CPU
cpupower frequency-set -g performance
```

```
# 1 2 3 4 5 6 7 8 9
sysctl -w net.core.rmem_max=134217728
sysctl -w net.core.wmem_max=134217728
```

◆ ◆ ◆ ◆

◆ ◆ ◆

$$\begin{aligned} \text{CPU} &= (\text{PPS} \div 10,000,000) \times 1.5 \quad (50\%) \\ \text{ } &= (\text{ } \times 212 \text{ B} \times 3) + 100 \text{ MB} \quad (\text{eBPF} + \text{ }) \\ \text{ } &= (\text{ } \times 2) + 10 \text{ Gbps} \quad (\end{aligned}$$

◆◆◆100 ◆◆◆◆20 Gbps ◆◆◆◆

- CPU: $(20 \text{ Gbps} \div 10 \text{ Gbps } \diamond\diamond\diamond) \times 1.5 = 3\text{-}4 \diamond$
- $\diamond\diamond$: $(1\text{M} \times 212 \text{ B} \times 3) + 100 \text{ MB} \approx 750 \text{ MB}$
- $\diamond\diamond$: $(20 \text{ Gbps} \times 2) + 10 \text{ Gbps} = 50 \text{ Gbps } \diamond\diamond$






- UPF $\diamond \diamond \diamond \diamond$ - $\diamond \diamond$ UPF $\diamond \diamond \diamond \diamond \diamond$
- $\diamond \diamond \diamond \diamond \diamond \diamond$ - PDR $\diamond$ FAR $\diamond$ QER $\diamond$ URR $\diamond \diamond \diamond \diamond$
- $\diamond \diamond \diamond \diamond \diamond$ - $\diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- Web UI $\diamond \diamond \diamond \diamond \diamond$ - $\diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond \diamond \diamond \diamond \diamond \diamond \diamond$ - $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$



OmniUPF



- 1. [!\[\]\(63750d57d3fbc43ebce98f4204e5b61a_img.jpg\)!\[\]\(05f52e575df6ce4b53c1ac1f72964ddc_img.jpg\)](#)
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- 5. [!\[\]\(d90a16c1c8384fd3f341aa4ae137d0d6_img.jpg\)!\[\]\(4baa5f2224ca00303f3345d3b4907223_img.jpg\)!\[\]\(c8dc240c558485bea612eb8c00818da6_img.jpg\)!\[\]\(79820902a41764525b75b25db78910ba_img.jpg\)](#)
- 6. [!\[\]\(263b880bb926f6c87ad91fa1110019bd_img.jpg\)!\[\]\(1815b1d93e8a9684c336eadba868b213_img.jpg\)!\[\]\(55a102dc09a170fb05808f65026f5a10_img.jpg\)!\[\]\(edb7dbb68e6344e6aefc2d9a960f40b1_img.jpg\)!\[\]\(467a9d6933d6e4a6c48f232a00b47fe1_img.jpg\)!\[\]\(46c993f98490b253aa53b0d60b953a05_img.jpg\)!\[\]\(223631446d2e41036016cda321e05b7a_img.jpg\)!\[\]\(6a160937f80c9c2204f4c91353587168_img.jpg\)!\[\]\(4f6be8785a49afe03ae754cabc2d4503_img.jpg\)!\[\]\(896c0d51aa5ef4899bbe485f54e56c85_img.jpg\)](#)
- 7. [!\[\]\(5eec84fb241c72d061043573990077ae_img.jpg\)!\[\]\(1223a2b2e0f636aba45b21b9b2dfa22f_img.jpg\)!\[\]\(49fad15f5a9044756a5631d6345fcc3f_img.jpg\)!\[\]\(a43bf76f24816cfaec8f8db4a7cb2f7b_img.jpg\)!\[\]\(3f1ae2696bda24664743624df1ad0049_img.jpg\)](#)
- 8. [!\[\]\(b22b8f427e440e2435474cfabaeabe4f_img.jpg\)!\[\]\(8fdbb6d408d46d339eb70a3cf1fddcd5_img.jpg\)!\[\]\(c2dfdc6dcc6b7f80c5edaf24d689888b_img.jpg\)!\[\]\(9d8c51b71f1504259148ec43867b339b_img.jpg\)](#)
- 9. [!\[\]\(2ea017d11ee2d41ef8960d1566d21ca6_img.jpg\)!\[\]\(96f41dd9753ae034a38bef00950015c4_img.jpg\)!\[\]\(b8ba1635ff037d2a1ad6fd98b1c238f8_img.jpg\)!\[\]\(3d8e2692102845824079271e0f66371d_img.jpg\)!\[\]\(cf1e37cb0ad43190e8eef3b3d166d4ed_img.jpg\)!\[\]\(4fdff05b5fb1de40c0f3a0e74d0217d7_img.jpg\)!\[\]\(a46181d07efa8d2ec8f6538e5c26ba80_img.jpg\)!\[\]\(2f24284b1b80e9015ac197c45c9cbf3b_img.jpg\)!\[\]\(fcd73f38a7b8716dcd274316bc48aa6e_img.jpg\)!\[\]\(b494bb22345d06e6b5dda9bb082ad6f6_img.jpg\)](#)



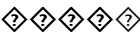
OmniUPF  4G (EPC)  5G 
 YAML 



OmniUPF  



  (SMFPGW-C  SGW-C)  OmniUPF  PFCP 
 OmniUPF 



- OmniUPF  PFCP 
-  OmniUPF  UPFPGW-U  SGW-U
- 

XDP

OmniUPF  XDP (eXpress Data Path) 

- 100G (~5-10 Mpps 100G)
- 100G 100G 100G 100G 100G
- 100G 100G 100G 100G
- 100G 100G SR-IOV 100G

100G

- 100G XDP 100G 100G
- 100G 100G 100G/100G 100G 100G XDP

100G

`xdp_attach_mode: native`

100G 100G

- 100G 100G 100G 100G
- 100G SR-IOV 100G 100G 100G
- 100G 100G XDP 100G 100G (100G Intel 100G Mellanox 100G)

100G

- 100G XDP 100G 100G 100G (100G 100G 100G 100G)
- Linux 100G 5.15+ 100G 100G XDP 100G

100G (100G 100G)

100G XDP 100G 100G SmartNIC 100G 100G

100G

- 100G (~10-40 Mpps)
- 100G 100G CPU 100G 100G
- 100G 100G
- 100G CPU 100G 100G 100G 100G

100G

- 100G 100G SmartNIC 100G
- SmartNIC 100G 100G
- 100G 100G 100G

100G

`xdp_attach_mode: offload`

100G 100G

- 323232323232
- 3232323232323232
- CPU 32323232

323

- 32 XDP 323 SmartNIC (Netronome Agilio CX3 Mellanox BlueField)
- 323232323232

32323232

32323232

32	32	32	32
interface_name	N3/N6/N9 323232323232 (XDP 323)	32 [lo]	32
n3_address	N3 323 IPv4 32 (32 RAN 3 GTP-U)	IP	127.0.0.1
n9_address	N9 323 IPv4 32 (UPF 3 UPF 3 ULCL)	IP	3 n3_address 32

32323

```
interface_name: [eth0, eth1]
n3_address: 10.100.50.233
n9_address: 10.100.50.234
```

PFCP 32

32	32	32	32
pfcip_address	PFCP 323232323232 (N4/Sxb/Sxc 323)	32:	32 :8805
pfcip_node_id	PFCP 323232323232 ID	IP	127.0.0.1
pfcip_remote_node	323232323232 PFCP 323 (SMF/PGW-C/SGW-C)	32	[]
association_setup_timeout	3232323232323232 (32)	32	5
heartbeat_retries	323232323232323232323232323232323232	32	3
heartbeat_interval	PFCP 323232 (32)	32	5
heartbeat_timeout	PFCP 323232 (32)	32	5

32323

```
pfcip_address: :8805
pfcip_node_id: 10.100.50.241
pfcip_remote_node:
- 10.100.50.10 # OmniSMF
- 10.100.60.20 # OmniPGW-C
```

heartbeat_interval: 10
heartbeat_retries: 5

API

api_address REST API :8080
metrics_address Prometheus :9090
logging_level (trace, debug, info, warn, error) info

api_address: :8080
metrics_address: :9090
logging_level: debug

GTP

gtp_peer GTP []
gtp_echo_interval GTP () 10

gtp_peer:
- 10.100.50.50:2152 # gNB
- 10.100.50.60:2152 # N9 UPF
gtp_echo_interval: 15

eBPF

max_sessions 65535
pdr_map_size PDR eBPF 0 max_sessions × 2
far_map_size FAR eBPF 0 max_sessions × 2
qer_map_size QER eBPF 0 max_sessions
urr_map_size URR eBPF 0 max_sessions × 2
0 () max_sessions

max_sessions: 100000

2222222222

PDR: 200,000 22

FAR: 200,000 22

QER: 100,000 22

URR: 200,000 22

22222222

max_sessions: 50000

pdr_map_size: 131070 # 222222

far_map_size: 131070

qer_map_size: 65535

urr_map_size: 131070

22222

22	22	22	22
buffer_port	22 eBPF 22222222 UDP 22	22	22 22152
buffer_max_packets	22 FAR 2222222222	22	22 10000
buffer_max_total	2222222222 (0=2222)	22	22 100000
buffer_packet_ttl	22222222 TTL2222 (0=2222)	22	22 30
buffer_cleanup_interval	2222222222 (0=2222)	22	22 60

222

buffer_port: 22152

buffer_max_packets: 20000

buffer_max_total: 200000

buffer_packet_ttl: 60

buffer_cleanup_interval: 30

2222

22	22	22	22
feature_ueip	22 OmniUPF 22 UE IP 22	222	22 false
ueip_pool	UE IP 222 IP 22 (22 feature_ueip)	CIDR10.60.0.0/24	
feature_ftup	22 OmniUPF 22 F-TEID 22	222	22 false
teid_pool	F-TEID 222 TEID 2222 (22 feature_ftup)	22	22 65535

22 (UE IP 22)2

feature_ueip: true

ueip_pool: 10.45.0.0/16 # 22222222 UE IP

❖❖ (F-TEID ❖❖)❖

```
feature_ftup: true
teid_pool: 1000000 # ❖❖❖❖ 1M TEID ❖❖
```

❖❖❖❖

YAML ❖❖❖❖ (❖❖)

❖❖: config.yml

```
# ❖❖❖❖
interface_name: [eth0]
n3_address: 10.100.50.233
n9_address: 10.100.50.233
xdp_attach_mode: native

# PFCP ❖❖
pfcf_address: :8805
pfcf_node_id: 10.100.50.241
pfcf_remote_node:
  - 10.100.50.10

# API ❖❖❖
api_address: :8080
metrics_address: :9090
logging_level: info

# ❖❖
max_sessions: 100000

# GTP ❖❖❖
gtp_peer:
  - 10.100.50.50:2152
gtp_echo_interval: 10

# ❖❖
feature_ueip: true
ueip_pool: 10.45.0.0/16
feature_ftup: false

# ❖❖
buffer_max_packets: 15000
buffer_packet_ttl: 45
```

❖❖ OmniUPF❖

- 5~10 Mpps

3

- SR-IOV (Intel X710 Mellanox ConnectX-5)
- BIOS SR-IOV
- IOMMU (intel_iommu=on amd_iommu=on GRUB)

Proxmox SR-IOV

```
# GRUB
nano /etc/default/grub

# GRUB_CMDLINE_LINUX_DEFAULT:
intel_iommu=on iommu=pt

# GRUB
update-grub
reboot

# VFs (eth0 4 )
echo 4 > /sys/class/net/eth0/device/sriov_numvfs

#
echo "echo 4 > /sys/class/net/eth0/device/sriov_numvfs" >> /etc/rc.local
chmod +x /etc/rc.local
```

Proxmox

```
 → → PCI
SR-IOV
GPU
PCI-Express ( )
```

OmniUPF

```
interface_name: [ens1f0] # SR-IOV VF
xdp_attach_mode: native
```

3. PCI (XDP)

- 10000000000000000000
- XDP native offload (SmartNIC)
- ~5-40 Mpps (1000000)

Proxmox 111111

```
11 → 11 → PCI 11
11111111 (11100000:01:00.0)
11111111
11 GPU11
PCI-Express11
```

OmniUPF 111

```
interface_name: [ens1f0]
xdp_attach_mode: native # 11 'offload' 11 SmartNIC
```

KVM/QEMU

```
111111
```

```
virt-install \
  --name omniupf \
  --network bridge=br0,model=virtio \
  --disk path=/var/lib/libvirt/images/omniupf.qcow2 \
  ...
```

SR-IOV 111

```
<interface type='hostdev' managed='yes'>
  <source>
    <address type='pci' domain='0x0000' bus='0x01' slot='0x10'
function='0x1' />
  </source>
</interface>
```

VMware ESXi

11 vSwitch (11 XDP)1

- 11111111111111111111
- XDP 1111generic

SR-IOV (11 XDP)1

- 1 ESXi 11111111111111111111 SR-IOV

- SR-IOV
- XDP native

Microsoft Hyper-V

(XDP)

-
- XDP generic

SR-IOV (XDP)

- Hyper-V SR-IOV
- SR-IOV
- XDP native

VirtualBox

NAT/ (XDP)

- VirtIO-Net Intel PRO/1000
- XDP generic
- VirtualBox SR-IOV

Mpps

(Mpps) (Gbps) -
VoIP

UPF N3 GTP-U N6 IP

GTP-U (N3)

- IPv4 20
- UDP 8
- GTP-U 8
- GTP-U 36

GTP-U (N3)

- **IP** 20 (IPv4)
- **UDP** 8
- 1
- 29
- **GTP-U** 36
- 65

1 Mpps GTP-U

$$65 \times 1,000,000 \text{ pps} \times 8 = 520 \text{ Mbps}$$

GTP-U (N3 MTU 1500)

- **IP MTU** 1500 (IP)
- **GTP-U** 36
- 1536

1 Mpps GTP-U

$$1536 \times 1,000,000 \text{ pps} \times 8 = 12,288 \text{ Mbps} \approx 12.3 \text{ Gbps}$$

IP (N6)

N6 (IP) IP GTP-U

N6

- **IP** 20
- **UDP** 8
- 1
- 29

1 Mpps N6

$$29 \times 1,000,000 \text{ pps} \times 8 = 232 \text{ Mbps}$$

N6 (MTU 1500)

- **IP MTU** 1500
- 1500

1 Mpps N6

$$1500 \times 1,000,000 \text{ pps} \times 8 = 12,000 \text{ Mbps} = 12 \text{ Gbps}$$

◆◆◆◆◆◆◆◆

Intel X710 ◆◆ (N3 ◆◆◆◆ 10 Mpps ◆◆◆◆◆ GTP-U)◆

◆◆◆◆	◆◆◆◆◆◆◆◆	GTP-U ◆◆	10 Mpps ◆◆◆◆◆ ◆	◆◆◆◆◆
VoIP ◆◆ (N3) 65-150 ◆◆	101-186 ◆◆	0.8-1.5 Gbps	AMR-WB ◆◆, G.711	
◆◆◆◆◆ (N3) 400-600 ◆◆	436-636 ◆◆	3.5-5.1 Gbps	HTTP/HTTPS, ◆◆	
◆◆◆◆◆ (N3) 1200 ◆◆	1236 ◆◆	9.9 Gbps	◆◆ 2024 ◆◆◆◆◆	
◆◆◆◆ (N3) 1400-1450 ◆◆ ◆	1436-1486 ◆◆ ◆	11.5-11.9 Gbps	HD/4K ◆◆◆◆	
◆◆ MTU (N3) 1500 ◆◆	1536 ◆◆	12.3 Gbps	◆◆ TCP ◆◆	

◆ N6 ◆◆ (◆◆ IP◆◆ GTP-U)◆

◆◆◆◆	◆◆◆◆◆	10 Mpps ◆◆◆◆◆	◆◆◆◆
VoIP ◆◆◆ 65-150 ◆◆	0.5-1.2 Gbps	◆◆ RTP ◆◆	
◆◆◆◆◆ 400-600 ◆◆	3.2-4.8 Gbps	HTTP ◆◆	
◆◆◆◆◆ 1200 ◆◆	9.6 Gbps	◆◆ 2024 ◆◆	
◆◆◆ 1400-1450 ◆◆	11.2-11.6 Gbps	◆◆◆◆	
◆◆ MTU 1500 ◆◆	12.0 Gbps	◆◆◆◆◆	

◆ 10 Mpps ◆◆◆◆◆◆◆◆ (1200 ◆◆◆◆◆)◆◆◆◆ N3 ◆ N6 ◆◆◆◆◆◆◆◆◆◆ ~10 Gbps◆

◆◆◆◆◆◆◆◆◆◆

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆ GTP-U ◆◆ (36 ◆◆) ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

◆◆◆◆◆◆◆◆ (◆◆◆◆◆◆◆◆)◆

- **VoIP (AMR-WB ◆◆◆◆◆)◆**65-80 ◆◆ → ◆◆ GTP-U: 101-116 ◆◆
- ◆◆◆◆◆◆◆◆◆◆◆◆50-200 ◆◆ → ◆◆ GTP-U: 86-236 ◆◆
- ◆◆◆◆◆ **(HTTP/3)◆**400-800 ◆◆ → ◆◆ GTP-U: 436-836 ◆◆
- ◆◆◆◆◆1200-1450 ◆◆ → ◆◆ GTP-U: 1236-1486 ◆◆
- ◆◆◆◆◆1500 ◆◆ → ◆◆ GTP-U: 1536 ◆◆

GTP-U ◆◆◆◆◆◆◆

- ◆◆◆◆◆ (< 200 ◆◆)◆~**35-70%** ◆◆ - Mpps ◆◆◆◆◆◆
- ◆◆◆◆◆◆ (200-800 ◆◆)◆~**5-20%** ◆◆ - ◆◆◆◆◆
- ◆◆◆◆◆ (> 1200 ◆◆)◆~**3%** ◆◆ - ◆◆◆◆◆◆◆◆◆◆◆◆

◆◆◆◆◆◆

❖❖	❖❖	XDP	❖❖	❖❖	❖❖
Intel E1000	e1000		❖❖❖	~1	Mpps

Mellanox/NVIDIA ❖❖

❖❖	❖❖	XDP	❖❖	❖❖	❖❖
Mellanox ConnectX-5	mlx5	❖	❖❖	~12	Mpps
Mellanox ConnectX-6	mlx5	❖	❖❖	~20	Mpps
Mellanox BlueField	mlx5	❖	❖❖ + ❖❖	~40	Mpps
Mellanox ConnectX-4	mlx4	❖❖	❖❖	~2	Mpps

Broadcom ❖❖

❖❖	❖❖	XDP	❖❖	❖❖	❖❖
Broadcom BCM57xxx	bnxt_en	❖	❖❖	~8	Mpps
Broadcom NetXtreme II	bnx2x	❖	❖❖❖	~1	Mpps

❖❖❖❖

❖❖	❖❖	XDP	❖❖❖❖	❖❖
Netronome Agilio CX	nfp	❖	❖❖	~30 Mpps
Amazon ENA	ena	❖	❖❖	~5 Mpps
Solarflare SFC9xxx	sfc	❖	❖❖	~8 Mpps
VirtIO	virtio_net	❖❖	❖❖	~2 Mpps

❖❖❖❖ XDP ❖❖

❖❖❖❖❖❖❖❖ XDP ❖

```
# ❖❖❖❖❖❖❖
ethtool -i eth0 | grep driver

# ❖❖❖❖❖❖❖ XDP ❖❖
modinfo <driver_name> | grep -i xdp

# Intel i40e ❖❖❖
modinfo i40e | grep -i xdp
```

❖❖ XDP ❖❖❖❖❖❖

```
# ❖❖ XDP ❖❖❖❖❖❖❖
ip link show eth0 | grep -i xdp

# ❖❖❖❖ (XDP ❖❖)❖
# 2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 xdp qdisc mq
```

1200 (N3)

1200 (N3)

		Mpps	(N3)	
/	(VirtIO E1000)	1-2 Mpps	1-2 Gbps	PoC
	Intel X710 Mellanox CX-5	5-10 Mpps	5-10 Gbps	
	Intel E810 Mellanox CX-6	10-20 Mpps	10-20 Gbps	
	Mellanox CX-6 Intel E810	20-40 Mpps	20-40 Gbps	
	Mellanox BlueField	40+ Mpps	40+ Gbps	
Proxmox (SR-IOV)	VirtIO	1-2 Mpps	1-2 Gbps	
	Intel X710/E810 VF Mellanox CX-5 VF	5-10 Mpps	5-10 Gbps	

- 1200 GTP-U (N3 1236)
- N6 (~9.6 Gbps 10 Mpps) GTP-U
- VoIP

XDP

- [XDP](#)
- [XDP](#)

- [Cilium XDP](#)
 - [IO Visor XDP](#)
-

◆◆◆◆

◆◆ 1◆◆◆◆◆ (◆◆◆◆)

◆◆◆◆◆ SR-IOV ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆ OmniUPF

```
# ◆◆◆◆◆
interface_name: [eth0]
xdp_attach_mode: generic
api_address: :8080
pfcp_address: :8805
pfcp_node_id: 127.0.0.1
n3_address: 127.0.0.1
metrics_address: :9090
logging_level: debug
max_sessions: 1000
```

◆◆ 2◆◆◆◆◆◆ (◆◆◆◆)

◆◆◆◆◆ Intel X710 ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆ UPF

```
# ◆◆◆◆◆◆◆◆◆◆
interface_name: [ens1f0, ens1f1] # N3 ◆ ens1f0◆N6 ◆ ens1f1
xdp_attach_mode: native
api_address: :8080
pfcp_address: 10.100.50.241:8805
pfcp_node_id: 10.100.50.241
n3_address: 10.100.50.233
n9_address: 10.100.50.234
metrics_address: :9090
logging_level: info
max_sessions: 500000
gtp_peer:
  - 10.100.50.10:2152 # gNB 1
  - 10.100.50.11:2152 # gNB 2
gtp_echo_interval: 30
pfcp_remote_node:
  - 10.100.50.50 # OmniSMF
heartbeat_interval: 10
feature_ueip: true
ueip_pool: 10.45.0.0/16
buffer_max_packets: 50000
buffer_packet_ttl: 60
```

3 SR-IOV Proxmox ()

Proxmox SR-IOV UPF

```
# Proxmox SR-IOV
interface_name: [ens1f0] # SR-IOV VF
xdp_attach_mode: native
api_address: :8080
pfcp_address: 192.168.100.10:8805
pfcp_node_id: 192.168.100.10
n3_address: 192.168.100.10
metrics_address: :9090
logging_level: info
max_sessions: 100000
gtp_peer:
  - 192.168.100.50:2152
gtp_echo_interval: 15
pfcp_remote_node:
  - 192.168.100.20 # SMF
```

4 PGW-U (4G EPC)

OmniUPF 4G EPC PGW-U

```
# PGW-U
interface_name: [eth0]
xdp_attach_mode: native
api_address: :8080
pfcp_address: 10.200.1.10:8805
pfcp_node_id: 10.200.1.10
n3_address: 10.200.1.10 # S5/S8 (GTP-U)
metrics_address: :9090
logging_level: info
max_sessions: 200000
gtp_peer:
  - 10.200.1.50:2152 # SGW-U
gtp_echo_interval: 20
pfcp_remote_node:
  - 10.200.2.10 # OmniPGW-C (Sxb)
heartbeat_interval: 5
```

5 (UPF + PGW-U)

OmniUPF 5G 4G

```
#
```

```

interface_name: [eth0, eth1]
xdp_attach_mode: native
api_address: :8080
pfc_p_address: :8805
pfc_p_node_id: 10.50.1.100
n3_address: 10.50.1.100
n9_address: 10.50.1.101
metrics_address: :9090
logging_level: info
max_sessions: 300000
gtp_peer:
  - 10.50.2.10:2152 # 5G gNB
  - 10.50.2.20:2152 # 4G eNodeB (?? SGW-U)
gtp_echo_interval: 15
pfc_p_remote_node:
  - 10.50.3.10 # OmniSMF (5G)
  - 10.50.3.20 # OmniPGW-C (4G)
heartbeat_interval: 10
feature_ueip: true
ueip_pool: 10.60.0.0/16

```

?? 6?SmartNIC ????

???? Netronome Agilio CX SmartNIC ????????

```

# SmartNIC ???
interface_name: [enp1s0np0] # SmartNIC ??
xdp_attach_mode: offload
api_address: :8080
pfc_p_address: 10.10.1.50:8805
pfc_p_node_id: 10.10.1.50
n3_address: 10.10.1.50
metrics_address: :9090
logging_level: warn # ???
max_sessions: 1000000
pdr_map_size: 2000000
far_map_size: 2000000
qer_map_size: 1000000
gtp_peer:
  - 10.10.2.10:2152
  - 10.10.2.20:2152
  - 10.10.2.30:2152
gtp_echo_interval: 30
pfc_p_remote_node:
  - 10.10.3.10
heartbeat_interval: 15
buffer_max_packets: 100000

```

buffer_max_total: 1000000

⬢⬢⬢⬢⬢⬢⬢⬢⬢

⬢⬢⬢⬢⬢⬢ (⬢⬢)

⬢⬢ max_sessions⬢⬢ OmniUPF ⬢⬢⬢⬢⬢⬢⬢⬢⬢

max_sessions: 100000

```
# ⬢⬢⬢⬢⬢⬢⬢⬢⬢
# PDR: 200,000 ⬢⬢ (2 × max_sessions)
# FAR: 200,000 ⬢⬢ (2 × max_sessions)
# QER: 100,000 ⬢⬢ (1 × max_sessions)
# URR: 200,000 ⬢⬢ (2 × max_sessions)
```

⬢⬢⬢⬢⬢~91 MB ⬢⬢ 100K ⬢⬢

⬢⬢⬢⬢⬢⬢

⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢

```
max_sessions: 100000
pdr_map_size: 300000 # ⬢⬢⬢⬢⬢⬢⬢⬢⬢⬢ PDR
far_map_size: 200000
qer_map_size: 150000 # ⬢⬢⬢⬢⬢⬢ QER
urr_map_size: 200000
```

⬢⬢⬢⬢

⬢⬢⬢⬢⬢⬢⬢⬢

```
⬢⬢⬢⬢⬢ = min(
    pdr_map_size / 2,
    far_map_size / 2,
    qer_map_size
)
```

⬢⬢⬢

- PDR ⬢⬢⬢200,000
- FAR ⬢⬢⬢200,000
- QER ⬢⬢⬢100,000

⬢⬢⬢⬢⬢ = min(100,000, 100,000, 100,000) = **100,000**

□□□□

□□□□□□□□□□

- PDR: $2 \times 212 \text{ B} = 424 \text{ B}$
- FAR: $2 \times 20 \text{ B} = 40 \text{ B}$
- QER: $1 \times 36 \text{ B} = 36 \text{ B}$
- URR: $2 \times 20 \text{ B} = 40 \text{ B}$
- □□□□~540 B □□□□

□□ **100K** □□□□~52 MB □□□□

□□□□□□□□□□□□□□ 2× □□□□□□□□

```
# □□□□□□□□
```

```
ulimit -l
```

```
# □□□□□□□□ (eBPF □□)
```

```
ulimit -l unlimited
```

□□□□

- [□□□□□](#) - eBPF/XDP □□□□□□□□□□
- [□□□□□□□□](#) - PDR□FAR□QER□URR □□
- [□□□□□□](#) - □□□□□□□□□□□□
- **Web UI** □□ - □□□□□□□□
- [□□□□□□](#) - UPF □□□□□□□□□□



1. □ □
2. □ □ □ □
3. □ □ □ □
4. □ □ □ □
5. □ □ □ □ □
6. □ □ □ □
7. □ □ □ □ □ □

[illegible]

	⬢ ⬢		⬢ ⬢		⬢ ⬢ ⬢ ⬢		⬢ ⬢ ⬢ ⬢
⬢ ⬢ ⬢ ⬢ ⬢		⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢		⬢ ⬢	RX/TX	⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢	
⬢ ⬢ ⬢ ⬢		⬢ ⬢ N3/N6 ⬢ ⬢ ⬢ ⬢		⬢ ⬢	N3 RX/TX, N6 RX/TX		
XDP ⬢ ⬢		⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢		⬢ ⬢	XDP	⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢	
⬢ ⬢ ⬢ ⬢		⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢		⬢ ⬢	FIB	⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ / ⬢ ⬢ ⬢	
eBPF ⬢ ⬢ ⬢ ⬢	⬢ ⬢ ⬢ ⬢ ⬢ ⬢			⬢ 10 ⬢	⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢		
⬢ ⬢ ⬢ ⬢ ⬢	⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢		⬢ 5 ⬢		⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ ⬢ FAR	⬢ ⬢	



N3/N6

N3/N6  RAN (N3)  (N6) 



- **RX N3** RAN GTP-U IP
- **TX N3** RAN GTP-U IP
- **RX N6** IP
- **TX N6** IP
-

???

- **RX N3** ≈ **TX N6** RAN
- **RX N6** ≈ **TX N3** RAN
- -
 -
 -

XDP

XDP (eXpress Data Path)

??

- XDP 0
- XDP
-
-
- **TX** XDP

??

- > 0 eBPF
- > 0
-
-

???

???

???

- **RX ARP**
- **RX GTP ECHO** GTP-U
- **RX GTP OTHER** GTP
- **RX GTP PDU** GTP-U
- **RX GTP UNEXP** GTP
- **RX ICMP** ping
- **RX ICMP6** ICMPv6
- **RX IP4** IPv4
- **RX IP6** IPv6
- **RX OTHER**
- **RX TCP**
- **RX UDP**

???

- ?? **GTP-U PDU** ???? ? ? ? ? ? ? ? ?
- ?? **ICMP** ? ? ? ? ? ? ? ? ? ? ? ? ?
- ?? **TCP** ? **UDP** ? ? ? ? ? ? ? ?
- ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

????

FIB (? ? ? ? ?) ? ? ? ? ? ? ? ? ? ?

IPv4 FIB ? ? ?

- ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?
- **OK** ? ? ? ? ? ? ? ?

IPv6 FIB ? ? ?

- ? ? ? ? ? ? ? IPv6 ? ? ? ?
- **OK** ? ? ? ? IPv6 ? ? ? ?

?? ? ? ? ?

- ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?
- ? **OK** ? ? ? ? ? ? ? ? ? ? ? ?
- ?

?? ? ? ? ?

eBPF ? ? ? ?

eBPF ?

?? **eBPF** ??

far_map (? ? ? ? ? ?) ?

- ? ? ? 131,070 ? ?
- ? ? ? ? 4 B (FAR ID)
- ? ? ? ? 16 B (? ? ? ?)
- ? ? ? ? ~2.6 MB
- ? ? ? ? ? - ? ? ? ? ? ? ? ? ? ? ? ?

pdr_map_downlin (? ? PDR - IPv4) ?

- 131,070
- 4 B (UE IPv4)
- 208 B (PDR)
- ~27 MB
- -

pdr_map_downlin_ip6 (PDR - IPv6)

- 131,070
- 16 B (UE IPv6)
- 208 B (PDR)
- ~29 MB
- - IPv6

pdr_map_teid_ip (PDR)

- 131,070
- 4 B (TEID)
- 208 B (PDR)
- ~27 MB
- -

qer_map (QoS)

- 65,535
- 4 B (QER ID)
- 32 B (QoS)
- ~2.3 MB
- - QoS

urr_map

- 131,070
- 4 B (URR ID)
- 16 B
- ~2.6 MB
- -

0-50% ()	-	
50-70% ()	-	
70-90% ()	- 1	
90-100% ()	-	











1. 
2. 
3. 

◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆

1.  OmniUPF 
2.           
3.  OmniUPF 
4.           
5.           

 eBPF UPF

?

$$\diamond\diamond\diamond\diamond\diamond \text{ (pps)} = (\diamond\diamond\diamond\diamond\diamond\diamond\diamond) / (\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond)$$

?

- $\frac{17,000}{10} = 1,700$ pps
- $\frac{17,000}{10} = 1,700$ pps
- $\frac{17,000 - 7,000}{10} = 1,000$ pps

- **UPF** 10,000 - 100,000 pps
- **UPF** 100,000 - 1,000,000 pps
- **UPF** 1,000,000 - 10,000,000 pps

- XDP 
-  CPU 
-       
-    

- XDP ≥ 0
- $\geq 5\%$
- UPF ≥ 0

≥ 1 ≥ 0

- eBPF $\geq 70\%$
- $\geq 1\%$
- ≥ 0
- ≥ 30

≥ 0

- eBPF $\geq 50\%$
- ≥ 0
- ≥ 0
- URR ≥ 0

≥ 0

≥ 0

1. **Prometheus** ≥ 0
2. ≥ 0 OmniUPF ≥ 0
3. **REST API** ≥ 0 /map_info/ ≥ 0 packet_stats ≥ 0
4. **Web UI** ≥ 0

≥ 0

≥ 0

≥ 0

```

 $\geq = \min($ 
  PDR  $\geq / 2, \# \geq + \geq$  PDR
  FAR  $\geq / 2, \# \geq + \geq$  FAR
  QER  $\geq \# \geq$  QER
)

```

≥ 0

- PDR $\geq 131,070$
- FAR $\geq 131,070$
- QER $\geq 65,535$

$\geq = \min(131,070 / 2, 131,070 / 2, 65,535) = 65,535$

□□□□

□□□ **eBPF** □□□□□

$$\square\square = \sum (\square\square\square\square \times (\square\square\square + \square\square\square))$$

□□□□□

- PDR □□□3 × 131,070 × 212 B = 83.3 MB
- FAR □□□131,070 × 20 B = 2.6 MB
- QER □□□65,535 × 36 B = 2.3 MB
- URR □□□131,070 × 20 B = 2.6 MB
- □□□~91 MB □□□□□

□□□□□□□□

- □□□□□□□□□ (ulimit -l)
- □□□□□□□□ 2 □□□□□□
- □□□□□□□□

□□□□

□□□□□□□□□□

1. □□□□□□□□□

- □□□□~5 Mbps
- □□□□~1 Mbps
- VoIP□~0.1 Mbps

2. □□□□□□□

$$\square\square\square\square = \square\square\square \times \square\square\square\square\square\square\square$$

3. □□□□□

$$\square\square\square\square = \square\square\square\square \times 2 \ \# \ 100\% \ \square\square$$

□□□

- 10,000 □□□□□
- □□□□□□ 2 Mbps
- □□□20 Gbps
- □□□□□40 Gbps (N3 + N6 □□)

□□□□

□□□□□

???

1. ??? → XDP ??
2. ???
3. ?? OmniUPF ??? eBPF ??

????

- eBPF ?????
- ?????
- eBPF ?????
- ?????

????

- ?? OmniUPF ??
- ?????????????Linux 5.4+?
- ?? eBPF ?????
- ?????????????

????

???????????? 100%

???

1. ?????
2. ????? 100%
3. ?????????

?????

1. ?????????
2. ?? SMF ?????
3. ????????? FAR ??

?????

1. ?? eBPF ?????
2. ?? UPF ?????????
3. ?????????

????

????????CPU ??

???

1. ?????????????????
2. ?? XDP ?????????
3. ?? UPF ??? CPU ???
4. ?? N3/N6 ??????

?????

- ????? UPF ??
- ?????? CPU ?????
- ???????
- eBPF ???????

?????

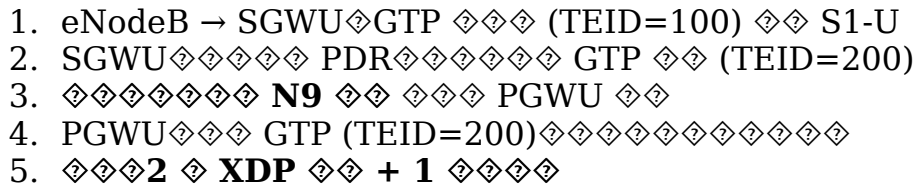
- ????? UPF ???????
- ?? CPU ??? RSS????????
- ????????
- ?? eBPF ???????

????

- [UPF](#) ????? - ?? UPF ?????
- [????](#) - PDR?FAR?QER?URR ??
- [Web UI](#) ????? - ??????
- [????](#) - ??????
- [????](#) - eBPF ??????



- N3
 N9
 IP
 OmniUPF
 SGWU
 PGWU
 eBPF



?? ? ? ? ?

?? ? ? **eNodeB** → **SGWU** → **PGWU** → ? ? ?

?? ? ? ? cmd/ebpf/xdp/n3n6_etrypoint.c ? 349-403

?? ? ? ? ?

1. ? ? ? ? ? eNodeB ? GTP ? ? ? ? ? TEID=100
 2. **PDR** ? ? ? ? ? SGWU ? ? ? ? ? PDR (TEID=100)
 3. **FAR** ? ? ? ? ? TEID=200 ? ? ? GTP ? ? ? ? ? 10.0.1.10
 4. ? ? ? ? ? is_local_ip(10.0.1.10) ? ? TRUE
 5. ? ? **TEID** ? ? ctx->gtp->teid ? 100 ? ? ? 200 (? ? ? ? ?)
 6. ? ? ? ? ? ? ? TEID=200 ? PDR (PGWU ? ?)
 7. **FAR** ? ? ? ? ? GTP ? ? ? ? ? ? ? ?
 8. ? ? ? ? ? IP ? ? ? ? ? ? ? N6 ? ?
-

?? ? ? ? ? ? ? ? → **PGWU** → **SGWU** → **eNodeB**

?? ? ? ? ? cmd/ebpf/xdp/n3n6_etrypoint.c ? 137-194 (IPv4) ? 265-322 (IPv6)

?? ? ? ? ?

1. ? ? ? ? ? ? ? ? ? ? ? IP ? ? ? ? ? ? ? UE (10.60.0.1)
 2. **PDR** ? ? ? ? ? UE IP ? ? ? ? ? PDR (PGWU ? ?)
 3. **FAR** ? ? ? ? ? TEID=200 ? ? ? GTP ? ? ? ? ? 10.0.1.10
 4. ? ? ? ? ? is_local_ip(10.0.1.10) ? ? TRUE
 5. ? ? **GTP** ? ? ? ? ? TEID=200 ? ? ? ? ?
 6. ? ? ? ? ? ? ? TEID=200 ? PDR (SGWU ? ?)
 7. **FAR** ? ? ? ? ? GTP ? ? ? ? ? eNodeB TEID=100
 8. ? ? ? ? ? GTP ? ? ? ? ? ? ? S1-U ? ? (eNodeB)
-

? ?

? ?

?? ? ? ?

- **SGWU-C** ? ? ? ? ? OmniUPF PFCP ? ? (? ? ? 192.168.1.10:8805)
- **PGWU-C** ? ? ? ? ? ? ? ? OmniUPF PFCP ? ?

?? ? ?

- **N3** ? **N9** ? ? ? ? ? ? **IP** ? ?

```
# S1-MME 0mniUPF PFCP
upf_pfcip_address: "192.168.1.10:8805"

# S1-U 0mniUPF n3_address
sgwu_s1u_address: "10.0.1.10"

# N9 PGWU 0mniUPF
```

sgwu_n9_address: "10.0.1.10"

PGWU-C

OmniUPF PFCP
upf_pfcip_address: "192.168.1.10:8805"

N9 SGW
pgwu_n9_address: "10.0.1.10"

SGi
pgwu_sgi_address: "192.168.100.1"

- PFCP (:8805)
- OmniUPF SGWU-C PGWU-C PFCP
- ID

UE PDU

UE

PFCP

SGWU OmniSGW-C

- PDR TEID=100 eNodeB → FAR TEID=200
dst=10.0.1.10
- PDR TEID=200 PGWU → FAR TEID=100
eNodeB

PGWU OmniPGW-C

- PDR TEID=200 SGWU → FAR
- PDR UE IP=10.60.0.1 → FAR TEID=200 dst=10.0.1.10

N9

XDP

```
# ❷❸❹❺ eBPF ❶❷❸❹
sudo cat /sys/kernel/debug/tracing/trace_pipe | grep loopback
```

❶❷❸❹❺

```
upf: [n3] session for teid:100 -> 200 remote:10.0.1.10
upf: [n9-loopback] self-forwarding detected, processing inline
TEID:200
upf: [n9-loopback] decapsulated, routing to N6

upf: [n6] use mapping 10.60.0.1 -> teid:200
upf: [n6-loopback] downlink self-forwarding detected, processing
inline TEID:200
upf: [n6-loopback] SGWU updating GTP tunnel to eNodeB TEID:100
upf: [n6-loopback] forwarding to eNodeB
```

❶❷ REST API ❶❷❸❹

❶❷ PFCP ❶❷❸

```
curl http://localhost:8080/api/v1/upf_pipeline | jq
```

❶❷❸❹❺

```
{
  "associations": [
    {
      "node_id": "sgwc.example.com",
      "address": "192.168.1.20:8805",
      "sessions": 1000
    },
    {
      "node_id": "pgwc.example.com",
      "address": "192.168.1.21:8805",
      "sessions": 1000
    }
  ],
  "total_sessions": 2000
}
```

❶❷❸❹❺❻❽❾❿ⓂⓃⓄⓅⓆⓇⓈⓉ SGWU-C❶❷❸❹ PGWU-C❶❷

❶❷❸❹❺❻❽

```
curl http://localhost:8080/api/v1/sessions | jq '.sessions[] |
{local_seid, ue_ip, uplink_teid}'
```

????

```
{
  "local_seid": 12345,
  "ue_ip": "10.60.0.1",
  "uplink_teid": 100
}
{
  "local_seid": 67890,
  "ue_ip": "10.60.0.1",
  "uplink_teid": 200
}
```

?? UE ?????

- ?? SGWU-C ????TEID=100?S1-U ???
- ?? PGWU-C ????TEID=200?N9 ???

????

????????

```
curl http://localhost:8080/api/v1/xdp_stats | jq
```

????

- xdp_processed?? eBPF ????????
- xdp_pass????????????????????
- xdp_redirect??? XDP ????????
- xdp_tx????????????????

?? N9 ?????

- xdp_pass ??? ????????
- xdp_tx ? xdp_redirect ???????

????

N9 ?????????

???? ?????????

???? n3_address ≠ n9_address

????

```
# 3 3 3
n3_address: "10.0.1.10"
n9_address: "10.0.1.20" # 3 3 3 IP 3 3 3 3 3 3
```

```
# 3 3 3
n3_address: "10.0.1.10"
n9_address: "10.0.1.10" # 3 3 3 IP 3 3 3 3 3 3
```

3 3 3

```
curl http://localhost:8080/api/v1/dataplane_config | jq
```

3 3 3 3

```
{
  "n3_ipv4_address": "10.0.1.10",
  "n9_ipv4_address": "10.0.1.10"
}
```

3 3 3 3 3 3 PDR

3 3 3 3 3 3 [n9-loopback] no PDR for destination TEID

3 3 3 3 3 PGWU 3 3 3 3 3 3 TEID 3 3 3

3 3 3

1. 3 3 PFCP 3 3 3

```
curl http://localhost:8080/api/v1/sessions | jq '.sessions[] |
select(.uplink_teid == 200)'
```

2. 3 3 FAR 3 3 3

```
curl http://localhost:8080/api/v1/far_map | jq '.[ ] |
select(.teid == 200)'
```

3 3 3 3 3 3 3 PGWU-C 3 3 3 SGWU-C 3 3 N9 3 3 3 3 3 3 TEID 3 3 3

CPU 3 3 3 3

3 3 3 CPU 3 3 3 3 3 3 3 3

3 3 3 3 3 eBPF 3

3 3 3

- [❖❖❖ ARCHITECTURE.md](#)
- [❖❖❖ OPERATIONS.md](#)
- [❖❖❖❖❖ TROUBLESHOOTING.md](#)

 PDR

 RAN
 N3

◆◆◆◆: TEID (◆◆◆◆◆◆◆◆)

- 32 ◆◆◆◆◆◆
- ◆ SMF ◆◆◆◆◆◆ gNB
- ◆◆ UE ◆◆◆◆◆◆

◆◆◆:

- **FAR ID:** ◆◆◆◆◆◆◆◆◆◆
- **QER ID:** QoS ◆◆◆◆◆◆◆◆◆◆◆◆
- **URR IDs:** ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
- ◆◆◆◆◆◆◆: ◆◆ GTP-U ◆◆◆◆◆◆◆◆

◆◆◆◆:

1. ◆ GTP-U ◆◆◆◆ TEID
2. ◆ uplink_pdr_map eBPF ◆◆◆◆◆◆◆◆◆◆◆◆
3. ◆◆◆◆◆◆◆◆◆◆◆◆ FAR ID◆QER ID ◆ URR IDs
4. ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

◆◆:

TEID: 5678

FAR ID: 2

QER ID: 1

◆◆◆◆◆◆◆: ◆

SDF ◆◆: ◆ SDF

◆◆ PDR

◆◆ PDR ◆◆◆◆◆◆◆◆◆◆ N6 ◆◆◆◆◆◆◆◆◆◆

◆◆◆◆: UE IP ◆◆

- IPv4 ◆◆ (32 ◆) ◆ IPv6 ◆◆ (128 ◆)
- ◆ SMF ◆ PDU ◆◆◆◆◆◆◆◆◆◆
- ◆◆ UE ◆◆

◆◆◆:

- **FAR ID:** ◆◆◆◆◆◆◆◆◆◆
- **QER ID:** QoS ◆◆◆◆◆◆◆◆◆◆◆◆
- **URR IDs:** ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
- **SDF** ◆◆: ◆◆◆◆◆◆◆◆◆◆◆◆
 - ◆ SDF: ◆◆◆◆◆◆◆◆◆◆◆◆
 - ◆ SDF: ◆◆◆◆ SDF ◆◆◆◆◆◆◆◆
 - SDF + ◆◆: ◆ SDF ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆ FAR
- **SDF** ◆◆◆: ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆ IP ◆◆◆◆

FAR

FAR            

     
  1 2         
  2 4          
  0 1     
  3 8         
  4 16          

     :

-  : 2 ( ) -        
-  : 6 (  +  ) -          
-  : 4 ( ) -          
-  : 1 ( ) -                 

BUFFER     2               

   :

-    :   FAR     2 (Action |= 4)
-     :   FAR     2 (Action &= ~4)
-     :     FAR           
-     :            

      GTP-U   

  **FAR** (N3 → N6):

-       : 
-  :   GTP-U       IP   

  **FAR** (N6 → N3):

-       : 
-   IP: gNB IP        200.198.5.10 
- TEID: UE       ID
-  :   GTP-U       gNB

Web UI $\diamond\diamond$ FAR $\diamond\diamond$

$\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$ ID $\diamond\diamond$ FAR $\diamond\diamond\diamond\diamond$

$\diamond\diamond$:

1. $\diamond\diamond\diamond\diamond\diamond \rightarrow$ FARs $\diamond\diamond$
2. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$ FAR ID
3. $\diamond\diamond$ " $\diamond\diamond$ " $\diamond\diamond$ FAR $\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond$:

- FAR ID
- $\diamond\diamond\diamond\diamond\diamond + \diamond\diamond\diamond\diamond\diamond$
- $\diamond\diamond\diamond\diamond\diamond\diamond\diamond/\diamond\diamond$
- $\diamond\diamond\diamond\diamond\diamond\diamond$
- $\diamond\diamond$ IP $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
- TEID
- $\diamond\diamond\diamond\diamond\diamond$

QoS $\diamond\diamond\diamond\diamond$ (QER)

$\diamond\diamond$

QER $\diamond$

QER $\diamond\diamond$

QoS $\diamond\diamond$

QFI (QoS $\diamond\diamond\diamond\diamond$):

- 5G QoS $\diamond\diamond$ 6 $\diamond\diamond\diamond\diamond$
- $\diamond$ 1-9 $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$ QFI 9 = $\diamond\diamond\diamond\diamond\diamond$
- $\diamond\diamond$ 5GC $\diamond\diamond\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond$:

- $\diamond\diamond$ (0): $\diamond\diamond\diamond\diamond$
- $\diamond\diamond$ ($\diamond\diamond$): $\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond\diamond$ (MBR):

- $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
- $\diamond$ kbps $\diamond\diamond\diamond$
- **MBR = 0:** $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
- $\diamond\diamond$ MBR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$

◆◆◆◆◆ (GBR):

- $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond$ kbps $\diamond \diamond \diamond$
- **GBR = 0:** $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- **GBR > 0:** $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$

QoS

◆◆◆◆◆ (GBR = 0):

QER ID: 1

QFI: 9

❖❖ MBR: 100000 kbps (100 Mbps)

❓❓ MBR: 100000 kbps (100 Mbps)

GBR: 0 kbps

GBR: 0 kbps

◆◆◆ (GBR > 0):

QER ID: 2

QFI: 1

❖❖ MBR: 10000 kbps (10 Mbps)

◆◆ MBR: 10000 kbps (10 Mbps)

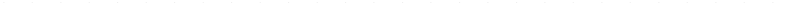
GBR: 5000 kbps (5 Mbps)

GBR: 5000 kbps (5 Mbps)

QoS

◆◆◆◆◆ (URR)

?

URR  SMF


URR






◆ ◆ ◆ ◆ :

- $\diamond$ UE $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond$ GTP-U $\diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond \diamond$ IP $\diamond \diamond \diamond \diamond \diamond \diamond \diamond$

◆ ◆ ◆ ◆ :

- 128 UE 128
- 1 GTP-U 128
- 1 IP 128

128:

- 128 128 128 128
- 128 128 128 128

128 128 128 128

URR 128 128 128 128 128 128 128 128

128 128 128:

- 128 128 128 128 128 128 128 128
- 128: 1 1 GB 128 128 128 128

128 128 128:

- 128 128 128 128 128
- 128: 1 5 128 128 128 128

128 128 128:

- 128 128 128 128 128
- QoS 128 128 128 128
- 128 128 128 128

128 128 128 128 128

Web UI 128 128 128 128 128 128 128 128 128 128 128 128 128 128 128

	128	128
0 - 1023		B (128)
1024 - 1048575		KB (128)
1048576 - 1073741823		MB (128)
1073741824 - 1099511627775		GB (128)
1099511627776+		TB (128)

128:

URR ID: 0
 128 128: 12.3 KB
 128 128: 9.0 KB
 128 128: 21.3 KB

URR [?][?][?][?]

[?][?][?][?]

PDR → FAR → QER → URR [?]

[?][?] PDR [?][?][?][?] FAR[?]FAR [?][?][?][?][?][?] QER [?][?][?][?][?][?] URR[?]

[?][?][?][?][?][?]

[?][?] **PDR:**

TEID: 5678
FAR ID: 2
QER ID: 1
URR IDs: [0]
[?][?][?][?][?][?]: [?]

[?][?] **PDR:**

UE IP: 10.45.0.1
FAR ID: 1
QER ID: 1
URR IDs: [0]
SDF [?][?]: [?] SDF

FAR ID 1 ([?][?]):

[?][?]: 2 ([?][?])
[?][?][?][?][?][?][?]: [?]
[?][?] IP: 200.198.5.10
TEID: 5678

FAR ID 2 ([?][?]):

[?][?]: 2 ([?][?])
[?][?][?][?][?][?][?]: [?]

QER ID 1:

QFI: 9
[?][?] MBR: 100000 kbps
[?][?] MBR: 100000 kbps
[?][?] GBR: 0 kbps
[?][?] GBR: 0 kbps

URR ID 0:

3. $\diamond\diamond$ URR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$

$\diamond\diamond$ FAR $\diamond\diamond$:

1. $\diamond\diamond\diamond\diamond\diamond \rightarrow$ FARs
2. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
3. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$:

1. $\diamond\diamond\diamond\diamond\diamond\diamond$
2. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
3. $\diamond\diamond > 30 \diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
4. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
5. $\diamond$ FAR $\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond$:

1. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond 100,000\diamond$
2. $\diamond\diamond\diamond\diamond$ FAR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond$ FAR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond 10,000\diamond$
3. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
4. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$

URR $\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond\diamond\diamond\diamond$:

1. $\diamond\diamond$ PDR $\diamond\diamond\diamond\diamond$ URR ID
2. $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$ PDR
3. $\diamond\diamond$ FAR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
4. $\diamond\diamond$ URR ID $\diamond\diamond\diamond\diamond$ URR $\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond\diamond\diamond$ **SMF**:

1. $\diamond\diamond$ PFCP $\diamond\diamond\diamond\diamond\diamond$
2. $\diamond\diamond$ URR $\diamond\diamond\diamond\diamond\diamond\diamond\diamond/\diamond\diamond\diamond\diamond$
3. $\diamond\diamond$ PFCP $\diamond\diamond\diamond\diamond\diamond\diamond\diamond$

$\diamond\diamond\diamond\diamond$

- [UPF \$\diamond\diamond\diamond\diamond\$](#) - OmniUPF $\diamond\diamond\diamond\diamond\diamond\diamond$
- [PFCP \$\diamond\diamond\diamond\diamond\$](#) - PFCP $\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
- [Web UI \$\diamond\diamond\diamond\diamond\$](#) - $\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond\diamond$
- [\$\diamond\diamond\diamond\diamond\$](#) - $\diamond\diamond\diamond\diamond\diamond\diamond$
- [\$\diamond\diamond\diamond\diamond\diamond\$](#) - $\diamond\diamond\diamond\diamond\diamond\diamond$



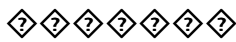
OmniUPF



1.  
2.    
3.    
4.    
5. PFCP    
6.      
7. XDP  eBPF  
8.    
9.          
10. NIC      
11.     
12.    



          OmniUPF                  
    



```
# 1.   OmniUPF      
systemctl status omniupf #  ps aux | grep eupf
```

```
# 2.   PFCP    
curl http://localhost:8080/api/v1/upf_pipeline
```

```
# 3.   eBPF        
ls /sys/fs/bpf/
```

```
# 4.   XDP        
ip link show | grep -i xdp
```

```
# 5.           
dmesg | tail -50  
journalctl -u omniupf -n 50
```

◆◆◆◆

OmniUPF REST API

◆◆ **UPF** ◆◆◆

```
curl http://localhost:8080/api/v1/upf_status
```

◆◆ **PFCP** ◆◆◆

```
curl http://localhost:8080/api/v1/upf_pipeline
```

◆◆◆◆◆◆◆

```
curl http://localhost:8080/api/v1/sessions | jq 'length'
```

◆◆ **eBPF** ◆◆◆◆◆

```
curl http://localhost:8080/api/v1/map_info
```

◆◆◆◆◆◆◆◆◆

```
curl http://localhost:8080/api/v1/packet_stats
```

◆◆ **XDP** ◆◆◆◆◆

```
curl http://localhost:8080/api/v1/xdp_stats
```

eBPF ◆◆◆◆

◆◆◆◆ **eBPF** ◆◆◆

```
ls -lh /sys/fs/bpf/  
bpftool map list
```

◆◆◆◆◆◆◆◆◆

```
bpftool map show  
bpftool map dump name pdr_map_downlin
```

◆◆◆◆◆◆◆◆◆

```
bpftool map dump name far_map | grep -c "key:"
```

XDP

?? XDP

```
ip link show eth0 | grep xdp
```

?? XDP

```
bpftool net list
```

?? XDP

```
bpftool prog show
```

?? XDP

```
bpftool prog dump xlated name xdp_upf_func
```

??

?? N3 ?? GTP-U ??

```
tcpdump -i eth0 -n udp port 2152 -w /tmp/n3_traffic.pcap
```

?? N4 ?? PFCP ??

```
tcpdump -i eth0 -n udp port 8805 -w /tmp/pfcp_traffic.pcap
```

??

```
watch -n 1 'ip -s link show eth0'
```

??

```
ip route show
ip route get 10.45.0.100 # ?? UE IP ??
```

?? ARP ??

```
ip neigh show
```

??

?? "eBPF

??

```
ERROR[0000] failed to load eBPF objects: mount bpf filesystem at /sys/fs/bpf
```

```
❖❖❖eBPF ❖❖❖❖❖❖❖
```

```
❖❖❖❖❖
```

```
# ❖❖ eBPF ❖❖❖❖
```

```
sudo mount bpffs /sys/fs/bpf -t bpf
```

```
# ❖❖❖❖❖❖❖❖❖ /etc/fstab❖
```

```
echo "bpffs /sys/fs/bpf bpf defaults 0 0" | sudo tee -a /etc/fstab
```

```
# ❖❖❖❖
```

```
mount | grep bpf
```

```
❖❖❖“❖❖ eBPF ❖❖❖❖❖❖❖”
```

```
❖❖❖
```

```
ERROR[0000] failed to load eBPF program: operation not permitted
```

```
❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖
```

```
❖❖❖❖❖
```

```
# ❖❖❖❖❖❖❖❖❖❖❖❖
```

```
ulimit -l
```

```
# ❖❖❖❖❖❖❖❖❖❖❖❖eBPF ❖❖❖
```

```
ulimit -l unlimited
```

```
# ❖❖❖❖❖❖❖❖❖❖❖❖ /etc/security/limits.conf❖
```

```
echo "* soft memlock unlimited" | sudo tee -a /etc/security/limits.conf
```

```
echo "* hard memlock unlimited" | sudo tee -a /etc/security/limits.conf
```

```
# ❖❖❖❖❖❖❖❖ OmniUPF
```

```
sudo setcap cap_sys_admin,cap_net_admin,cap_bpf+eip /usr/bin/eupf
```

```
# ❖❖❖ sudo ❖❖
```

```
sudo ./eupf
```

ERR0[0000] unable to read config file: unmarshal errors

YAML

YAML

```
cat config.yml | python3 -c "import yaml, sys;
yaml.safe_load(sys.stdin)"
```

#

-

-

-

-

YAML

```
cat > config.yml <<EOF
interface_name: [eth0]
xdp_attach_mode: generic
api_address: :8080
pfcp_address: :8805
EOF
```

ERR0[0000] interface eth0 not found

#

ip link show

#

ip addr show eth0

config.yml

interface_name: [ens1f0] #

#

ls /sys/class/net/

- Web UI “ ”
- SMF “PCFP ”

```
# 1.  PCFP 
sudo netstat -ulpn | grep 8805

# 2. 
sudo iptables -L -n | grep 8805
sudo ufw status

# 3.  PCFP 
tcpdump -i any -n udp port 8805 -vv

# 4.  API  PCFP 
curl http://localhost:8080/api/v1/upf_pipeline
```

PCFP

```
#  PCFP  UDP 8805
sudo ufw allow 8805/udp
sudo iptables -A INPUT -p udp --dport 8805 -j ACCEPT
```

PCFP ID

```
#  PCFP  ID  N4  IP
pfcf_node_id: 10.100.50.241 #  N4  IP
```

SMF

```
#  SMF 
ping <SMF_IP>

#  SMF 
ip route get <SMF_IP>

# 
sudo ip route add <SMF_NETWORK>/24 via <GATEWAY>
```

SMF ❷❷❷❷❷❷ UPF IP

❷❷❷❷❷

- ❷❷ SMF ❷❷❷❷❷ UPF ❷❷
- ❷❷ SMF ❷❷❷ UPF ❷ pfcpc_node_id IP
- ❷❷ SMF ❷❷❷❷❷ UPF ❷ N4 ❷❷

❷❷❷❷PFPCP ❷❷❷❷❷

❷❷❷

```
WARN[0030] PFCP heartbeat timeout for association 10.100.50.10
```

❷❷❷

```
# ❷❷ PFCP ❷❷❷❷❷
curl http://localhost:8080/api/v1/upf_pipeline | jq '.associations[]
| {remote_id, uplink_teid_count}'
```

```
# ❷❷❷❷❷❷❷
journalctl -u omniupf -f | grep heartbeat
```

❷❷❷❷❷❷❷❷❷

❷❷❷❷❷❷❷❷❷

❷❷❷❷❷❷

```
# ❷❷❷❷ SMF ❷❷❷❷❷❷❷
ping -c 100 <SMF_IP> | grep loss
```

```
# ❷❷❷❷❷❷❷❷❷❷❷❷❷❷❷❷
# - ❷❷❷❷❷❷❷
# - ❷❷❷❷❷❷/❷❷❷❷❷❷
# - ❷❷❷❷❷❷❷
```

❷❷❷❷❷❷❷❷❷❷

❷❷❷❷❷❷

```
# ❷❷❷❷❷❷❷❷
heartbeat_interval: 30 # ❷ 5 ❷❷❷❷ 30 ❷
heartbeat_retries: 5 # ❷❷❷❷❷❷❷
heartbeat_timeout: 10 # ❷❷❷❷❷❷❷❷
```

```
#  FIB 
curl http://localhost:8080/api/v1/packet_stats | jq '.route_stats'
```

```
#  UE IP 
ip route get 10.45.0.100
```

```
# 
sudo ip route add 10.45.0.0/16 dev eth1 #  UE  N6
```

QER

```
#  QER 
curl http://localhost:8080/api/v1/sessions | jq '[][.qers]'
```

```
#  MBR  SMF  QER 
# 
```

- RX N3 TX N3
- RX N6 TX N6

```
# 
curl http://localhost:8080/api/v1/packet_stats | jq 
'.interface_stats'
```

```
# 
tcpdump -i eth0 -n udp port 2152 & # N3
tcpdump -i eth1 -n not udp port 2152 & # N6
```

RX N3 TX N6

FAR N6

```
#  FAR  FORWARD 
curl http://localhost:8080/api/v1/sessions | jq '[][.fars[] | 
select(.applied_action == 2)]'
```

```
#  N6
```



```
#  eBPF 
#  BPF_ENABLE_LOG=1  OmniUPF
```

eBPF

-
- 100%

```
# 
curl http://localhost:8080/api/v1/map_info | jq '[] | {map_name, capacity, used, usage_percent}'
```

```
# 
curl http://localhost:8080/api/v1/map_info | jq '[] | select(.usage_percent > 90)'
```

```
# 1. 
curl http://localhost:8080/api/v1/sessions | jq '[] | {seid, uplink_teid, created_at}'
```

```
# 2.  SMF 
#  SMF  API
```

```
# 3. 
watch -n 5 'curl -s http://localhost:8080/api/v1/map_info | jq ".[] | select(.map_name==\"pdr_map_downlin\") | .usage_percent\"'
```

```
#  config.yml 
max_sessions: 200000 #  100000 
```

```
# 
pdr_map_size: 400000
far_map_size: 400000
qer_map_size: 200000
```

OmniUPF

❖❖❖❖

❖❖❖❖❖❖❖❖❖❖❖❖❖❖

❖❖❖

- ❖❖❖ < 1 Gbps ❖❖ NIC ❖❖❖❖
- CPU ❖❖❖❖

❖❖❖

```
# ❖❖❖❖❖❖❖❖  
curl http://localhost:8080/api/v1/packet_stats | jq '.total_rx,  
.total_tx'
```

```
# ❖❖ CPU ❖❖❖❖❖  
top -bn1 | grep eupf
```

```
# ❖❖ NIC ❖❖❖❖❖  
ethtool -S eth0 | grep -i drop
```

```
# ❖❖ XDP ❖❖  
ip link show eth0 | grep xdp
```

❖❖❖❖❖

❖❖❖❖ **XDP** ❖❖

❖❖❖❖❖

```
# ❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖❖  
xdp_attach_mode: native # ❖❖❖❖ XDP ❖ NIC/❖❖❖❖❖
```

❖❖❖❖

❖❖❖❖❖

```
# ❖ NIC ❖❖❖ RSS❖❖❖❖❖❖❖❖❖❖❖❖  
ethtool -L eth0 combined 4 # ❖❖ 4 ❖ RX/TX ❖❖
```

```
# ❖❖ RSS ❖❖❖❖❖  
ethtool -l eth0
```

```
# ❖❖❖❖❖❖❖❖❖ CPU  
# ❖❖❖ /proc/interrupts ❖❖❖ irqbalance ❖❖❖❖❖❖❖❖
```


❖❖❖❖❖

❖❖ 1❖❖❖❖❖❖❖❖❖❖❖❖❖❖

xdp_attach_mode: generic

❖❖ 2❖❖❖ SR-IOV ❖❖

```
# ❖ Proxmox ❖❖❖❖
# 1. ❖❖ IOMMU
nano /etc/default/grub
# ❖❖❖intel_iommu=on iommu=pt
update-grub
reboot

# 2. ❖❖ VF
echo 4 > /sys/class/net/eth0/device/sriov_numvfs

# 3. ❖ Proxmox UI ❖❖ VF ❖❖❖❖❖❖❖❖
# ❖❖ → ❖❖ → PCI ❖❖ → ❖❖ VF

# ❖❖❖❖❖❖❖
interface_name: [ens1f0] # SR-IOV VF
xdp_attach_mode: native
```

VMware❖❖❖❖❖❖❖❖❖❖

❖❖❖

- OmniUPF ❖❖❖❖❖❖❖❖

❖❖❖vSwitch ❖❖❖❖❖❖❖ MAC ❖❖

❖❖❖❖❖

```
# ❖ vSphere ❖❖❖❖❖❖❖ vSwitch ❖❖❖❖❖❖❖
# 1. ❖❖ vSwitch → ❖❖❖❖❖
# 2. ❖❖❖ → ❖❖❖❖❖❖❖❖❖❖
# 3. ❖❖❖ → MAC ❖❖❖❖❖❖❖❖❖❖
# 4. ❖❖❖ → ❖❖❖❖❖❖❖❖❖❖
```

VirtualBox❖❖❖❖❖❖❖

❖❖❖❖❖

- ❖❖❖ < 100 Mbps

VirtualBox SR-IOV XDP

```
#  
xdp_attach_mode: generic  
  
# VirtualBox  
# - VirtIO-Net  
# - "veth" veth pair  
# - CPU  
# - NAT  
  
# KVM/Proxmox
```

NIC

NIC XDP

ERROR[0000] failed to attach XDP program: operation not supported

```
# NIC  
ethtool -i eth0 | grep driver  
  
# XDP  
modinfo <driver_name> | grep -i xdp  
  
# XDP  
ip link show | grep -B 1 "xdpgeneric\|xdpdrv\|xdpoffload"
```

1

xdp_attach_mode: generic

2 NIC

```
# Ubuntu  
sudo apt update  
sudo apt install linux-modules-extra-$(uname -r)  
  
#
```

```
# 1. 1.1.1.1 Intel
# 2. https://downloadcenter.intel.com/ 3.3
```

3.3.3.3 NIC

```
# 4. 4.4.4.4 XDP 5. NIC
# - Intel X710, E810
# - Mellanox ConnectX-5, ConnectX-6
# - Broadcom BCM57xxx (bnxt_en 6.6.6.6)
```

7.7.7.7.7.7.7.7.7.7.7.7.7.7.7.7

8.8.8

- 9.9 XDP 10.10.10.10
- NIC 11.11.11

12.12.12

```
# 13. 13.13.13.13
dmesg | tail -100
```

```
# 14. 14.14.14.14.14
journalctl -k | grep -E "BUG:|panic:"
```

15.15.15.15

```
# 1. 16.16.16.16.16.16
sudo apt update
sudo apt upgrade
sudo reboot
```

```
# 2. 17.17 XDP 18.18.18.18.18.18.18
xdp_attach_mode: native
```

```
# 3. 19.19.19.19.19.19.19.19.19
xdp_attach_mode: generic
```

```
# 4. 20.20.20.20 Linux 21.21.21.21.21.21.21
```

22.22.22.22.22.22

23.23.23.23.23.23.23.23.23

24.24.24

- SMF 11111111
- UE 1111 PDU 11

111

```
# 11 OmniUPF 111111111111
journalctl -u omniupf | grep -i "session establishment"

# 11 PCFP 1111
curl http://localhost:8080/api/v1/sessions | jq 'length'

# 111111111111 PCFP 11
tcpdump -i any -n udp port 8805 -w /tmp/pfcp_session.pcap
```

111111

11111111

111111

```
# 111111111111
curl http://localhost:8080/api/v1/map_info | jq '.[0] |
select(.usage_percent > 90)'

# 111111111111 eBPF 11111111
```

1111 **PDR/FAR** 11

111111

```
# 11 OmniUPF 111111111111
journalctl -u omniupf | grep -E "invalid|error" | tail -20

# 111111
# - 111 UE IP 11110.0.0.0 11111
# - 111 TEID10 11111
# - PDR 11 FAR
# - 111 FAR 11

# 11 SMF 1111111111
```

11111111**UEIP/FTUP**11

111111

```
# 1111111111111111
feature_ueip: true # UPF 11 UE IP
ueip_pool: 10.60.0.0/16
```

```
feature_ftup: true # UPF F-TEID
teid_pool: 100000
```

◆◆◆◆

◆◆◆◆◆◆◆◆◆◆

◆◆◆

- ◆◆◆◆◆◆◆◆◆◆
- ◆◆◆◆◆◆◆◆◆◆

◆◆◆

```
# ◆◆◆◆◆◆◆◆
```

```
curl http://localhost:8080/api/v1/upf_buffer_info
```

```
# ◆◆◆◆ FAR ◆◆◆
```

```
curl http://localhost:8080/api/v1/upf_buffer_info | jq '.buffers[] |
{far_id, packet_count, oldest_packet_ms}'
```

```
# ◆◆◆◆◆◆◆◆
```

```
watch -n 5 'curl -s http://localhost:8080/api/v1/upf_buffer_info | jq
".total_packets_buffered"'
```

◆◆◆◆◆◆◆◆

FAR ◆◆◆◆◆ FORWARD

◆◆◆SMF ◆◆◆◆ PFCP ◆◆◆◆◆◆◆◆ FAR

◆◆◆◆◆

```
# ◆◆ FAR 000◆
```

```
curl http://localhost:8080/api/v1/sessions | jq '[][.fars[] |
{far_id, applied_action}]'
```

```
# ◆◆ BUFF = 1◆◆◆◆
```

```
# ◆◆ FORW = 2◆◆◆◆
```

```
# ◆◆◆◆ BUFF ◆◆◆◆◆ SMF◆
```

```
# - ◆◆ PFCP ◆◆◆◆◆
```

```
# - ◆◆ FAR ◆◆◆ FORW ◆◆
```

❖❖ TTL ❖❖

❖❖❖❖❖❖❖ FAR ❖❖❖❖❖❖

❖❖❖❖❖

```
# ❖❖❖❖❖ TTL
```

```
buffer_packet_ttl: 60 # ❖ 30 ❖❖❖ 60 ❖
```

❖❖❖❖❖

❖❖❖❖❖❖ FAR ❖❖❖❖❖❖❖❖❖

❖❖❖❖❖❖

```
# ❖❖❖❖❖❖❖
```

```
buffer_max_packets: 20000 # ❖❖ FAR
```

```
buffer_max_total: 200000 # ❖❖❖❖❖
```

❖❖❖❖❖

❖❖❖❖❖❖❖❖

```
logging_level: debug # trace | debug | info | warn | error
```

```
# ❖❖❖❖❖❖❖❖❖ OmniUPF
```

```
sudo systemctl restart omniupf
```

```
# ❖❖❖❖❖❖❖
```

```
journalctl -u omniupf -f --output cat
```

eBPF ❖❖❖❖❖

```
# ❖❖ eBPF ❖❖❖❖❖❖❖❖❖ bpftrace❖
```

```
sudo bpftrace -e 'tracepoint:xdp:* { @[probe] = count(); }'
```

```
# ❖❖❖❖❖❖❖
```

```
sudo bpftrace -e 'tracepoint:bpf:bpf_map_lookup_elem { printf("%s\n",  
str(args->map_name)); }'
```

❖ XDP ❖❖❖❖❖❖❖❖❖

```
# ❖❖ XDP ❖❖❖❖❖❖❖❖❖❖❖tcpdump❖
```

```
tcpdump -i eth0 -w /tmp/before_xdp.pcap
```

```
# XDP XDP_PASS
tcpdump -i any -w /tmp/after_xdp.pcap
```

```
#
```

?

?

1. ?

```
#
uname -a
cat /etc/os-release

# OmniUPF
curl http://localhost:8080/api/v1/upf_status
curl http://localhost:8080/api/v1/map_info
curl http://localhost:8080/api/v1/packet_stats

#
journalctl -u omniupf --since "1 hour ago" > /tmp/omniupf.log
dmesg > /tmp/dmesg.log

#
ip addr > /tmp/network.txt
ip route >> /tmp/network.txt
ethtool eth0 >> /tmp/network.txt
```

2. ?

- OmniUPF
- Linux
-
-
-
-
-

3. ?

- GitHub <https://github.com/edgecomllc/eupf/issues>
-

?? ??

- ???? - ??????
- ???? - eBPF/XDP ??????
- ???? - ??????
- ?????? - PDR?FAR?QER?URR ??
- ???? - UPF ?????





















?
 ?? PFCP ??? SMF/PGW-C IP ??
 ???? ID ???? PFCP ?? ID

???

- ?? SMF ? UPF ???
- ???? ? ? ? ? ? ?
- ???? ? ? ? ? ? ? ID ??

????

????? UE PDU ??? PFCP ???

?
 ? SEID UPF ? ? ? ? ? ? ?
 ? SEID SMF ? ? ? ? ? ? ? ?
UE IP ? ? ? ? ? IPv4 ? IPv6 ? ?
TEID ? ? ? ? ? GTP-U ? ? ? ? ? ?
PDRs ? ? ? ? ? ? ? ? ? ? ?
FARs ? ? ? ? ? ? ? ? ? ?
QERs ? ? ? ? QoS ? ? ? ? ?
URRs ? ? ? ? ? ? ? ? ? ?
 ? ? ? ? ? ? ? ? ? ? ? ?

???

- ? **IP** ? ? ? ? ? ? ? UE IP ? ? ? ? ?
- ? **TEID** ? ? ? ? ? ? ? ID ? ? ? ?
- ? ? ? ? ? ? ? ? ? PDR/FAR/QER/URR JSON ? ? ? ?
- ? ? ? ? ? ? 10 ? ? ? ? ?

????? ?

????? "??" ? ? ? ? ? ? ?

- ? ? ? ? ? ? ? (**PDRs**) ? ? ? TEID ? UE IP ? FAR ID ? QER ID ? SDF ? ? ? ? ? ?
JSON
- ? ? ? ? ? ? ? (**FARs**) ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?
- **QoS** ? ? ? ? (**QERs**) ? MBR ? GBR ? QFI ? ? ? QoS ? ?
- ? ? ? ? ? ? ? (**URRs**) ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

??

?? UE ? ? ? ? ?

1. 
2.  UE IP 
3.  TEID 
4.  PDR/FAR 

- 
-  UPF 
- 



- $\diamond \diamond \diamond \diamond$ UE IP $\diamond$ TEID
- $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond \diamond$ FAR $\diamond \diamond \diamond \diamond$
- $\diamond \diamond$ QER QoS $\diamond \diamond$






10 UPF

-  UPF 
-  UPF 
- 

URL/rules

QoS

PDR $\diamond\diamond\diamond - \diamond\diamond\diamond\diamond\diamond\diamond$

◆◆◆◆◆ UPF ◆◆◆◆◆ PDR◆

◇◇ PDRs ◇ N3 → N6 ◇◇

- **TEID** $\diamond \diamond \diamond$ gNB $\diamond$ GTP-U $\diamond \diamond \diamond \diamond$ ID
- **FAR ID** $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- **QER ID** $\diamond \diamond \diamond \diamond$ QoS $\diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond \diamond$
- $\diamond \diamond \diamond \diamond \diamond \diamond \diamond$ GTP-U $\diamond \diamond \diamond \diamond \diamond$

◇◇ PDRs ◇ N6 → N3 ◇◇

- **UE IP**       IPv4  IPv6  
- **FAR ID**         
- **QER ID**     QoS         

- **SDF** 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 sdf + 16 16

IPv6 PDRs

- IPv6 16 16 16 16 PDR 16 16 16 16
- 16 16 IPv4 16 16 16 16 IPv6 16 16 16 16

FAR 16 16 - 16 16 16 16 16

16 16 16 16 FAR 16 16 16 16 16 16 16 16

16

16 16

FAR ID 16 16 16 16 16 16 16 16

16 16 16 16 16 16 16 16 FORWARD 16 16 DROP 16 16 BUFFER 16 16 DUPLICATE 16 16 NOTIFY 16

16 16 16 16 16 16 16 16 / 16 16

16 16 16 16 16 16 16 16 TEID 16 16 IP 16 16 16

FAR 16 16 16 16 16

- **FORWARD (1)** 16 16 16 16 16 16 16 16 16 16
- **DROP (2)** 16 16 16 16 16
- **BUFFER (4)** 16 16 16 16 16 16 16 16 16 16
- **NOTIFY (8)** 16 16 16 16 16 16 16 16 16 16 16 16
- **DUPLICATE (16)** 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16

16 16 16 16 16

- 16 16 "16 16 16 16" 16 "16 16 16 16" 16 16 16 16 16 16
- 16 16 16 16 16 16 16 16 16 16 16 16
- 16 16 16 eBPF 16 16 16 16 FAR 16 16

QER 16 16 16 - QoS 16 16 16 16

16 16 16 16 16 16 16 16 QoS 16 16 16

16

16 16

QER ID 16 16 16 QoS 16 16 16 16 16

MBR 16 16 16 16 16 16 16 16 16 16 16 16 16 16 kbps 16

MBR 16 16 16 16 16 16 16 16 16 16 16 16 16 16 kbps 16

GBR 16 16 16 16 16 16 16 16 16 16 16 16 16 16 kbps 16

GBR 16 16 16 16 16 16 16 16 16 16 16 16 16 16 kbps 16

QFI QoS 16 16 16 16 16 5G 16 16 16

QoS 16 16 16

- **MBR = 0** 16 16 16 16 16 16 16
- **GBR = 0** 16 16 16 16 16 16 16 16 16 16 16 16 16 16

- **GBR** > 0

URR -

URR ID

UE

UE

- B KB MB GB TB
-
-

- URR
- 1000 URR

1. → PDR
2. TEID UE IP
3. PDR FAR QER

1. → FAR
2. PDR FAR ID
3. FORWARD DROP BUFFER
- 4.

QoS

1. → QER
2. MBR GBR
3. 5G QFI

1. → URR

2. ????????????
3. ??????????
4. ??????

?????

URL?/buffers

??

??????? UPF ??????????????????????

???

???????????????

- ??????? FAR ????????
- ??????????
- ? **FARs** ????????? FAR ??
- ?? **FAR** ??????? FAR ?????????
- ???????????????
- ??? **TTL** ???????????????

? **FAR** ????

????????? FAR ????

?

??

FAR ID ????????

?????? FAR ????????

???? ? FAR ?????

???????????????

???????????????

?? ?????????????

???????

??????????? FAR ???????????

?????

- ???????????? FAR ?????? FAR ?????
- ???????????? FAR ???

?????

N6

- N6/IMS
- N6

1. /
- 2.
3. N3 N6

- 1.
2. XDP
- 3.

1. XDP
2. XDP
3. N3/N6

- 1.
2. UPF
- 3.

10

URL/capacity

UPF eBPF

eBPF

eBPF

uplink_pdr_map far_map

- <50%
- 50-70%
- 70-90%
- >90%

uplink_pdr_map

- TEID PDR
-
-

downlink_pdr_map / downlink_pdr_map_ip6

- UE IP PDR
- UE IPv4/IPv6
-

far_map

- FAR ID
- PDR
-

qer_map

- QER ID QoS
- QoS

urr_map

- 3 3 3 URR ID 3 3 3 3 3 3 3 3
- 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3

3 3

3 3 3 3 3

1. 3 3 3 3 3 3 3 3 3 3 3
2. 3 3 3 3 3 3 3 3 3 3
3. 3 3 3 3 3 3 3 3 3 3 3 3

3 3 3 3 3 3 3 3 3

1. 3 3 3 3 3 3 3 3 3 3 3 PDR 3 3 3 3 3 3
2. 3 3 3 3 3 3 3 3 3 3 3 3
3. 3 3 3 3 3 3 3 3 3 3

3 3 3 3 3 3 3 3 3

1. 3 3 3 3 3 3 3 3 3 3 3 3 3 3
2. 3 3 PDR 3 3 3 3 3 3 >90% 3 3 3 3 3 3 3 3
3. 3 3 3 3 3 3 3 3 3 3 3 3

3 3 3 3 3 3 3

1. 3 3 3 3 3 3 3 3
2. 3 3 3 3 3 3 3 3 3 3 3 3
3. 3 3 3 3 3 3 3 3 3 3 3 3 3 3

3 3 3 3

eBPF 3 3 3 3 3 3 UPF 3 3 3 3 UPF 3 3 3 3 3 3 3 3 3 3 3 3

- 3 3 3 3 3 3 3 3 3 3 10,000 - 100,000 3 3
- 3 3 3 3 3 3 3 3 3 3 100,000 - 1,000,000 3 3
- 3 3 3 3 3 3 3 3 3 3 1,000,000+ 3 3

3 3 3 3 3

3 3 3 3 = 3 3 3 3 + 3 3 3 3 × 3 3

3 3 3 3 3 3 3 3 100 3 3 3 3 3 3 64 3 3 3 3 PDR 3 3 3 3 3 3 3 3 64 MB 3 3 3 3 3 3

3 3 3 3

3 3 3 3 3 3 10 3 3 3 3 3 3

???

URL/routes

?

UE IP OSPF BGP

?

?

- ?
- ? UE IP ?
- ? ? ? ? ? ? ? ?
- ? ? ? ? ? ? ? ?

UE IP

IP

UE IP UE IPv4 IPv6

?

- ? UE IP
- ? ? ? ? ? ? ? ?
- ? ? ? ? ? ? ? ?

OSPF

OSPF

ID OSPF
OSPF IP
OSPF
OSPF
OSPF
OSPF
OSPF
OSPF

OSPF

- 222322222222222222
- 222222222222222222

BGP 222

BGP2222222222222222

2 22
 22 IP BGP 2222 IP 22
 ASN 2222222222
 22 BGP 2222222222222222
 2/2 2222222222
 22222222222222222222
 2222222222222222 BGP 22
 2222222222222222 BGP 22

BGP 222

- 2222222222222222 BGP 22222222
- 222222222222222222222222

22222222 BGP 222 ID 2 ASN222222 BGP 222

OSPF 22222

222222 UE 222 OSPF 22 LSA2222222222222222

2 22
 2222 IDLSA 2222222222222222
 22 2222222222
 222222 22222222222222 ID
 2222 OSPF 22222222E1 2 E22
 22 222 OSPF 22222
 22 LSA 22222222222222
 222 LSA 2222222222

222

- 22 UE 22222222222222 OSPF
- 222222222222222222
- 22 LSA 22222222

2222222

2222222

- 1-2 Mpps
-
-
-
-

- XDP
-

- “ ”
- XDP

XDP Mpps

- "✓ XDP_DRV"
-

- "△ XDP_DRV"
-
- "△ XDP_DRV"
-

- XDP

Mpps

Mpps Gbps

Mpps

- 0.1 - 100 Mpps
- XDP Mpps

- 128B - 9000 GTP

128B - 9000 GTP

- 128B - 9000 GTP
- 1200 GTP
- 1200 GTP

128B - 9000 GTP

- 64B
- 128B
- 256B
- 512B
- 1024B
- 1518B

128B - 9000 GTP

128B - 9000 GTP

- 128B - 9000 GTP
- 1200 Gbps = Mpps × Packet_Size × 8 / 1000
- 1200 GTP UDP IP

128B - 9000 GTP

- 128B - 9000 GTP
- 1200 Gbps ~ 50 GTP
- 1200 Gbps = Mpps × (Packet_Size - 50) / 1000

128B - 9000 GTP

- 128B - 9000 GTP
- 1200 Mpps = 10,000,000 / 1000

128B - 9000 GTP

- 128B - 9000 GTP
- 1200 Mpps × 1200 × 8 / 1000 ÷ 1000 = 96 Gbps

128B - 9000 GTP

128B - 9000 GTP

128B - 9000 GTP

- 128B - 9000 GTP

1. XDP DRV SKB
- 2.
- 3.
- 4.

XDP_DRV

- XDP NIC Intel i40e/ixgbe Mellanox mlx5
- NIC
- RSS
- NIC

XDP_SKB

-
-
-

- CPU
-
- RSS

XDP 30

URL/logs

OmniUPF

- Phoenix LiveView
-
-
-

OmniUPF Elixir Logger

- **DEBUG** 
- **INFO** 
- **WARNING** 
- **ERROR** 

?

1. 
2.  SMF 
3.  PCF 

◆◆ PFCP ◆◆◆

1. $\diamond \diamond$ PFCP $\diamond \diamond \diamond \diamond \diamond \diamond$
2. $\diamond \diamond \diamond \diamond \diamond \diamond / \diamond \diamond / \diamond \diamond$
3. $\diamond \diamond \diamond \diamond \diamond \diamond$

1.         
2.   eBPF      
3.   FAR/PDR     






◆ ◆ ◆ ◆

???

-
-               
-                
-              
-                 **XDP**    

- 
- 
- 
- 

- UE UE
- UE
- UPF UPF
- UPF

UE

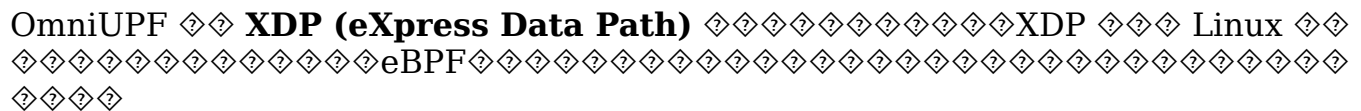
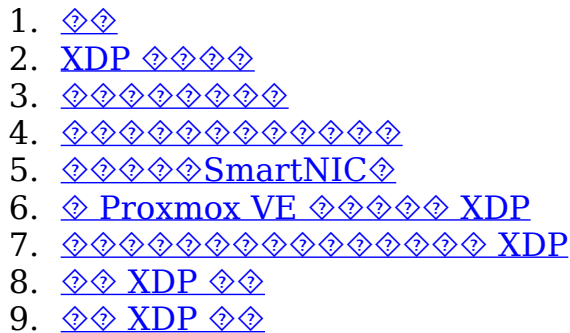
- UE UE
- UE UE
- UE
- UE

UE

- 5-10 5-10
- 5-10
- URR URR
- UPF UPF

UE

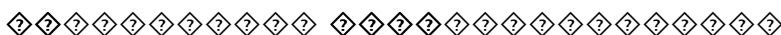
- PFCP PFCP
- PDR FAR QER URR
- UE FRR
- XDP XDP eBPF
- UPF UPF



 XDP
 OmniUPF
 UPF



			
	Linux 		NIC 
	~1-2 Mpps	~5-10 Mpps	~10-40 Mpps
	~100 μ s	~10 μ s	~1 μ s
CPU 			
NIC 	 NIC	 XDP 	 XDP  SmartNIC
			
			
			
			
	xdp_attach_mode: generic	xdp_attach_mode: native	xdp_attach_mode: offload



???????

??

?? XDP ?????? ?? Linux ????? eBPF ????? XDP ???
???????

????

- ????? ~?? 1-2 ????? (Mpps)
- ????? ~100 ??
- **CPU** ????? XDP ?????

????

- ?????
- ?????
- ?????

??

```
# config.yaml
interface_name: [eth0]
xdp_attach_mode: generic # ????
```

????? ???? ???? ???? ???? ???? ???? ???? ???? ???? ???? ???? CPU ???

????????

??

?? XDP ?????? ?? eBPF ????? Linux ??????
???????

????

- ????? ~5-10 ????? (Mpps)
- ????? ~10 ??
- **CPU** ?????
- ???? CPU ???? NIC ?????

????

- ?????

- 100Gbps
- 100Gbps
- 100Gbps

NIC

XDP XDP NIC XDP

NIC

- Intel: ixgbe (10G), i40e (40G), ice (100G)
- Broadcom: bnxt_en
- Mellanox: mlx4_en, mlx5_core
- Netronome: nfp
- Marvell: mvneta, mvpp2

NIC

- VirtIO: virtio_net (KVM, Proxmox, OpenStack) ✓
- VMware: vmxnet3 ✓
- Microsoft: hv_netvsc (Hyper-V) ✓
- Amazon: ena (AWS) ✓
- SR-IOV: ixgbevf, i40evf PCI ✓

VirtualBox XDP

```
# config.yaml
interface_name: [eth0]
xdp_attach_mode: native
```

NIC Proxmox

SmartNIC

XDP NIC SmartNIC eBPF CPU

- ~10-40 (Mpps)
- ~1
- CPU NIC

3. $\diamondsuit \diamondsuit \diamondsuit \diamondsuit \diamondsuit$

- " "
- **8** vCPU 16
-

4.     

-

?? B?? Proxmox ??

SSH  Proxmox 

```
#        ID
qm list
```

```
# XXX ID
qm set XXX -net0 virtio=XX:XX:XX:XX:XX:XX,bridge=vmbro,queues=8
```

```
# 191 MAC BC:24:11:1D:BA:00
qm set 191 -net0 virtio=BC:24:11:1D:BA:00,bridge=vmbro,queues=8
```

```
# 
qm shutdown XXX
```

```
#  
qm start XXX
```









- **4**  2-4 vCPU 
- **8**  4-8 vCPU 
- **16**  8+ vCPU 



3














◆◆◆◆◆ SSH ◆◆◆◆◆

```
#      
ethtool -l eth0
```

```
# 5
# eth0 6
# Combined:      8      <-- 10
```

```
# 
ls -ld /sys/class/net/eth0/queues/rx-* | wc -l
```

```
ls -ld /sys/class/net/eth0/queues/tx-* | wc -l
```

```
# 8
```

4 OmniUPF XDP

OmniUPF

```
#
```

```
sudo nano /etc/eupf/config.yaml
```

XDP

```
#
```

```
xdp_attach_mode: generic
```

```
#
```

```
xdp_attach_mode: native
```

OmniUPF

```
sudo systemctl restart eupf
```

5 XDP

```
#
```

```
journalctl -u eupf --since "1 minute ago" | grep -i "xdp\|attach"
```

```
#
```

```
# xdp_attach_mode:native
```

```
# XDPAttachMode:native
```

```
# XDP "eth0" 2
```

API

```
#
```

```
curl -s http://localhost:8080/api/v1/config | grep xdp_attach_mode
```

```
#
```

```
# "xdp_attach_mode": "native",
```

Proxmox

"XDP"

- `ethtool -l eth0`
- `uname -r ≥ 5.15`
- `VirtIO lsmod | grep virtio_net`

`1`

- `qm shutdown XXX && sleep 5 && qm start XXX`
- `Proxmox grep net0 /etc/pve/qemu-server/XXX.conf`

- `CPU`
- `top - CPU`
- `XDP curl http://localhost:8080/api/v1/xdp_stats`

XDP

VMware ESXi / vSphere

VMware `vmxnet3` XDP

- ESXi 6.7
- `vmxnet3` 1.4.16+
- 14

1.

2.

- `→`
- `→`
-

3. `.vmx`

```
ethernet0.pnicFeatures = "4"
ethernet0.multiqueue = "8"
```

4. `ethtool -l ens192`

```
ethtool -l ens192 #
```

OmniUPF

```
interface_name: [ens192] # VMware ens192
xdp_attach_mode: native
```

KVM / libvirt

`virsh`

```
#
```

```
virsh edit your-vm-name
```

```
<interface type='network'>
  <source network='default' />
  <model type='virtio' />
  <driver name='vhost' queues='8' />
</interface>
```

```
ethtool -l eth0
```

Microsoft Hyper-V

Hyper-V `hv_netvsc` XDP

- Windows Server 2016
- Linux 4.3+
-

Hyper-V PowerShell

```
# VMQ - Hyper-V
Set-VMNetworkAdapter -VMName "YourVM" -VrssEnabled $true -VmmqEnabled $true
```

OmniUPF

```
interface_name: [eth0]
```

xdp_attach_mode: native

VirtualBox

VirtualBox XDP
VirtualBox e1000 virtio-net XDP

xdp_attach_mode: generic # VirtualBox

XDP

XDP

1. OmniUPF

```
# journalctl -u eupf --since "5 minutes ago" | grep -i xdp
#
# ✓ "xdp_attach_mode:native"
# ✓ "XDP"
# x " " " "
```

2. API

```
# curl -s http://localhost:8080/api/v1/config | jq .xdp_attach_mode
#
# "native"
```

3. XDP

```
# XDP
curl -s http://localhost:8080/api/v1/xdp_stats | jq
#
{
  "xdp_aborted": 0,      # 0
  "xdp_drop": 1234,     #
  "xdp_pass": 5678,     #
  "xdp_redirect": 9012, #
  "xdp_tx": 3456        #
```

```
}
```

4. 检查驱动

```
# 检查 XDP 驱动
ethtool -i eth0 | grep driver

# 检查 Proxmox/KVM 驱动 "virtio_net"
# 检查 VMware 驱动 "vmxnet3"
# 检查 Hyper-V 驱动 "hv_netvsc"
```

5. 性能测试

检查 XDP 性能

```
# 持续监控 XDP 性能
watch -n 1 'curl -s http://localhost:8080/api/v1/packet_stats | jq .rx_packets'

# 目标性能 ~1-2 Mpps
# 目标性能 ~5-10 Mpps 5-10 秒
```

检查 XDP

检查“XDP 性能”

检查

检查 XDP 驱动 eth0

检查

1. 检查驱动

```
ethtool -i eth0 | grep driver

# 检查 virtio_net/vmxnet3/hv_netvsc 驱动 XDP 性能
```

2. 检查内核版本

```
uname -r

# 内核版本 ≥ 5.15 支持 XDP
```

3. 检查 XDP 性能

```
ip link show eth0 | grep xdp

# ❶❷❸❹❺❻❼❽❾❿ XDP ❶❷❸❹❺❻❼❽❾❿
ip link set dev eth0 xdp off
```

❶❷❸❹❺

- ❶❷❸❹❺❻❼❽❾❿ 5.15+
- ❶❷❸❹❺ virtio_net ❶❷❸❹❺ modprobe virtio_net
- ❶❷❸❹❺❻❼❽❾❿ XDP ❶❷❸❹❺❻❼❽❾❿

❶❷❸❹❺❻❼❽❾❿

❶❷❸

```
❶❷❸❹❺❻❼❽❾❿ XDP ❶❷
```

❶❷❸

❶❷ dmesg ❶❷❸❹❺❻❼❽❾❿

```
dmesg | grep -i xdp | tail -20
```

❶❷❸❹❺

1. ❶❷❸❹❺❻❼❽❾❿ **XDP**❶

- VirtualBox ❶❷❸❹❺❻❼❽❾❿ XDP❶
- ❶❷❸ NIC ❶❷❸❹

2. ❶❷❸❹❺❻❼❽❾❿

- ❶❷❸ ethtool -l eth0
- ❶❷❸ > 1 ❶❷❸❹❺

3. ❶❷ **XDP** ❶❷❸❹❺❻❼❽❾❿

```
# ❶❷❸❹❺❻❼❽❾❿ XDP
grep XDP /boot/config-$(uname -r)

# ❶❷❸❹❺
# CONFIG_XDP_SOCKETS=y
# CONFIG_BPF=y
```

❶❷❸❹❺❻❼❽❾❿

- ❶❷❸❹❺❻❼❽❾❿ Proxmox ❶❷❸
- ❶❷❸❹❺❻❼❽❾❿

- `cat /sys/kernel/debug/tracing/trace` XDP

`cat /sys/kernel/debug/tracing/trace`

`cat /sys/kernel/debug/tracing/trace`

`cat /sys/kernel/debug/tracing/trace`

1. `cat /sys/kernel/debug/tracing/trace`

```
# cat /sys/kernel/debug/tracing/trace
ethtool -S eth0 | grep rx_queue

# cat /sys/kernel/debug/tracing/trace
```

2. `cat /sys/kernel/debug/tracing/trace` CPU

```
# cat /sys/kernel/debug/tracing/trace CPU
mpstat -P ALL 1

# cat /sys/kernel/debug/tracing/trace CPU
```

3. `cat /sys/kernel/debug/tracing/trace` XDP

```
# cat /sys/kernel/debug/tracing/trace
sudo bpftool net list

# cat /sys/kernel/debug/tracing/trace XDP
```

`cat /sys/kernel/debug/tracing/trace`

- `cat /sys/kernel/debug/tracing/trace` 8-16
- `cat /sys/kernel/debug/tracing/trace` CPU
- `cat /sys/kernel/debug/tracing/trace` CPU

`cat /sys/kernel/debug/tracing/trace` XDP `xdp_aborted > 0`

`cat /sys/kernel/debug/tracing/trace`

```
curl http://localhost:8080/api/v1/xdp_stats
{
  "xdp_aborted": 1234, # cat /sys/kernel/debug/tracing/trace
  ...
}
```

`cat /sys/kernel/debug/tracing/trace`

XDP eBPF

1. **?? eBPF** **???**

```
dmesg | grep -i bpf | tail -20
```

[illegible]

```
# eBPF 111111
curl http://localhost:8080/api/v1/map_info

# 111111 100% 111
```







-  eBPF 
-  eBPF 
-  Linux  eBPF 

Proxmox

[illegible]

?

1. Proxmox

```
# Proxmox
grep net0 /etc/pve/qemu-server/YOUR_VM_ID.conf

# queues=8
```

[illegible]

```
# Proxmox
qm status YOUR_VM_ID

# " " " " " "
```







```
# ? Proxmox ? ? ?
# ? ? ? ? ? ? ?
qm shutdown YOUR_VM_ID
sleep 10
qm start YOUR_VM_ID

# ? ? ? ? ? ? ? ? ? ?
```


?

?

- ```
sudo systemctl restart eupf
```

- ```
# /lib/systemd/system/eupf.service
[Service]
CapabilityBoundingSet=CAP_NET_ADMIN CAP_SYS_ADMIN CAP_NET_RAW
AmbientCapabilities=CAP_NET_ADMIN CAP_SYS_ADMIN CAP_NET_RAW
```

- ```
docker run --privileged -v /sys/fs/bpf:/sys/fs/bpf ...
```

OmniUPF 


































Netronome Agilio CX 10G 10GbE XDP  
 Netronome Agilio CX 25G 25GbE  
 Netronome Agilio CX 40G 40GbE \$2,500-5,000  
 Netronome Agilio CX 100G 100GbE

NIC XDP

OmniUPF

**1-10 Gbps**

- **NIC** Intel X520 10GbE
- XDP
- UPF ~8-10 Gbps
- ~\$100-200 /

**10-50 Gbps**

- **NIC** Intel X710 40GbE Mellanox ConnectX-4 25GbE
- XDP
- UPF ~25-40 Gbps
- ~\$300-800

**50-100+ Gbps**

- **NIC** Mellanox ConnectX-5/6 100GbE
- XDP
- UPF ~80-100 Gbps
- ~\$1,000-2,500

**Proxmox/KVM**

- **NIC** VirtIO 8-16
- XDP
- UPF ~5-10 Gbps
- 

OmniUPF

NIC/  
**Realtek NICs** XDP Linux Intel i350

|                        |     |                |
|------------------------|-----|----------------|
| <b>NIC/</b>            |     |                |
| <b>VirtualBox</b>      | XDP | Proxmox/KVM    |
| <b>NICs</b>            |     | Intel/Mellanox |
| <b>NICs (&lt;2014)</b> | XDP | Intel X520     |

1. Linux XDP

```
#
modinfo <driver_name> | grep -i xdp
```

2.  $\geq 5.15$  XDP

```
uname -r
```

3. NIC RSS/VMDq

4. **PCI** PCIe

- 10GbE PCIe 2.0 x4
- 40GbE PCIe 3.0 x8
- 100GbE PCIe 3.0 x16 PCIe 4.0 x8

- 5.

- NIC
- VirtIO SR-IOV
- NIC

⚠ - **Omnitouch**

- [CONFIGURATION.md](#) -
- [TROUBLESHOOTING.md](#) -
- [ARCHITECTURE.md](#) - eBPF XDP
- [MONITORING.md](#) -

◆◆◆◆

## Proxmox ◆◆ XDP ◆◆◆TL;DR◆

```
◆ Proxmox ◆◆◆◆
qm set <VM_ID> -net0 virtio=<MAC>,bridge=vbr0,queues=8
qm shutdown <VM_ID> && sleep 10 && qm start <VM_ID>

◆◆◆◆◆◆◆
ethtool -l eth0 # ◆◆ 8 ◆◆◆
sudo nano /etc/eupf/config.yaml # ◆◆◆xdp_attach_mode: native
sudo systemctl restart eupf
journalctl -u eupf --since "1 min ago" | grep xdp # ◆◆◆◆◆◆
```

## ◆◆ XDP ◆◆◆◆◆◆◆◆◆◆

```
◆◆◆◆
curl -s http://localhost:8080/api/v1/config | grep xdp_attach_mode

◆◆◆◆◆◆
curl -s http://localhost:8080/api/v1/xdp_stats | jq

◆◆◆◆
ethtool -l eth0
```



# OmniUPF API



OmniUPF API RESTful eBPF API

- **PFCP**
- **(PDR)** IPv4 IPv6
- **(FAR)**
- **QoS (QER)**
- **(URR)**
- 
- 
- XDP N3/N6
- FRR UE
- UPF

## Swagger API

API **OpenAPI 3.0 (Swagger)** Swagger UI

- 
- API
- 
- HTTP

Swagger UI OmniUPF API

## Swagger UI

Swagger

`http://<upf-host>:8080/swagger/index.html`

`http://10.98.0.20:8080/swagger/index.html`

## API

API

`/api/v1`

## ? ?

- [UE ? ? ? ? ? ?](./routes.md) - FRR ? ? ? ? ? ? ? ? ? ? ? ? ? ?
- [? ? ? ?](../OPERATIONS.md) - Web UI ? ? ? ? ?
- [Swagger UI](http://10.98.0.20:8080/swagger/index.html) - ? ? ? API  
? ?



```

frr version 7.2.1
frr defaults traditional
hostname pgw02
log syslog informational
service integrated-vtysh-config
!
ip route {{
hostvars[inventory_hostname]['ansible_default_ipv4']['gateway'] }}/32
{{ ansible_default_ipv4['interface'] }}
!
interface {{ ansible_default_ipv4['interface'] }}
ip address ospf router-id
{{hostvars[inventory_hostname]['ansible_host']}}
ip ospf authentication null
!
router ospf
ospf router-id {{hostvars[inventory_hostname]['ansible_host']}}
redistribute kernel
network {{
hostvars[inventory_hostname]['ansible_default_ipv4']['network'] }}/{{
mask_cidr }} area 0
area 0 authentication message-digest
!
line vty
!
end

```

◆◆◆◆◆

1. ◆◆◆◆◆ Ansible ◆◆◆◆◆ FRR Jinja2 ◆◆◆◆◆roles/frr/  
templates/frr.conf.j2◆
2. ◆◆◆◆◆ Ansible ◆◆◆◆◆ UPF ◆◆◆◆◆
3. ◆◆◆◆◆ Ansible ◆◆◆ FRR ◆◆◆◆◆ UPF ◆◆
4. ◆◆◆◆◆Ansible ◆◆◆◆◆IP ◆◆◆◆◆ ID ◆◆◆◆◆ UPF ◆  
FRR ◆◆

## Jinja2 ◆◆◆◆◆

- **OSPF** ◆◆◆◆◆ ID◆◆◆◆◆
- **BGP** ◆◆◆ASN◆◆◆◆◆
- ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆redistribute kernel◆
- ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
- ◆◆◆◆◆OSPF/BGP ◆◆◆◆◆

**UPF** ◆◆◆◆◆ FRR ◆◆◆◆◆ UPF ◆◆◆UPF ◆◆◆◆◆ PFCP ◆◆◆◆◆  
UE IP ◆◆◆◆◆ /32 ◆◆◆◆◆ ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

1. ◆ **UPF** ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
2. ◆◆ **redistribute kernel** ◆◆◆ **FRR** ◆◆

3. **FRR** **OSPF** **BGP**
4. UE UPF

- Ansible FRR Jinja2 UPF
- **Ansible** Jinja2 OSPF BGP
- **UPF** UPF PFCP UE IP /32
- UPF FRR UE
- Ansible UPF

## Web UI

UPF

- 
- UE IP
- 
- UE IP
- **OSPF** OSPF
- **BGP** BGP
- **OSPF** UE LSA

UE

Web UI

1. UPF UE
2. FRR
- 3.
- 4.
- 5.

-



◇ ◇ ◇ ◇ ◇ ◇

1. UPF ◇ ◇ ◇ ◇ ◇ ◇ UE IP ◇ ◇
2. ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ FRR
3. FRR ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ OSPF
4. OSPF ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇