OmniUPF [illegible]

[illegible]

1. [illegible]
2. [illegible] 5G [illegible]
3. UPF [illegible]
4. PFCP [illegible] SMF [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]

[illegible]

OmniUPF[illegible] eBPF [illegible] 5G/LTE [illegible]QoS [illegible] Linux eBPF[illegible]OmniUPF [illegible] 5G SA[illegible]5G NSA [illegible] LTE [illegible]

[illegible]���[illegible]

[illegible]UPF[illegible] 3GPP [illegible] 5G [illegible] LTE [illegible]

- [illegible] [illegible]
- [illegible]**QoS**[illegible] [illegible]
- [illegible]
- [illegible] [illegible]
- [illegible] [illegible]
- [illegible] [illegible]

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

OmniUPF □□□□

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

QoS □□□□□□

- □□□□□ QoS □□□□□QER□
- □□□□□□□□□□□PDR□
- □□□□□□□□□□□□FAR□
- □□□□□□□□□□□□□□□□SDF□□□
- □□□□□□□□□□□□□□□URR□

□□□□���□

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

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- □□ eBPF □□□□□□□□□□
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□□□□□□□□□□□□□□□ Web UI □□□

[illegible]

OmniUPF [illegible] 5G [illegible]SA[illegible]5G NSA [illegible] 4G LTE/EPC [illegible]**OmniUPF** [illegible]

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

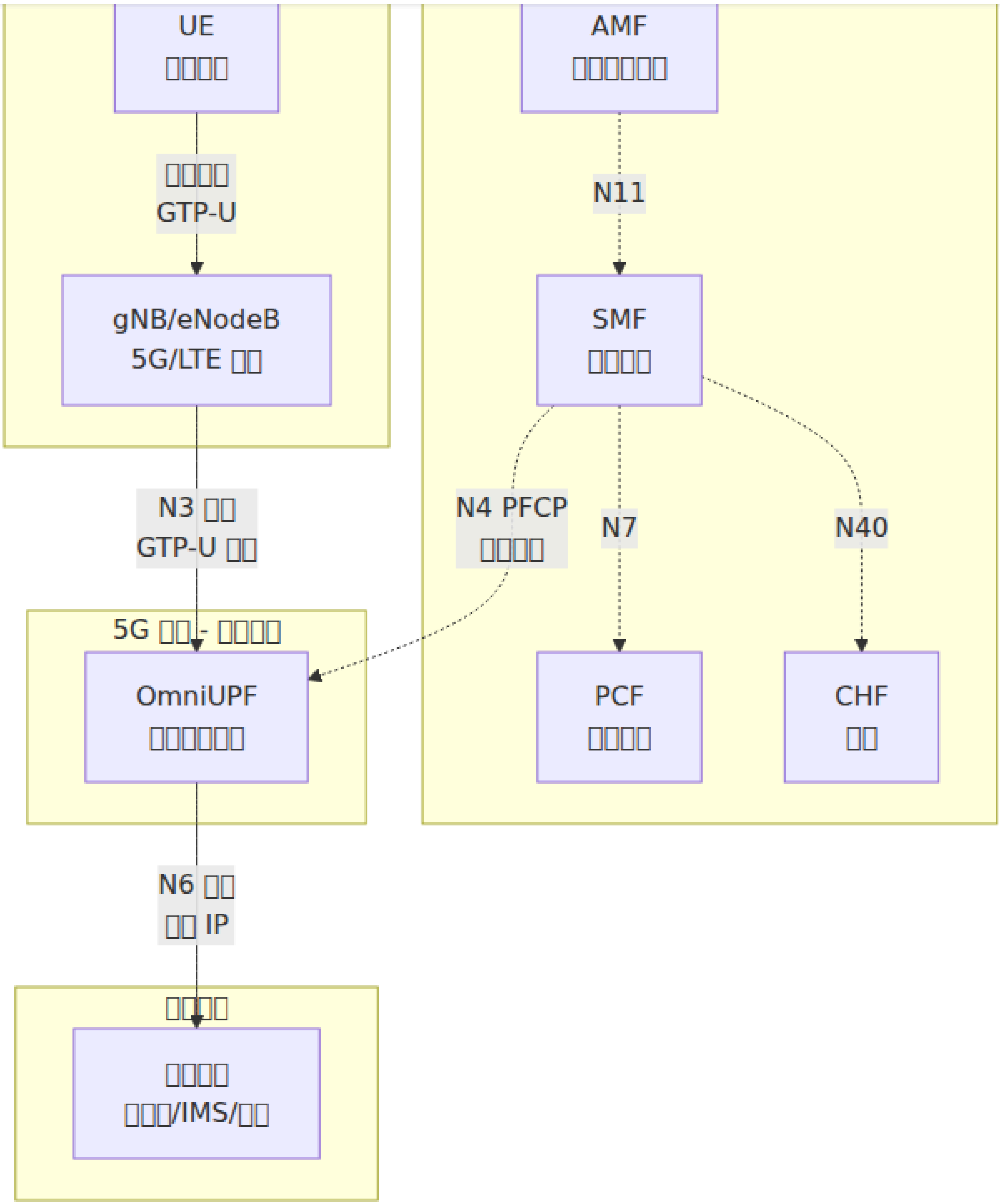
OmniUPF [illegible] [illegible] [illegible]

- [illegible] **UPF**[illegible] 5G [illegible]
- **PGW-U + SGW-U**[illegible] 4G [illegible] EPC [illegible]
- **UPF + PGW-U + SGW-U**[illegible] 4G [illegible] 5G[illegible]

[illegible] eBPF [illegible] PFCP [illegible]���[illegible] UPF[illegible]PGW-U[illegible]SGW-U [illegible]

5G [illegible]SA [illegible]

OmniUPF [illegible] 5G [illegible]


UE
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AMF
□□□□□□
□□□□
GTP-U
N11
gNB/eNodeB
5G/LTE □□
SMF
□□□□
N3 □□
GTP-U □□
N4 PFCP
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N7
N40
5G □□- □□□□
OmniUPF
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PCF
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CHF
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N6 □□
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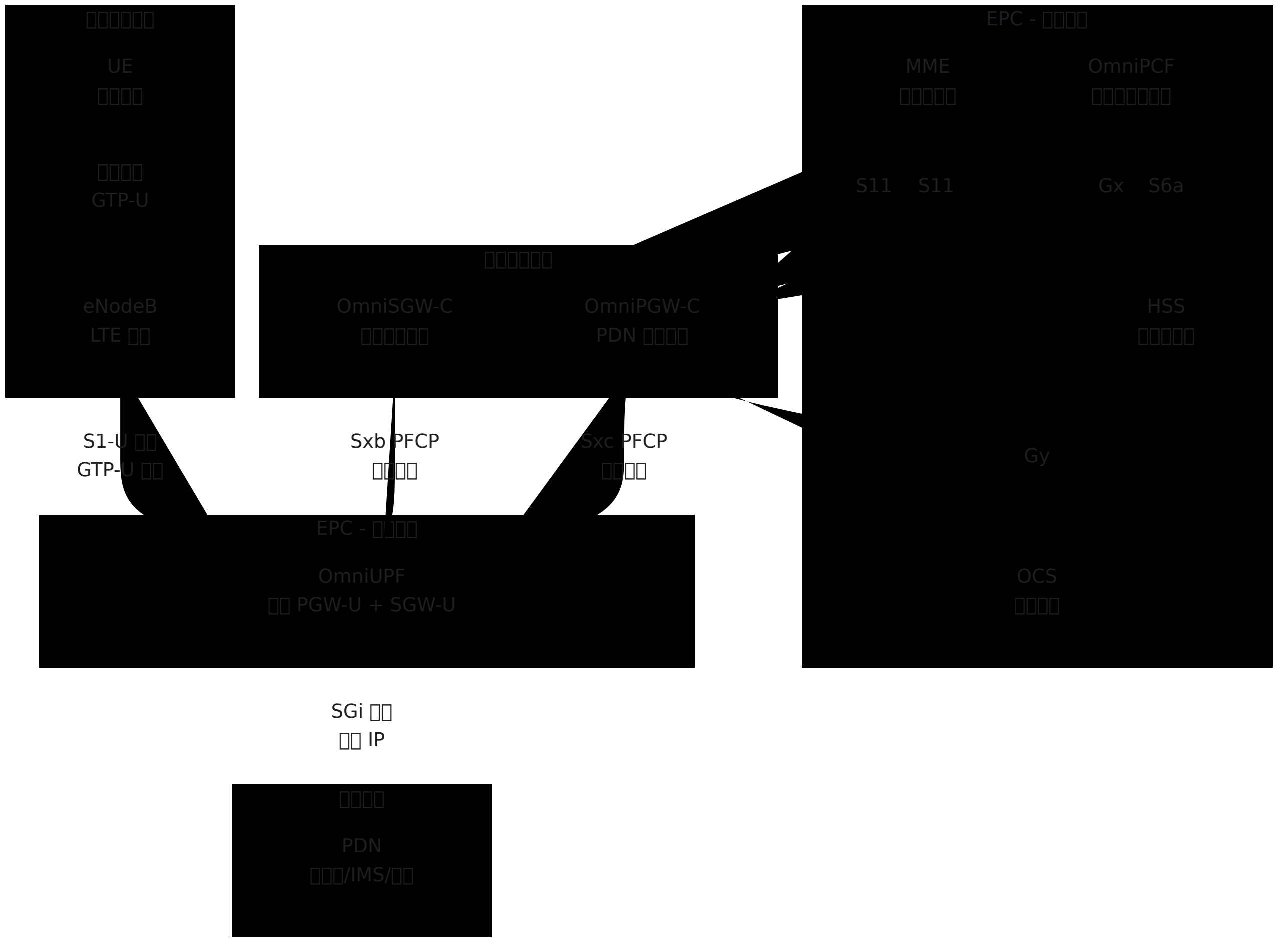
□□□/IMS/□□

4G LTE/EPC □□□□

OmniUPF □□□ 4G LTE □ EPC□□□□□□□□□□□□□□□□□□□□□□□□ OmniPGW-U □ OmniSGW-U □□□

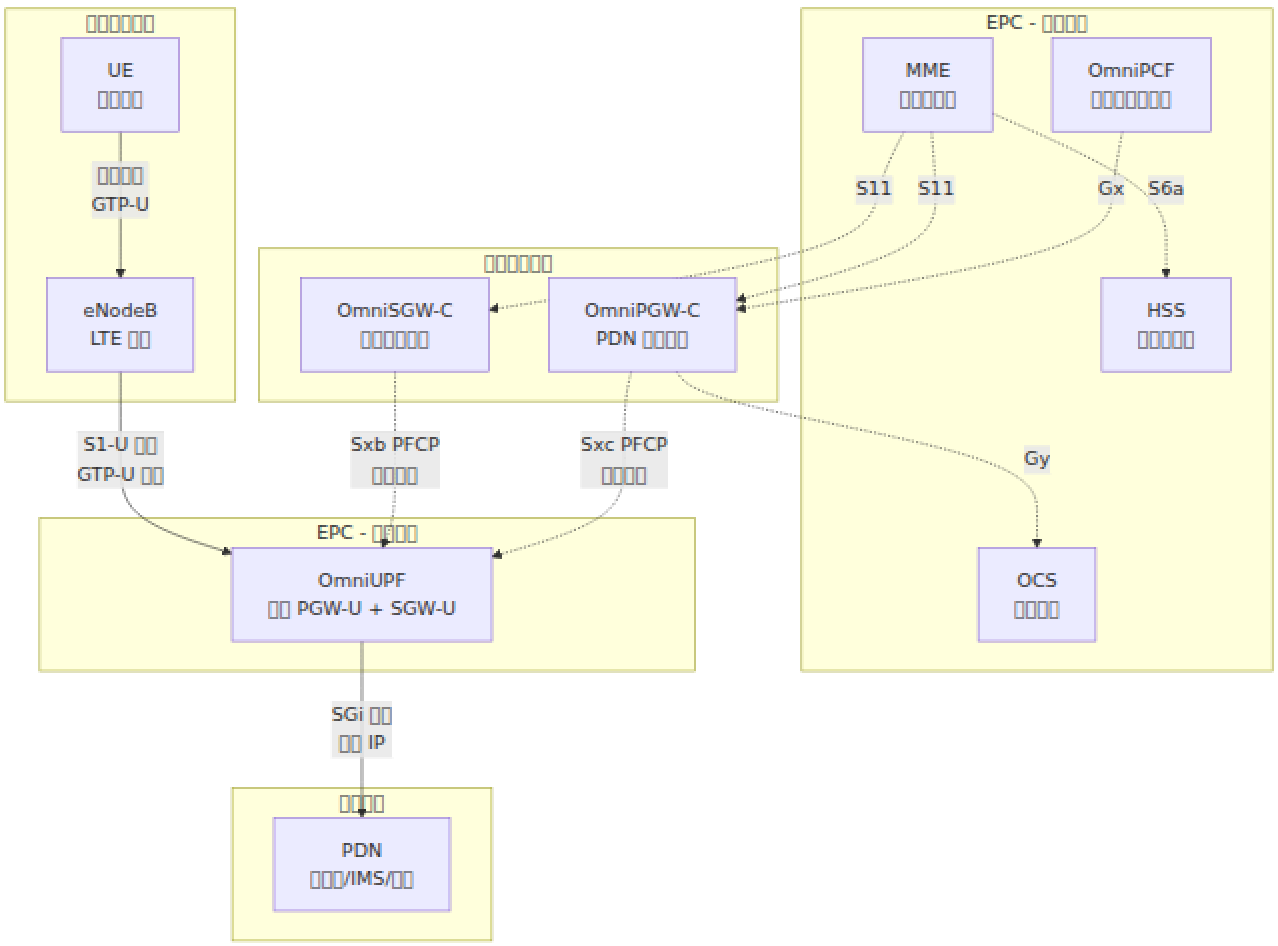
[illegible] PGW-U/SGW-U [illegible] 4G [illegible]

[illegible]OmniUPF [illegible] SGW-U [illegible] PGW-U[illegible]


UE
GTP-U
eNodeB
LTE
OmniSGW-C
OmniPGW-C
PDN
EPC -
MME
OmniPCF
S11
S11
Gx
S6a
HSS
S1-U
GTP-U
Sxb PFCP
Sxc PFCP
Gy
EPC -
OmniUPF
PGW-U + SGW-U
OCS
SGi
IP
PDN
/IMS/

[illegible] SGW-U [illegible] PGW-U [illegible]/[illegible]

[illegible] OmniUPF [illegible] - [illegible] SGW-U[illegible] PGW-U[illegible]


UE
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GTP-U
eNodeB
LTE [illegible]
EPC - [illegible]
MME
OmniPCF
S11
S11
Gx
S6a
OmniSGW-C
OmniPGW-C
PDN [illegible]
HSS
S1-U [illegible]
GTP-U [illegible]
Sxb PFCP
Sxc PFCP
Gy
EPC - [illegible]
OmniUPF
[illegible] PGW-U + SGW-U
OCS
SGi [illegible]
[illegible] IP
PDN
[illegible]/IMS/[illegible]

[illegible]

[illegible]OmniUPF[illegible]OmniPGW-U [illegible] OmniSGW-U[illegible]

1. [illegible]
   - **5G**[illegible]OmniSMF [illegible] N4 [illegible] OmniUPF [illegible] PFCP [illegible]
   - **4G**[illegible]OmniPGW-C [illegible] OmniSGW-C [illegible] Sxb/Sxc [illegible] OmniPGW-U/OmniSGW-U [illegible] PFCP [illegible]
   - [illegible] UE PDU [illegible]5G[illegible] PDP [illegible]4G[illegible] PFCP [illegible]
   - [illegible] PFCP [illegible] PDR[illegible]FAR[illegible]QER [illegible] URR [illegible]
   - eBPF [illegible]
2. [illegible]UE → [illegible]
   - **5G**[illegible] N3 [illegible] gNB [illegible] GTP-U [illegible]
   - **4G**[illegible] S1-U [illegible]SGW-U[illegible] S5/S8 [illegible]PGW-U[illegible] eNodeB [illegible] GTP-U [illegible]

    - [illegible] TEID [illegible] PDR [illegible]
    - eBPF [illegible] QER[illegible]
    - FAR [illegible]
    - [illegible] GTP-U [illegible] N6[illegible]5G[illegible] SGi[illegible]4G[illegible]
    - URR [illegible]

3. [illegible] → UE[illegible]

    - **5G**[illegible] N6 [illegible] IP [illegible]
    - **4G**[illegible] SGi [illegible] IP [illegible]
    - [illegible] UE IP [illegible] PDR [illegible]
    - SDF [illegible]
    - FAR [illegible] GTP-U [illegible]
    - [illegible] TEID [illegible] GTP-U [illegible]
    - **5G**[illegible] N3 [illegible] gNB
    - **4G**[illegible] S1-U[illegible]SGW-U[illegible] S5/S8[illegible]PGW-U[illegible] eNodeB

4. [illegible]

    - **5G**[illegible]OmniSMF [illegible] PDR/FAR [illegible]
    - **4G**[illegible]OmniSGW-C/OmniPGW-C [illegible] eNodeB [illegible] TAU[illegible]
    - [illegible]��[illegible]
    - [illegible]

[illegible]4G [illegible] 5G[illegible]

OmniUPF [illegible] 3GPP [illegible] 5G [illegible] 4G [illegible]

5G [illegible]

□□	□ → □	□□	**3GPP □□**
N4	OmniSMF ↔ OmniUPF	PFCP □□□□□□□□□□	TS 29.244
N3	gNB → OmniUPF	□□ RAN □□□□□□□□GTP-U□	TS 29.281
N6	OmniUPF → □□□□	□ DN □□□□□□□□□□ IP□	TS 23.501
N9	OmniUPF ↔ OmniUPF	□□/□□□□ UPF □□	TS 23.501

4G/EPC □□

□□	□ → □	□□	**3GPP □□**
Sxb	OmniSGW-C ↔ OmniUPF□SGW-U □□□	□□□□□ PFCP □□□□	TS 29.244
Sxc	OmniPGW-C ↔ OmniUPF□PGW-U □□□	PDN □□□ PFCP □□□□	TS 29.244
S1-U	eNodeB → OmniUPF□SGW-U □□□	□□ RAN □□□□□□□□GTP-U□	TS 29.281
S5/S8	OmniUPF□SGW-U□↔ OmniUPF□PGW-U□	□□□□□□□□GTP-U□	TS 29.281
SGi	OmniUPF□PGW-U □□□→ PDN	□□□□□□□□□□□□□□□IP□	TS 23.401

□□□□□ PFCP □��□N4□Sxb□Sxc□□□ TS 29.244 □□□□□□ PFCP □□□□□□□□□□□□□□□□□□□□□□

UPF [illegible]

eBPF [illegible]

eBPF [illegible] Linux [illegible]

[illegible]

- **GTP-U** [illegible]GTP-U [illegible]
- [illegible] TEID[illegible]UE IP [illegible] SDF [illegible] PDR [illegible]
- **QoS** [illegible] QER [illegible]
- [illegible] FAR [illegible]
- [illegible] URR [illegible]

eBPF [illegible] eBPF [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`uplink_pdr_map`	[illegible] PDR	TEID[illegible]32 [illegible]	PDR [illegible]FAR ID[illegible]QER ID[illegible]URR IDs[illegible]
`downlink_pdr_map`	[illegible] PDR [illegible]IPv4[illegible]	UE IP [illegible]	PDR [illegible]
`downlink_pdr_map_ip6`	[illegible] PDR [illegible]IPv6[illegible]	UE IPv6 [illegible]	PDR [illegible]
`far_map`	[illegible]	FAR ID	[illegible]
`qer_map`	QoS [illegible]	QER ID	QoS [illegible]MBR[illegible]GBR[illegible]
`urr_map`	[illegible]	URR ID	[illegible]
`sdf_filter_map`	SDF [illegible]	PDR ID	[illegible]

[illegible]

- [illegible]
- **XDP** [illegible]
- [illegible] CPU [illegible] CPU [illegible]
- [illegible]eBPF [illegible] PDR/FAR[illegible]

[illegible] [illegible][illegible]

PFCP [illegible]

PFCP [illegible] 3GPP TS 29.244[illegible] SMF [illegible] PGW-C [illegible]

[illegible]

- [illegible]PFCP [illegible]/[illegible]
- [illegible] PFCP [illegible]
- [illegible] PFCP [illegible] eBPF [illegible]
- [illegible] SMF [illegible]

PFCP [illegible]

[illegible]	[illegible]	[illegible]
[illegible]	SMF → UPF	[illegible] PFCP [illegible]
[illegible]	SMF → UPF	[illegible] PFCP [illegible]
[illegible]	[illegible]	[illegible]
[illegible]	SMF → UPF	[illegible] PDU [illegible] PDR/FAR/QER/URR
[illegible]	SMF → UPF	[illegible]QoS [illegible]
[illegible]	SMF → UPF	[illegible]��[illegible]
[illegible]	UPF → SMF	[illegible]

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- □□ PDR□FAR□QER□URR
- □□ PDR□FAR□QER□URR
- □□ PDR□FAR□QER□URR
- □□□□□□□□UE IP□F-TEID□SDF □□□□
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- QoS □□□MBR□GBR□QFI□
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REST API □□□

REST API □□□ UPF □□□□□□□□□□

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- □□□□□□□□□□ PFCP □□□□□
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- □□□□□□□□□□□□□□□□□□□XDP □□
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- □□□□□□□ eBPF □□□□□□□□

API □□□□□ 34 □□□□

[illegible]	[illegible]	[illegible]
[illegible]	`/health`	[illegible]
[illegible]	`/config`	UPF [illegible]
[illegible]	`/pfcp_sessions`, `/pfcp_associations`	PFCP [illegible]/[illegible]
PDRs	`/uplink_pdr_map`, `/downlink_pdr_map`, `/downlink_pdr_map_ip6`, `/uplink_pdr_map_ip6`	[illegible]
FARs	`/far_map`	[illegible]
QERs	`/qer_map`	QoS [illegible]
URRs	`/urr_map`	[illegible]
[illegible]	`/buffer`	[illegible]
[illegible]	`/packet_stats`, `/route_stats`, `/xdp_stats`, `/n3n6_stats`	[illegible]
[illegible]	`/map_info`	eBPF [illegible]
[illegible]	`/dataplane_config`	N3/N9 [illegible]

[illegible] API [illegible] [illegible]。

Web [illegible]

Web [illegible] UPF [illegible]

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- □□□□□□□ UPF □□□□□□□□□
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□□□□□ UI □□□□□□ **Web UI □□□□**□

PFCP □□□ SMF □□

PFCP □□

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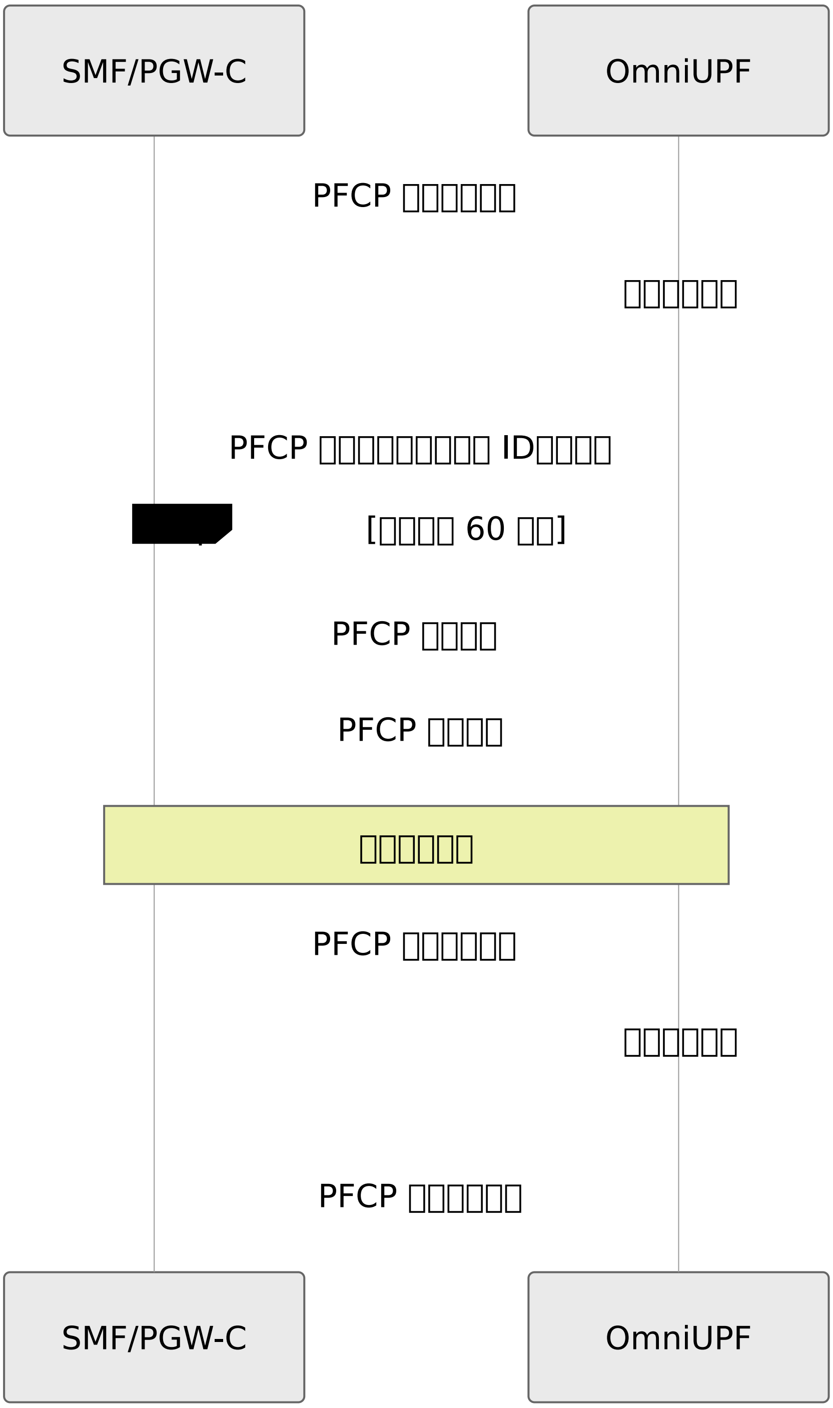
SMF/PGW-C
OmniUPF
PFCP [illegible]
[illegible]
PFCP [illegible] ID[illegible]
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PFCP [illegible]
PFCP [illegible]
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PFCP [illegible]
SMF/PGW-C
OmniUPF

[illegible]

- [illegible] SMF [illegible] UPF [illegible]
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SMF [illegible]

OmniUPF [illegible] SMF [illegible] 3GPP TS 29.244 [illegible]

[illegible]

[illegible] SMF [illegible] PFCP [illegible] [illegible]OmniUPF [illegible] SMF [illegible]

1. SMF [illegible]
2. SMF [illegible] UPF [illegible] PFCP [illegible]
3. SMF [illegible] [illegible]
4. UPF [illegible] = SMF [illegible]
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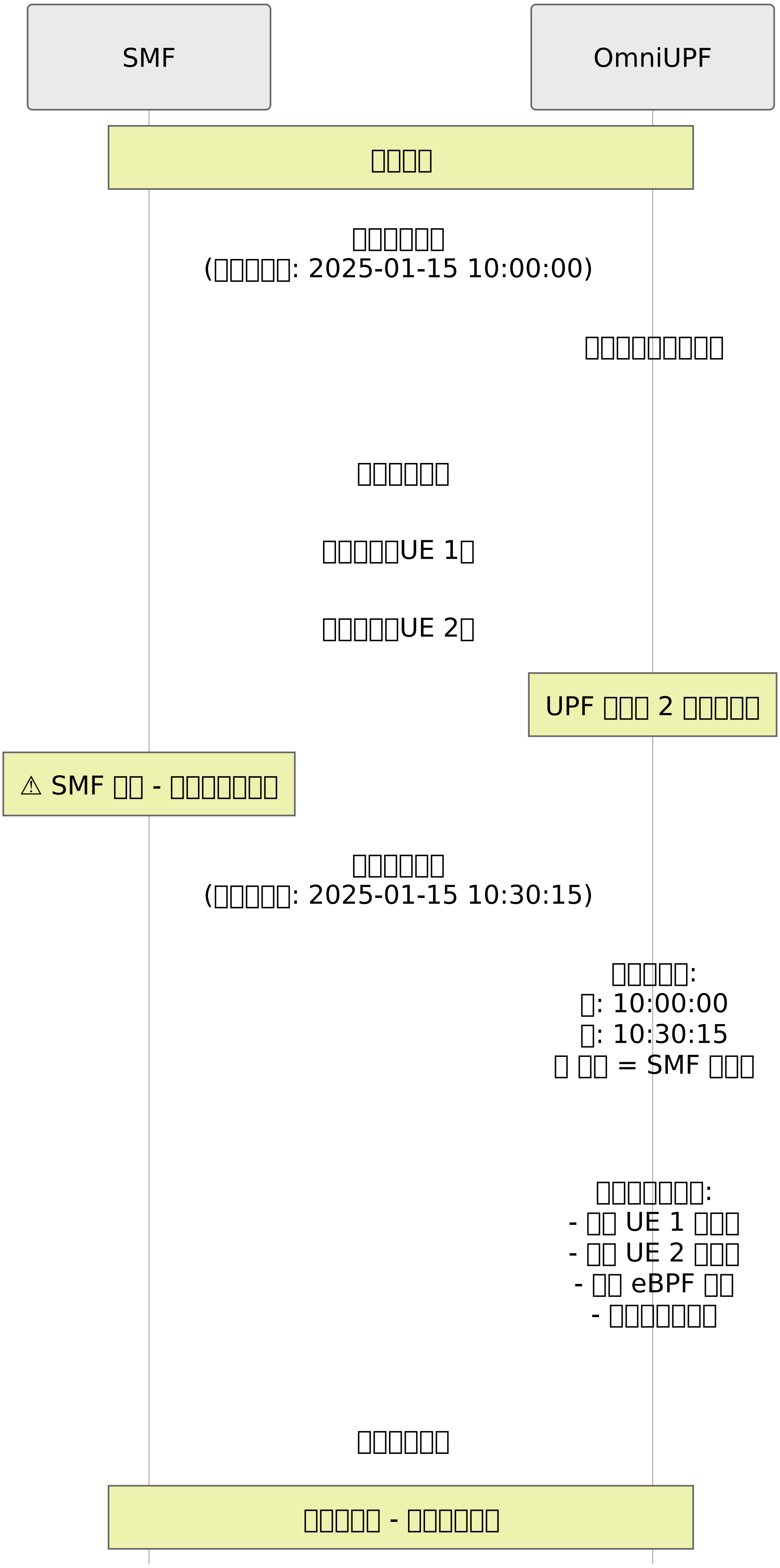
6. SMF [illegible]

[illegible]


SMF
OmniUPF
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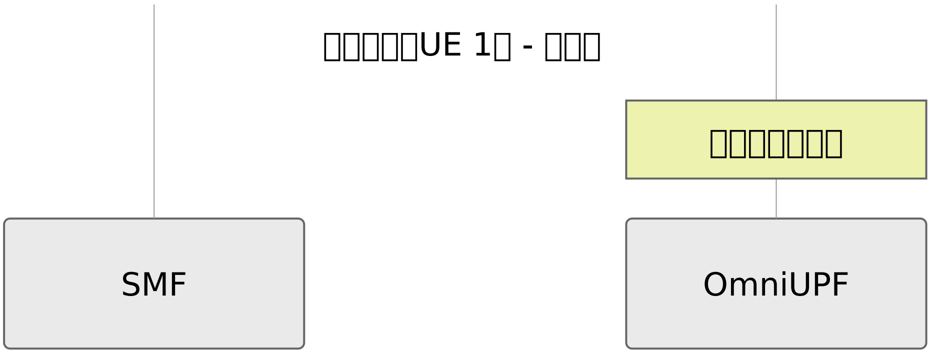

□□□□□

□ SMF □□□□□□□□□

```
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WARN: SMF □□□□□□□□□□: 2025-01-15T10:00:00Z□□: 2025-01-
15T10:30:15Z□ - SMF □□□□□ 245 □□□□□
INFO: □□ SMF □□□□□□□□□ 2□LocalSEID□
INFO: □□ SMF □□□□□□□□□ 3□LocalSEID□
...
INFO: □□ SMF □□□□□□□□□ 246□LocalSEID□
```

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1. □□□□□□□□□ SMF □□□□□□ SMF □□□□□□ □□□□□
2. □□□□□□□□□□□□□□□□□□□□□□□□□SMF□□□□□□□□□□
3. **3GPP**□□□□□□□□3GPP TS 29.244□5.22.2□□□□

> “□□CP□□□□□□□□□□□□□□□□□□□□□□□□UP□□□□□CP□□□□□□□□□□□□□□CP□□□□□□□PFCP□□□”

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GTP-U□□□□□□

OmniUPF□□3GPP TS 29.281□□□□□□□□□□□□PGW-U□SGW-U□eNodeB□gNodeB□□GTP-U□□□□□□□

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□OmniUPF□GTP-U□□□□□□□□□□□□□□□□SGW-U□□□□PGW-U□□□□□□□□□□□TEID□□□□□□
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1. **UPF**□□□□□ → □□□TEID X□GTP-U□��□□□□□□□□□□□□2152□
2. □□□□□□□□**TEID X** → □□□□□□□□TEID□□□□
3. □□□□□□□□□□□ → GTP-U□□□□26□IE□□□□□TEID
4. **UPF**□□□□□□ → □□□□□□□TEID X
5. **UPF**□□□□□□□□ → □□□□□□□□□□□□TEID X□FAR
6. **UPF**□□□□ → □eBPF□□□PFCP□□□□□□□
7. **UPF**□□□□ → □□□□□□□Prometheus□□□

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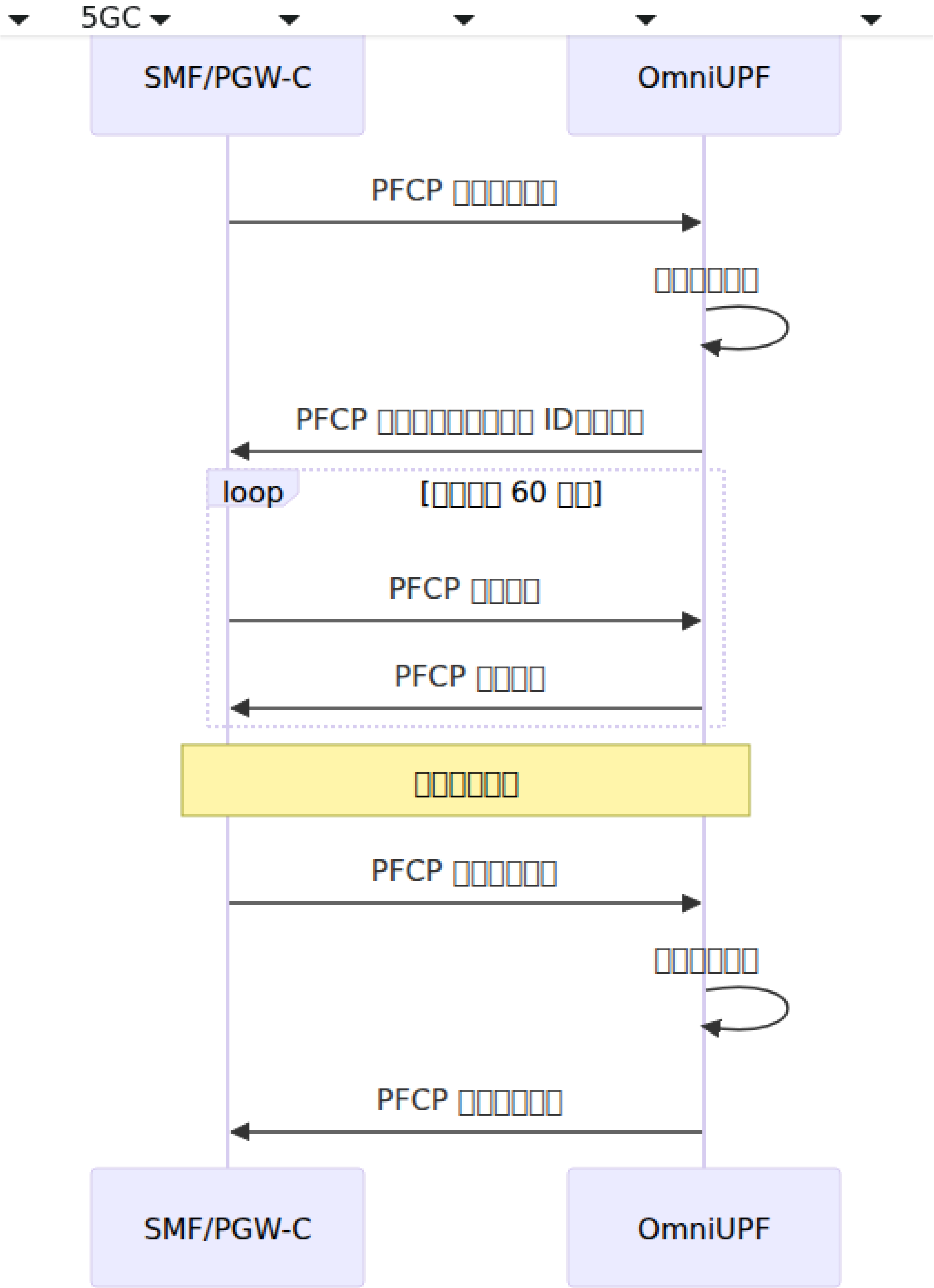
5GC
SMF/PGW-C
OmniUPF
PFCP □□□□□□
□□□□□□
PFCP □□□□□□□□□ ID□□□□
loop
[□□□□ 60 □□]
PFCP □□□□
PFCP □□□□
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PFCP □□□□□□
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PFCP □□□□□□
SMF/PGW-C
OmniUPF

□□□□□□3GPP TS 29.281□7.3.1□□□

```
GTP-U[illegible]
┌──────────────────────────────────────────┐
│ GTP-U[illegible]12[illegible]                    │
├──────────────────────────────────────────┤
│ [illegible]PT[illegible]        │ 0x32         │
│ [illegible]               │ 26 (0x1A)    │
│ [illegible]                     │ 9[illegible]       │
│ TEID                         │ 0 ([illegible])   │
│ [illegible]                    │ [illegible]       │
│ N-PDU[illegible]                  │ 0            │
│ [illegible]          │ 0            │
├──────────────────────────────────────────┤
│ IE: TEID[illegible]I[illegible]5[illegible]                   │
├──────────────────────────────────────────┤
│ [illegible]                          │ 16 (0x10)    │
│ [illegible]TEID                      │ 4[illegible]       │
└──────────────────────────────────────────┘
```

[illegible]

[illegible]1[illegible]S5/S8 GTP[illegible]PGW-U[illegible]

- SGW-U[illegible]OmniUPF[illegible]S5/S8[illegible]PGW-U
- PGW-U[illegible]S5/S8[illegible]
- SGW-U[illegible]TEID
- PGW-U[illegible]
- SGW-U[illegible]

[illegible]2[illegible]N9[illegible]UPF[illegible]

- UPF-1[illegible]OmniUPF[illegible]N9[illegible]UPF-2
- UPF-2[illegible]
- UPF-1[illegible]
- UPF-1[illegible]

[illegible]

[illegible]

```
WARN: □192.168.50.10:2152□□□GTP-U□□□□□TEID 0x12345678 - □□□□□□□□□
TEID
WARN: □□□□LocalSEID=42□FAR GlobalId=1□□□□□□TEID 0x12345678□□□□□□
192.168.50.10
INFO: □□□□LocalSEID=42□□□□192.168.50.10□TEID 0x12345678□GTP-U□□□□
WARN: □□□192.168.50.10□TEID 0x12345678□GTP-U□□□□□□□1□□□
```

Prometheus□□□

□□□□□□□□□□□□□□□□□□□□

```
# □□□□□□□□□□□□□
upf_buffer_listener_error_indications_received_total{node_id="pgw-u-
1",peer_address="192.168.50.10"}

# □□□□□□□□□□□
upf_buffer_listener_error_indication_sessions_deleted_total{node_id="
u-1",peer_address="192.168.50.10"}

# □□□□□□□□□□□□□□□TEID□
upf_buffer_listener_error_indications_sent_total{node_id="enodeb-
1",peer_address="10.60.0.1"}
```

□□□□□

- `node_id`□□□□□□PFCP□□ID□□□□□□□□□□“□□”□
- `peer_address`□□□□□□□IP□□

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1. □□□□□□□□□□□□ - □□□□□□□
2. **TEID**□□□□□□□□□□□□□TEID□□□
3. □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
4. □□□□□□□□□□□□□□□□□TEID□□□□□□□

5. [illegible]

   - [illegible] = [illegible]
   - [illegible] = [illegible]

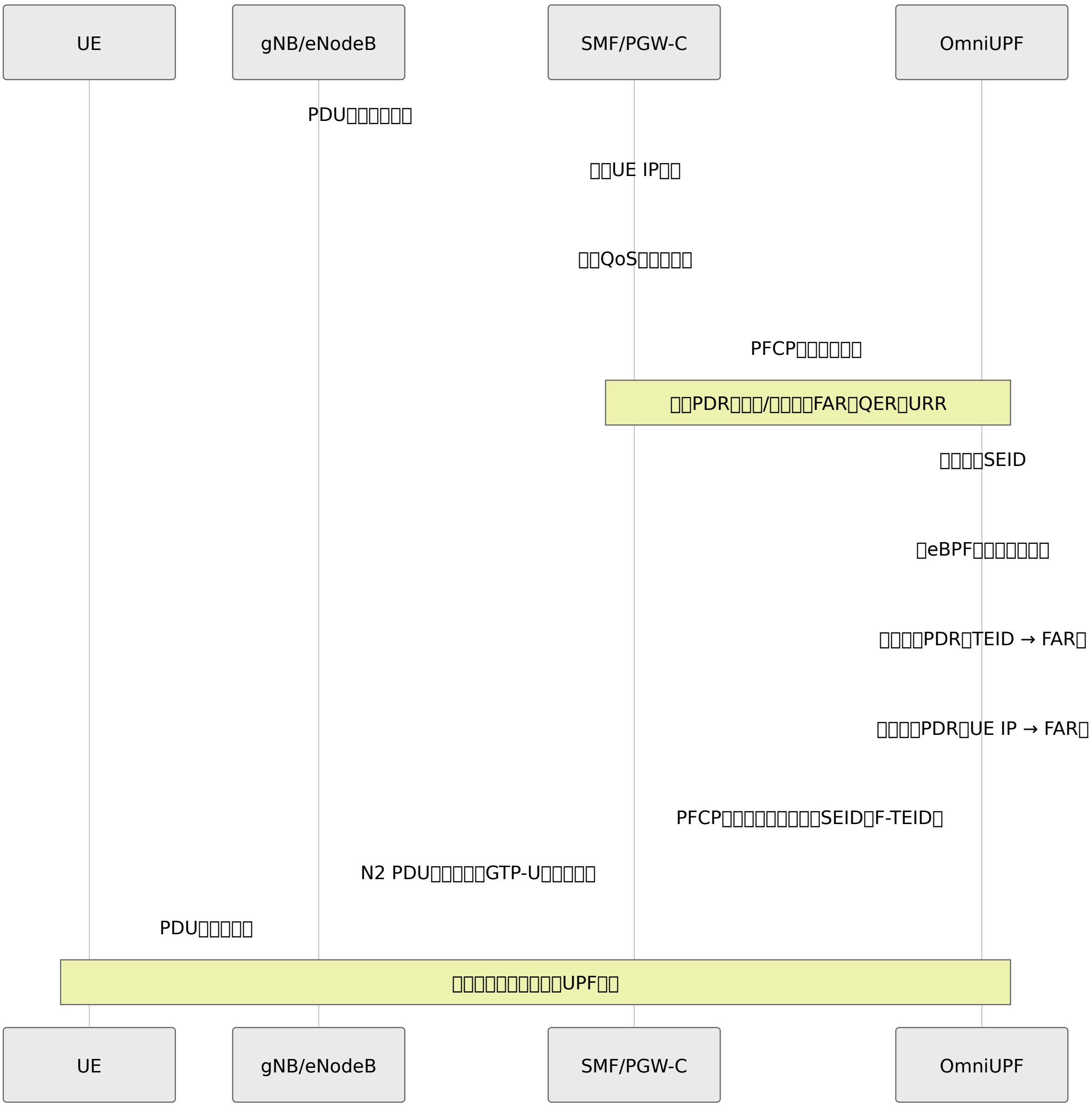
6. [illegible]

[illegible]

PFCP[illegible]

[illegible]UE[illegible]PDU[illegible]5G[illegible]PDP[illegible]LTE[illegible]SMF[illegible]UPF[illegible]PFCP[illegible]

[illegible]


UE
gNB/eNodeB
SMF/PGW-C
OmniUPF
PDU□□□□□□
□□UE IP□□
□□QoS□□□□□
PFCP□□□□□□
□□PDR□□□/□□□□FAR□QER□URR
□□□□SEID
□eBPF□□□□□□
□□□□PDR□TEID → FAR□
□□□□PDR□UE IP → FAR□
PFCP□□□□□□□□□SEID□F-TEID□
N2 PDU□□□□□GTP-U□□□□□
PDU□□□□□
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UE
gNB/eNodeB
SMF/PGW-C
OmniUPF

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- □□**PDR**□□□N3 TEID□□□FAR□□□N6
- □□**PDR**□□□UE IP□□□□□GTP-U□□□FAR□□□N3
- **FAR**□□□□□□□□□□□□□□□□□□
- **QER**□QoS□□□MBR□GBR□□□□□□□□QFI□
- **URR**□□□□□□□□□□□□□□

PFCP□□□□

SMF□□□□□□□□□□□□□□□□□□QoS□□□□□□□□

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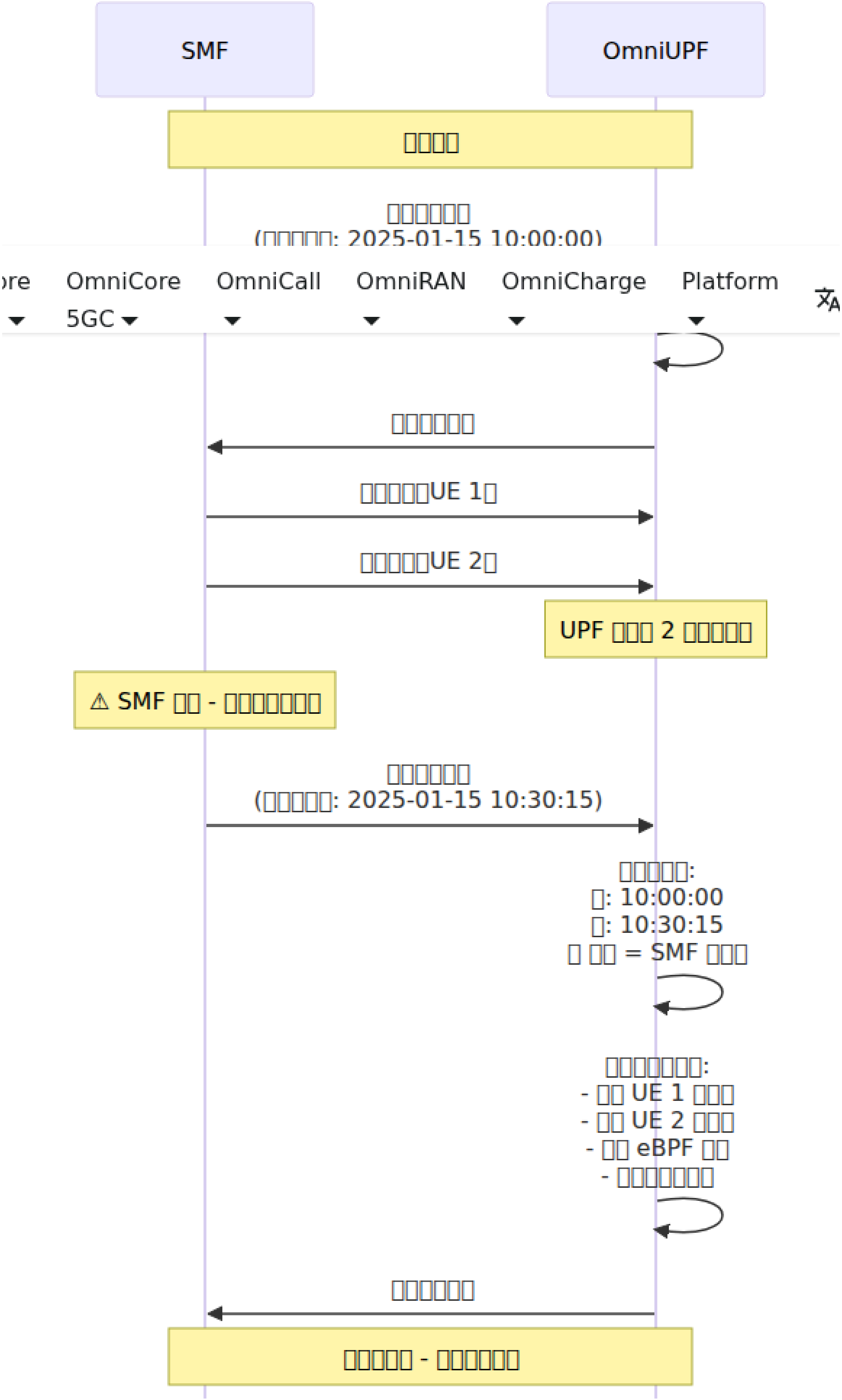
1. [illegible]**N2**[illegible]
   - [illegible]gNB[illegible]F-TEID[illegible]FAR
   - [illegible]
   - [illegible]
2. **QoS**[illegible]
   - [illegible]MBR/GBR[illegible]QER
   - [illegible]PDR[illegible]/[illegible]SDF[illegible]QoS
3. [illegible]
   - [illegible]PDR
   - [illegible]FAR[illegible]

[illegible]


SMF
OmniUPF
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□□□□□□
(□□□□□: 2025-01-15 10:00:00)
ore
OmniCore 5GC
OmniCall
OmniRAN
OmniCharge
Platform
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UPF □□□ 2 □□□□□
⚠ SMF □□ - □□□□□□□
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□: 10:00:00
□: 10:30:15
□ □□ = SMF □□□
□□□□□□□:
- □□ UE 1 □□□
- □□ UE 2 □□□
- □□ eBPF □□
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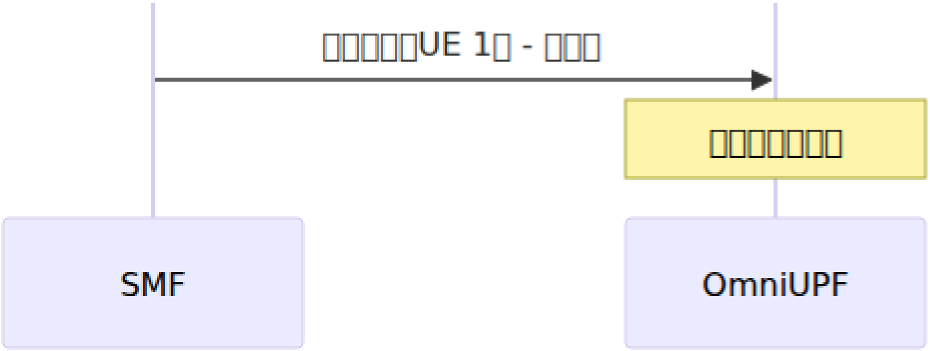
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SMF
OmniUPF

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PFCP□□□□

□PDU□□□□□□□SMF□□UPF□□□PFCP□□□

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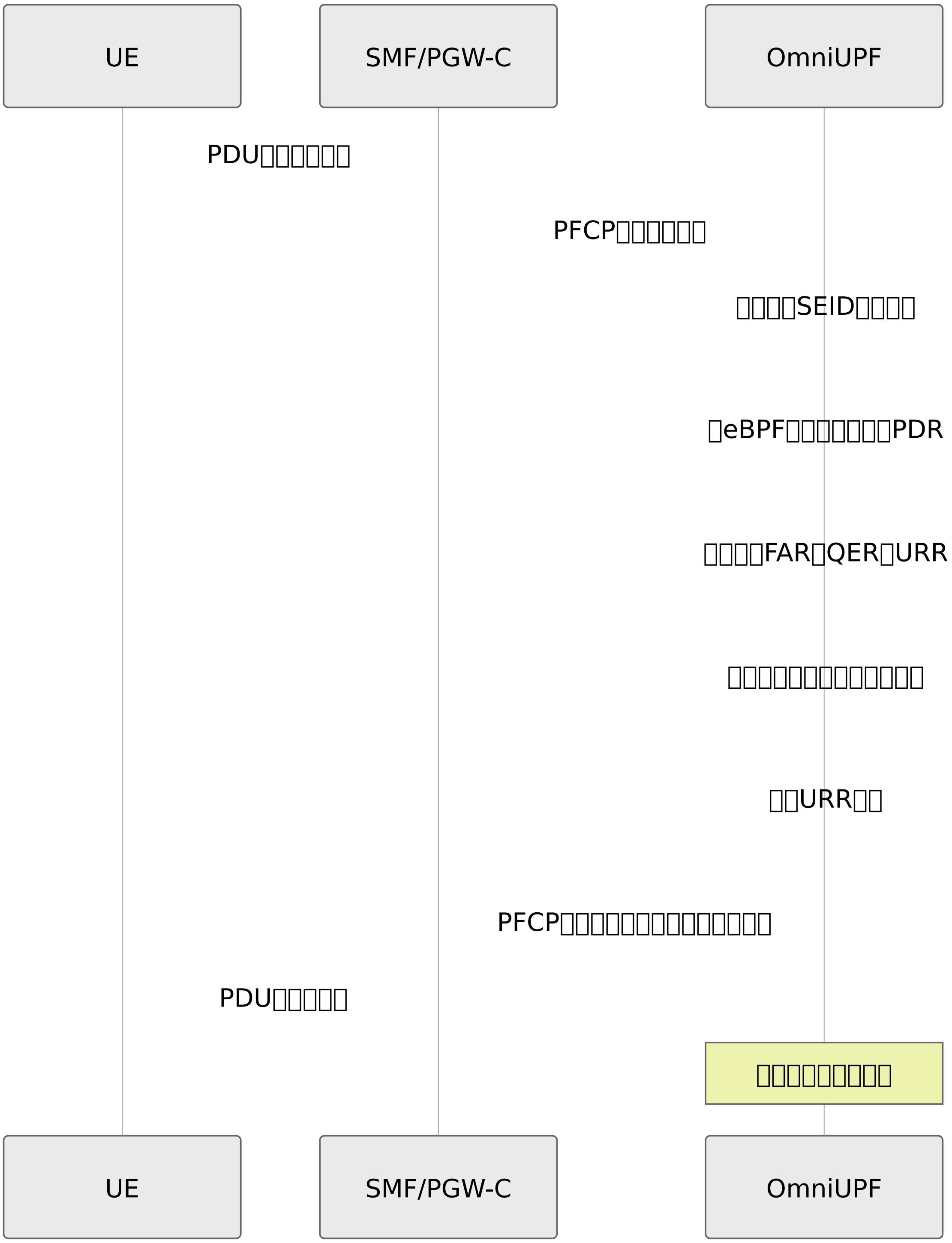
UE
SMF/PGW-C
OmniUPF
PDU□□□□□□
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□□□□FAR□QER□URR
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UE
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OmniUPF

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- □□□□FAR□QER□URR
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- □SMF□□□□□□□□□□□□□

[illegible]

OmniUPF[illegible]Web[illegible]REST API[illegible]

[illegible]

[illegible]**PFCP**[illegible]

PFCP[illegible]UE PDU[illegible]5G[illegible]PDP[illegible]LTE[illegible]

- [illegible]SEID[illegible]
- [illegible]PDR
- [illegible]FAR
- [illegible]QoS[illegible]QER[illegible]
- [illegible]URR[illegible]

[illegible]

- [illegible]UE IP[illegible]TEID[illegible]
- [illegible]**IP**[illegible]**TEID**[illegible]
- [illegible]PDR/FAR/QER/URR[illegible]
- [illegible]**PFCP**[illegible]

[illegible][illegible][illegible]

[illegible]

[illegible]**PDR**[illegible]

PDR[illegible]

- [illegible]**PDR**[illegible]N3���[illegible]TEID[illegible]
- [illegible]**PDR**[illegible]UE IP[illegible]IPv4[illegible]IPv6[illegible]
- [illegible]**SDF**[illegible]
- [illegible]**PDR**[illegible]

□□□□□□□FAR□□

FAR□□□□□□□□□□□□□□□□□□

- □□**FAR**□□□□□□□□□□□□□□□□□□
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- □□□□**FAR**□□□□□
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QoS□□□□□QER□□

QER□□□□□□□□□□□□□□□□□□□

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

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URR□□□□□□□□□□□□□□□

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- □□□□□□□□□**URR**

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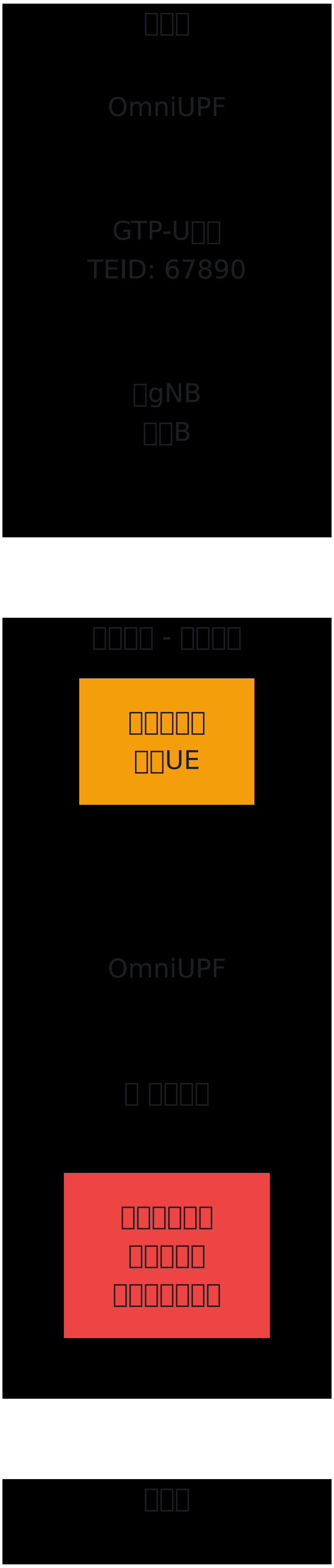
OmniUPF
GTP-U
TEID: 67890
gNB
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UE
OmniUPF

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TEID: 12345
OmniUPF

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- **TCP**□□□□□□□□□□□□□□□□□□
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- **VoIP□□□□□���**□□□□□□□□□□□□□
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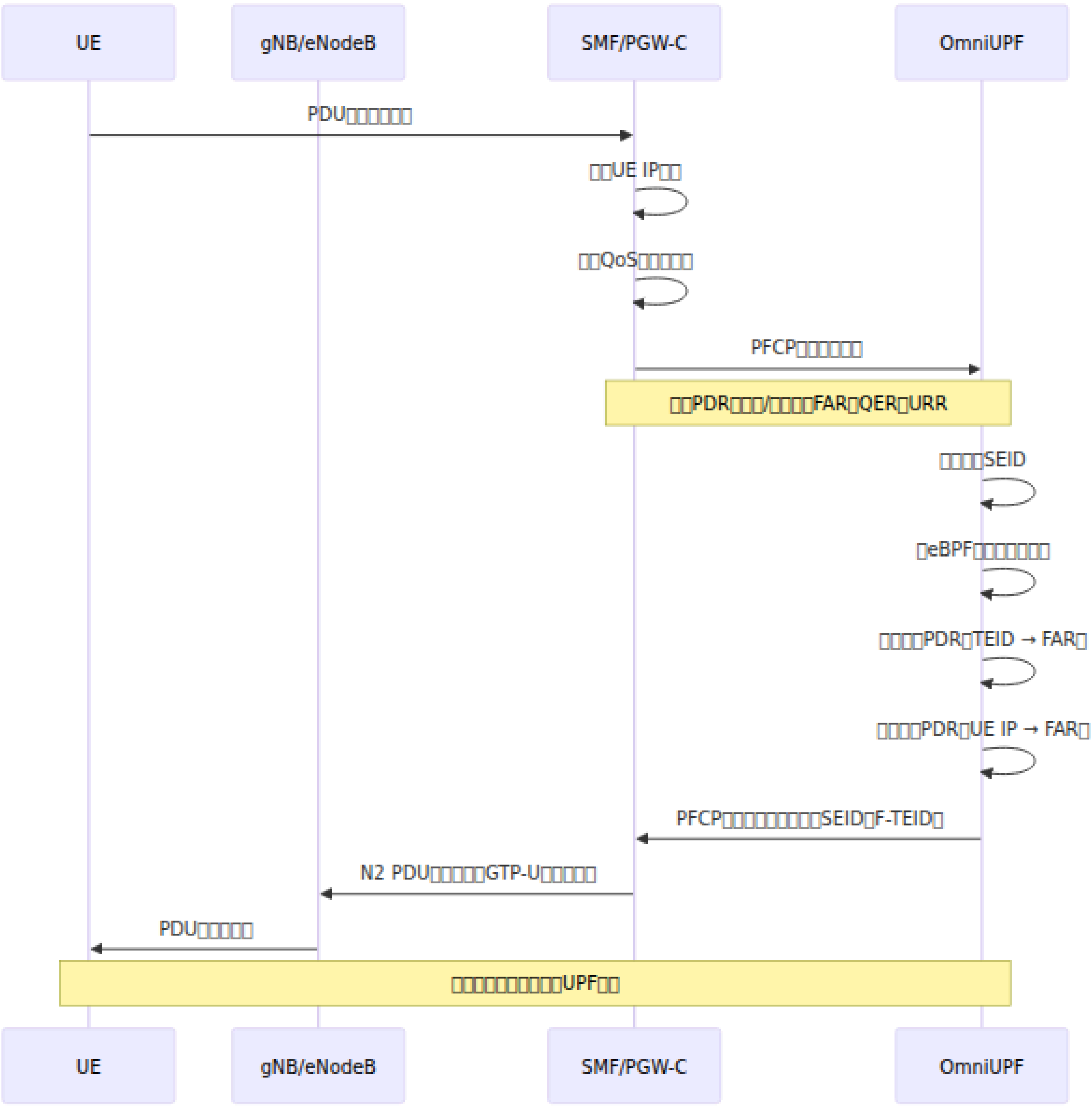
OmniUPF□□□□□□□□□□□□□□

1. □□N2□□□□5G□/□□X2□□□□4G□

□UE□□□□□□□□□


UE
gNB/eNodeB
SMF/PGW-C
OmniUPF
PDU[illegible]
[illegible]UE IP[illegible]
[illegible]QoS[illegible]
PFCP[illegible]
[illegible]PDR[illegible]/[illegible]FAR[illegible]QER[illegible]URR
[illegible]SEID
[illegible]eBPF[illegible]
[illegible]PDR[illegible]TEID → FAR[illegible]
[illegible]PDR[illegible]UE IP → FAR[illegible]
PFCP[illegible]SEID[illegible]F-TEID[illegible]
N2 PDU[illegible]GTP-U[illegible]
PDU[illegible]
[illegible]UPF[illegible]
UE
gNB/eNodeB
SMF/PGW-C
OmniUPF

[illegible]

- **T+0ms**[illegible]
- **T+10ms**[illegible]SMF[illegible]UPF[illegible]���[illegible]
- **T+10-50ms**[illegible] - [illegible]
- **T+50ms**[illegible]SMF[illegible]UPF[illegible]
- **T+50ms+**[illegible]UPF[illegible]

[illegible]~40ms[illegible] [illegible]

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2. [illegible]QoS[illegible]

[illegible]

- **QoS**□□/□□□□□□4G□□□5G□□□NSA□□□
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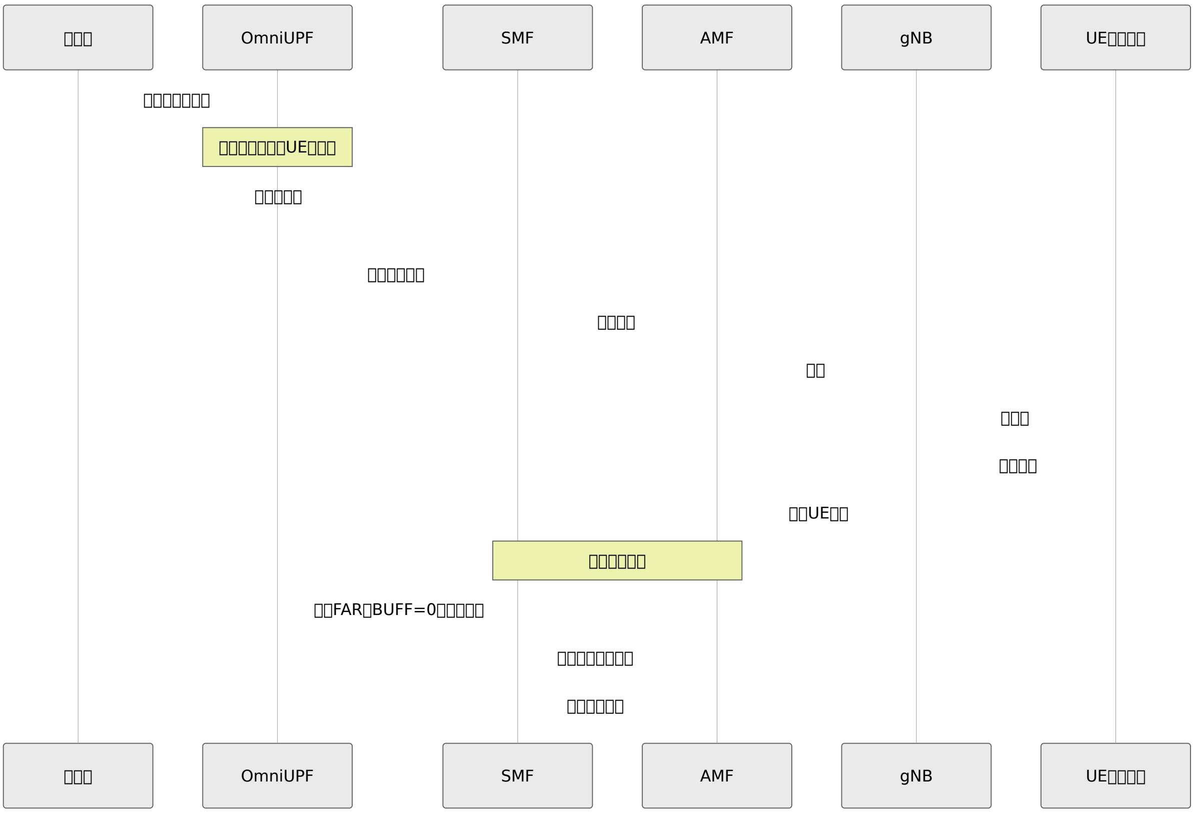
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SMF
AMF
gNB
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4. □RAT□□□4G ↔ 5G□

□UE□4G□5G□□□□□□□□

- □□□□□eNodeB ↔ gNB□
- □□□□□□□□□□TEID□□□
- □□□□□RAT□□□□□□□□

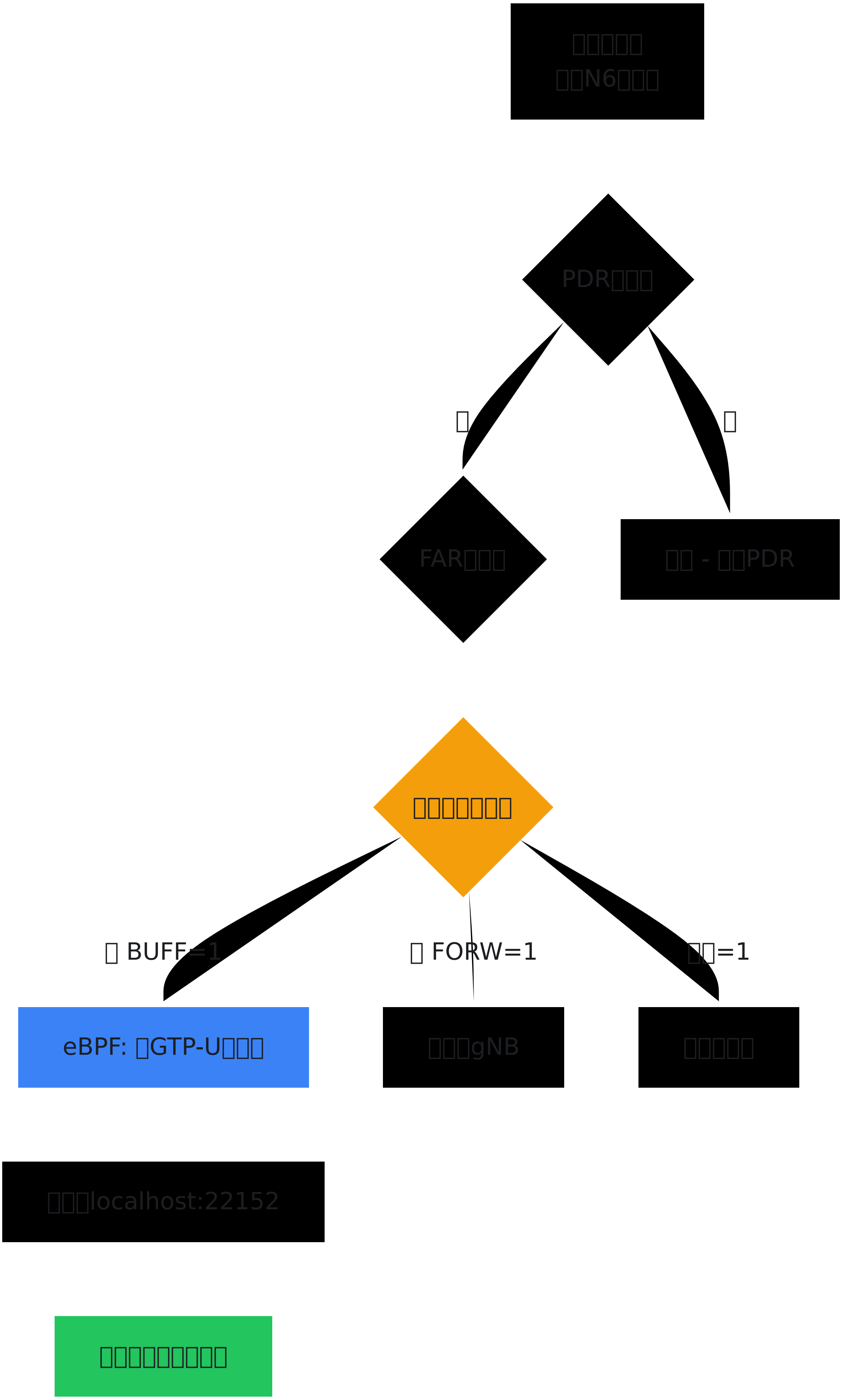
OmniUPF[illegible]

[illegible]

OmniUPF[illegible]

1. **eBPF**[illegible]FAR[illegible]
2. [illegible]

[illegible]


□□□□□
□□N6□□□
PDR□□□
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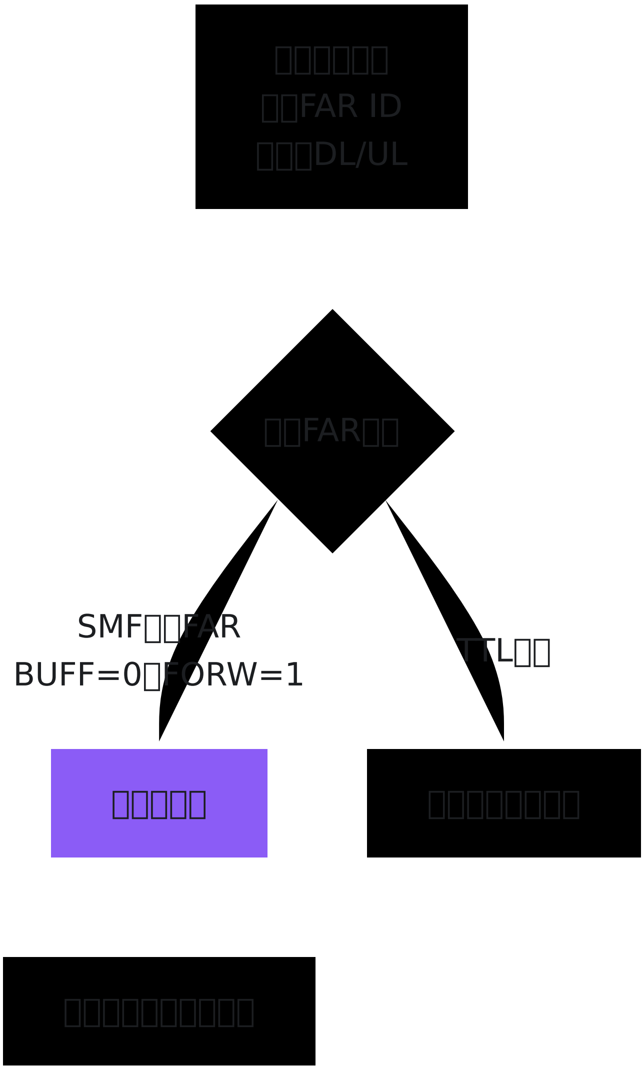
FAR□□□
□□ - □□PDR
□□□□□□□
□ BUFF=1
□ FORW=1
□□=1
eBPF: □GTP-U□□□
□□□gNB
□□□□□
□□□localhost:22152
□□□□□□□□□


[illegible]
[illegible]FAR ID
[illegible]DL/UL
[illegible]FAR[illegible]
SMF[illegible]FAR
BUFF=0[illegible]FORW=1
TTL[illegible]
[illegible]
[illegible]
[illegible]

[illegible]

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

[illegible]

1. [illegible]SMF[illegible]PFCP[illegible]FAR[illegible]BUFF=1[illegible]2[illegible]
2. [illegible]eBPF[illegible]BUFF[illegible]��[illegible]22152

3. □□□□□□□□□□□□□FAR ID□□□□□□□□□□□□
4. □□□□□SMF□□□□□□□□□FAR□□FORW=1□BUFF=0
5. □□□□□□□□□□□□□FAR□□□□□□□□□□□□□□□□□
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- □□□□□□□ **(CDR)**□□□□□□□□□□□□
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[illegible]

[illegible] Web UI [illegible] API [illegible]

[illegible]

- [illegible] **FAR ID** [illegible]
- [illegible] FAR[illegible]
- [illegible]
- [illegible] > TTL [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible] **TTL**[illegible]
- [illegible] FAR [illegible]

[illegible]

- [illegible] SMF [illegible] FAR [illegible]
- [illegible]���[illegible]
- [illegible]TTL [illegible] FAR [illegible]
- [illegible] SMF [illegible]

[illegible] [illegible][illegible]

[illegible]

[illegible] `/etc/omniupf/runtime.exs` [illegible]

```
# [illegible]
buffer_port = 22152                    # [illegible] UDP [illegible]
```

[illegible]

- [illegible] `buffer_max_packets` [illegible] 20,000+

- [illegible] `buffer_packet_ttl` [illegible] 15 [illegible]
- [illegible] `buffer_packet_ttl` [illegible] 10 [illegible]
- [illegible]

[illegible] [illegible][illegible]

[illegible]

[illegible]

[illegible]

- **RX** [illegible]
- **TX** [illegible]
- [illegible]
- **GTP-U** [illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]��[illegible]/[illegible]
- [illegible] TEID[illegible] UE IP

XDP [illegible]

eXpress [illegible]

- **XDP** [illegible] XDP [illegible]
- **XDP** [illegible]
- **XDP** [illegible] XDP [illegible]
- **XDP** [illegible]

N3/N6 [illegible]

[illegible]

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

UPF □□□□□ eBPF □□□□□□□□□□□

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- □□□□ **eBPF** □□□□□□□
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  - □□□<50%□□□□
  - □□□50-70%□□□□
  - □□□□70-90%□□□□
  - □□□>90%□□□□

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- `uplink_pdr_map`□□□□□□□
- `downlink_pdr_map`□□□ IPv4 □□□□
- `far_map`□□□□□
- `qer_map`□QoS □□
- `urr_map`□□□□□

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- □□ PDR □□□□□□□□□□□□ + □□□□
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UPF □□□

□□□□□ UPF □□□□□

- **N3** □□□□□ RAN □□□ IP □□□GTP-U□
- **N6** □□□□□□□□□□□ IP □□
- **N9** □□□□□ UPF □□□□□ IP □□□□□□
- **PFCP** □□□□□ SMF □□□ IP □□
- **API** □□□REST API □□□□
- □□□□□Prometheus □□□□

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□□□ eBPF □□□□□□□

- □□ **N3** □□□□□□ N3 □□□□
- □□ **N9** □□□□□□ N9 □□□□□□□□□□

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□□□PFCP □□□□□□□UE □□□□□□□□

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1. **PFCP □□□□□**
    - □□ SMF □□□□□□ UPF PFCP □□□□□ 8805□
    - □□□□□□□□ PFCP □□□□
    - □□ SMF □ UPF □□□□□ ID □□□□□□

2. **eBPF** □□□□□□
    - □□□□□□□□□□>90%□□□□□□□□
    - □ UPF □□□□□ eBPF □□□□
    - □□□□□□□□□□□□□
3. □□□ **PDR/FAR** □□
    - □□ UE IP □□□□□□□□□
    - □□ TEID □□□□□□
    - □□ FAR □□□□□□□□□
4. □□□□□□
    - □□ N3 □□ IP □□□□□ gNB □□
    - □□□□□□□□ N6 □□□□□□□□
    - □□ GTP-U □□□□□□□□□

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1. **PDR** □□□□
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    - □□□□ PDR UE IP □□□□□□ IP □□
    - □□ SDF □□□□□□□□□
2. **FAR** □□□□
    - □□ FAR □□□□□ FORWARD□□□□ DROP □ BUFFER□
    - □□ GTP-U □□□□□□□□
    - □□□□□□□□

3. **QoS □□□□**
   - □□ QER MBR□□□□□□□□□
   - □□ GBR□□□□□□□□□
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4. □□ **MTU** □□
   - □□ GTP-U □□□40-50 □□□□□□□□□
   - □□ N3/N6 □□□ MTU □□
   - □□ ICMP □□□□□□

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2. □□ **TTL** □□
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   - □□ max_per_far □ max_total □□□□

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[illegible]

[illegible]

[illegible]

1. [illegible]
    - eBPF [illegible] 64 [illegible]
    - [illegible]
    - [illegible] URR [illegible]
2. [illegible]
    - [illegible] eBPF [illegible]
    - [illegible] eBPF [illegible]
    - [illegible] XDP [illegible]
3. [illegible]
    - [illegible] N3/N6 [illegible]
    - ���[illegible]��� eBPF[illegible]
    - [illegible] XDP [illegible]

[illegible]

[illegible]CPU [illegible]

[illegible]

1. [illegible] **XDP** [illegible] XDP [illegible]
2. [illegible] **eBPF** [illegible]
3. [illegible] **CPU** [illegible]eBPF [illegible]
4. [illegible] NIC [illegible] XDP [illegible]

[illegible]

- **XDP** [illegible] 10M+ [illegible]

- **PDR** □□□□□□ PDR□□□□□□□□□
- □□□□□□□ UPF □□□□□□□□□
- □□□□□□□□ NIC □□□□□□□□□□□

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- □□□□□UPF/PGW-U/SGW-U□
- XDP □□□□□□
- □□□□□□□Proxmox□VMware□KVM□Hyper-V□VirtualBox□
- NIC □□□□ XDP □□□□
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- Proxmox VE □□ XDP □□□□□□□
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- VMware ESXi□KVM □ Hyper-V XDP □□
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- XDP □□□□□□□

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- □□□□□ XDP □□□□□□□
- PFCP □□□□
- □□□□□GTP-U □□□□□ 22152□
- QoS □□□□□□□□□5ms □□□
- □□□□□3.5μs □□□10 Mpps/core□

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PFCP □□□□□□□□

- □□□□□□□ (PDR) - □□□□
- □□□□□□ (FAR) - □□□□□□□□□□
- QoS □□□□ (QER) - □□□□ (MBR/GBR)
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- N3/N6 □□□□□□□□□
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Web UI □□□□

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- □□□□□PDR□FAR□QER□URR □□□□□
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API □□

□□□ REST API □□□□□□

- OpenAPI/Swagger □□□□□
- API □□□□□□□□□□□□□
- PFCP □□□□□□□
- □□□□□□□ (PDR) - IPv4 □ IPv6
- □□□□□□ (FAR)
- QoS □□□□ (QER)
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- eBPF □□□□
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Prometheus □□□□□□□□

- PFCP □□□□□□□□□□□□□□□□□□□□
- XDP □□□□□□□□□□□□
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- PFCP □□□□□□□□□□□□□□□□□
- URR □□□□□ PFCP □□□□□□□

- [illegible]
- [illegible]DLDR [illegible]
- eBPF [illegible]
- Prometheus [illegible]
- Grafana [illegible]

PFCP [illegible]

PFCP [illegible]

- [illegible] 3GPP [illegible]TS 129.244[illegible]
- [illegible]
- [illegible]
- [illegible] Prometheus [illegible]
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- [illegible]
- [illegible]

UE [illegible]

FRR [illegible]

- FRR[illegible]
- UE [illegible]
- [illegible]
- [illegible] OSPF [illegible] BGP [illegible]
- OSPF [illegible]
- OSPF [illegible] LSA [illegible]
- BGP [illegible]
- Web UI [illegible]
- [illegible]
- [illegible] Mermaid [illegible]

IPv6 / [illegible]

[illegible] IPv6 [illegible] IPv6 [illegible] IPv4v6 PDN [illegible]

- □□□□□□□□□ IPv6 □□□□
- UE IPv6 □□□□□
- UE `/128` □□□□□ OSPFv3 □□
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- NIC □□□□□□□
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1. □□□□□□□□□□□
2. □□□□ □□□□□□
3. Web UI □□ □□□□□□

□ Proxmox □□□

1. XDP □□□□ - Proxmox □□ XDP □□ - □□□□□□□□□□
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1. XDP □□□□ - **□□□□ XDP □□□ 5-10 □□□□□□**
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3. □□□□ - □□□□

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1. □□□□ - □□□□
2. □□□□ - □□□□
3. □□□□ - □□□□□□

□□ **UE □□□ FRR** □□

1. UE □□□□□□ - □□□□□□□□□
2. API □□ - □□□□ - □□ API □□
3. Web UI □□ - □□□□□□
4. UE □□□□ - FRR □□ - OSPF LSA □□

□□ **REST API**

1. API □□ - □□□ API □□
2. API □□ - Swagger UI - □□□ API □□□
3. API □□ - API □□ - API □□□□
4. Web UI □□ - Web □□□□ API □□□□□

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1. □□□□□□ - □□□□□
2. □□□□ - □□□□□□□□□

3. Web UI □□ - □□□□□□□□

□□□□

□□ **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`

□□□□□□

```
# /etc/omniupf/runtime.exs
xdp_interfaces = "eth0"                    # N3/N6/N9 □□□□□
xdp_attach_mode = "native"                 # "generic" | "native" |
"offload"
n3_address = "10.100.50.233"               # N3 □□ IP
pfcp_address = "10.100.50.241"             # PFCP □□□□
pfcp_port = 8805                           # PFCP □□
node_id = "10.100.50.241"                  # PFCP □□ ID

# □□
max_sessions = 100_000                     # □□□□□□□

# API
api_port = 8080                            # REST API □□
```

□□□□□□

- **eBPF □□□□ < 70%**□□□□□
- **eBPF □□□□ 70-90%**□□□□ 1 □□□□□□
- **eBPF □□□□ > 90%**□□□ - □□□□□□□□
- **□□□□□□ < 0.1%**□□□
- **□□□□□□ 0.1-1%**□□□ - □□□
- **□□□□□□ > 5%**□□□ - □□□□
- **XDP □□ > 0**□eBPF □□□□□□□□

3GPP □□□□

OmniUPF □□□□ 3GPP □□□

□□	□□	□□□
TS 23.501	5G □□ (5GS) □□□□□	5G UPF □□□□□
TS 23.401	E-UTRAN □□□□□□□□□□□ (GPRS) □□	LTE UPF (PGW-U) □□
TS 29.244	□□□□□□□□□□□□□□□□ (PFCP)	N4 PFCP □□
TS 29.281	□□□□□□□□ (GPRS) □□□□□□□□ (GTPv1-U)	GTP-U □□
TS 23.503	5G □□ (5GS) □□□□□□□□□□	QoS □□□
TS 29.212	□□□□□□□ (PCC)	QoS □□

□□□

5G □□□□

- **3GPP**□□□□□□□□□□ - □□□□□□□□
- **AMF**□□□□□□□□□□ - 5G □□□□□□□□□□□□□
- **CHF**□□□□□ - 5G □□□□
- **DN**□□□□□ - □□□□□□□□□IMS□□□□
- **eNodeB**□□□□□ B - LTE □□
- **F-TEID**□□□□□□□□□□□□□ - □ IP □□□ GTP-U □□ ID
- **gNB**□□□□□□ B - 5G □□
- **GTP-U**□□□□□□□□□□□□□□□□□ - □□□□□□□□□
- **MBR**□□□□□□ - QoS □□□□□□□□□
- **GBR**□□□□□□ - QoS □□□□□□□□□□
- **N3**□RAN □ UPF □□□□□□□□□□□□□
- **N4**□SMF □ UPF □□□□□□PFCP □□□
- **N6**□UPF □□□□□□□□□□□□□□□□□□
- **N9**□□□ UPF □□□□□□UPF □□□□□□□□□□
- **PCF**□□□□□□□ - 5G □□□□□

- **PDU**[illegible] - 5G [illegible]
- **PGW-C**[illegible]PDN [illegible] - LTE [illegible] SMF
- **PGW-U**[illegible]PDN [illegible] - LTE [illegible]UPF [illegible]
- **QFI**[illegible]QoS [illegible] - 5G QoS [illegible]
- **QoS**[illegible] - [illegible]
- **RAN**[illegible] - [illegible]gNB/eNodeB[illegible]
- **SEID**[illegible] - PFCP [illegible] ID
- **SMF**[illegible] - 5G [illegible]
- **TEID**[illegible] - GTP-U [illegible] ID
- **UE**[illegible] - [illegible]
- **UPF**[illegible] - 5G [illegible]

PFCP [illegible]

- **Association**: SMF [illegible] UPF [illegible]
- **FAR**: [illegible] - [illegible]
- **IE**: [illegible] - PFCP [illegible]
- **Node ID**: UPF [illegible] SMF [illegible] (FQDN [illegible] IP [illegible])
- **PDR**: [illegible] - [illegible]
- **PFCP**: [illegible] - N4 [illegible]
- **QER**: QoS [illegible] - [illegible]
- **SDF**: [illegible] - [illegible]
- **Session**: [illegible] UE PDU [illegible] PDP [illegible] PFCP [illegible]
- **URR**: [illegible] - [illegible]

eBPF [illegible] Linux [illegible]

- **BPF**: [illegible] - [illegible]
- **eBPF**: [illegible] BPF - [illegible]
- **Hash Map**: eBPF [illegible]
- **XDP**: eXpress [illegible] - [illegible]
- **Verifier**: [illegible] eBPF [illegible]
- **Map**: [illegible] eBPF [illegible]

- **Zero-copy**: [illegible]

OmniUPF [illegible]

- **OmniUPF**: [illegible] eBPF [illegible]
- **Datapath**: [illegible]eBPF [illegible]
- **Control Plane**: PFCP [illegible]
- **REST API**: [illegible] HTTP API
- **Web UI**: [illegible]

OmniUPF [illegible]

[illegible]

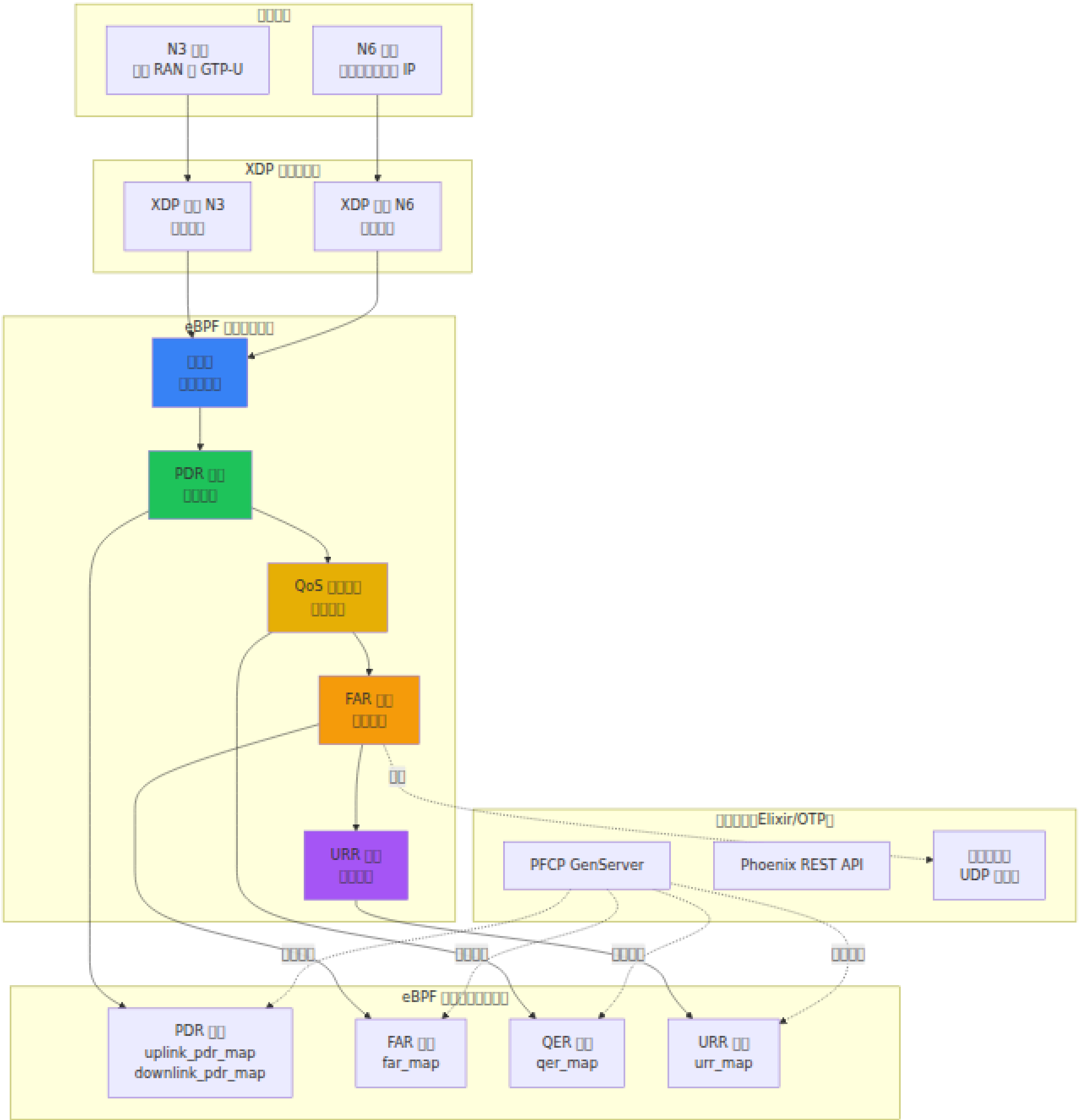
1. [illegible]
2. eBPF [illegible]
3. XDP [illegible]
4. [illegible]
5. eBPF [illegible]
6. [illegible]
7. QoS [illegible]
8. [illegible]
9. [illegible]

[illegible]

OmniUPF [illegible] eBPF[illegible] XDP[illegible] 5G/LTE [illegible] Elixir/OTP [illegible] GenServer [illegible] PFCP [illegible] Linux [illegible] eBPF [illegible]

eBPF [illegible]`ipentrypoint_bpf.o`[illegible] C [illegible] `ebpf/xdp/` [illegible] NIF [illegible] libbpf [illegible] Elixir [illegible]

��[illegible]


N3 [illegible]
[illegible] RAN [illegible] GTP-U
N6 [illegible]
[illegible] IP
XDP [illegible]
XDP [illegible] N3
XDP [illegible] N6
eBPF [illegible]
PDR [illegible]
QoS [illegible]
FAR [illegible]
URR [illegible]
[illegible]Elixir/OTP[illegible]
PFCP GenServer
Phoenix REST API
UDP [illegible]
PDR [illegible]
uplink_pdr_map
downlink_pdr_map
FAR [illegible]
far_map
QER [illegible]
qer_map
URR [illegible]
urr_map

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible] XDP [illegible]

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- eBPF □□□□□ CPU □□□□
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- XDP □□□□□□ SmartNIC □□
- □□□□ XDP □□□□
- □□□□□□□□□□□□

eBPF □□□□

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eBPF□□□□□□□□□□□□□□□□□□□□□ Linux □□□

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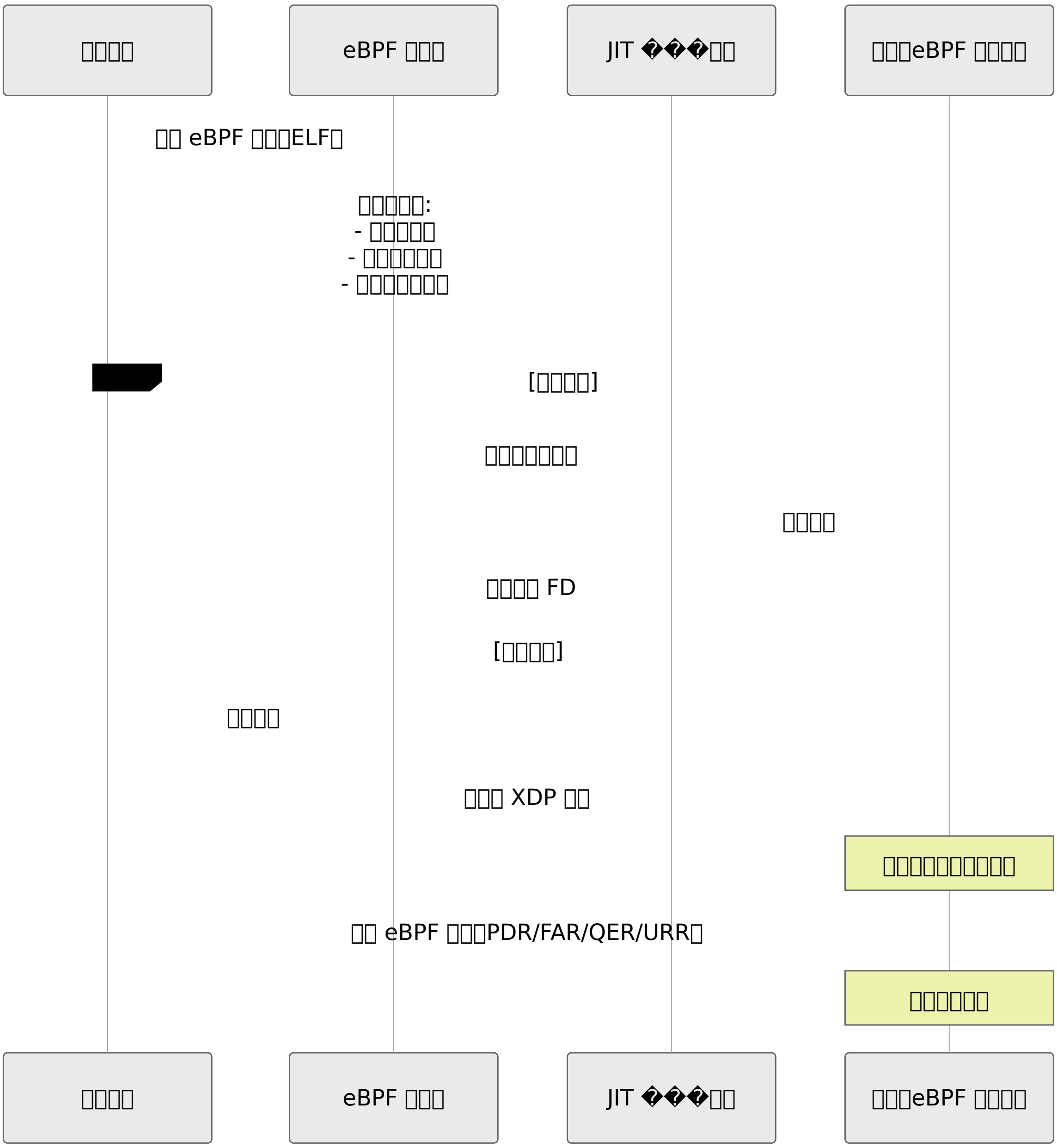
eBPF [illegible]


[illegible]
eBPF [illegible]
JIT ���[illegible]
[illegible]eBPF [illegible]
[illegible] eBPF [illegible]ELF[illegible]
[illegible]:
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- [illegible]
- [illegible]
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[illegible]
[illegible] FD
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[illegible] XDP [illegible]
[illegible]
[illegible] eBPF [illegible]PDR/FAR/QER/URR[illegible]
[illegible]

eBPF [illegible]

eBPF [illegible] eBPF [illegible]

OmniUPF [illegible]

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`BPF_MAP_TYPE_HASH`	□□□□□□□□	□ TEID □ UE IP □□ PDR
`BPF_MAP_TYPE_ARRAY`	□□□□□□□□	□ ID □□ QER□FAR□URR
`BPF_MAP_TYPE_PERCPU_HASH`	□ CPU □□□□□□□□	□□□ PDR □□
`BPF_MAP_TYPE_LRU_HASH`	LRU□□□□□□□□□□	□□□□□□□

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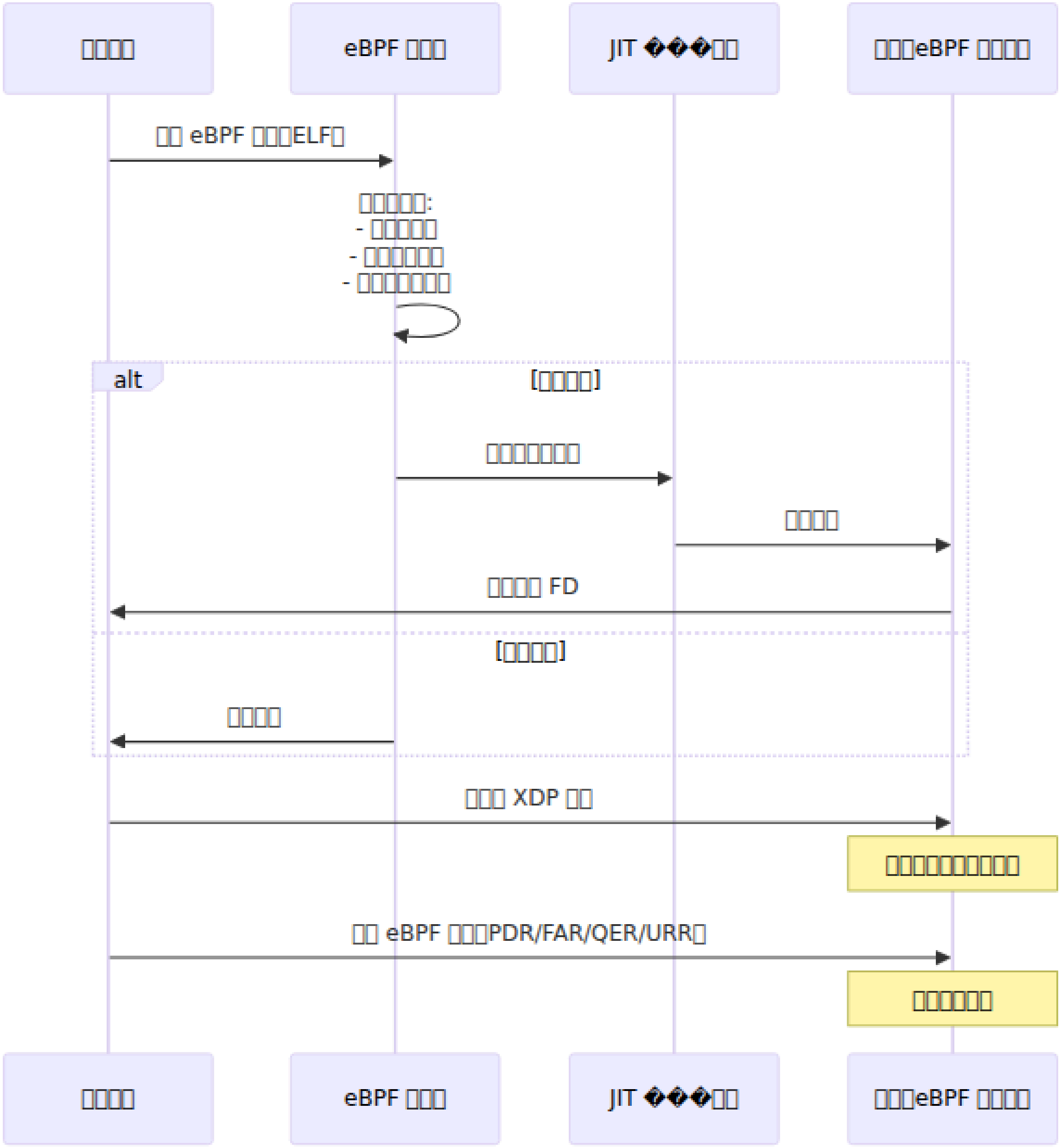
XDP □□□□

XDP □□

XDP□□□□□□□□□□□ Linux □□□□□□□ eBPF □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

XDP □□□□

OmniUPF □□□□ XDP □□□□□□□□□□□□□□□□□□□□□□□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JIT ���□□
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□□ eBPF □□□PDR/FAR/QER/URR□
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eBPF □□□
JIT ���□□
□□□eBPF □□□□

1. XDP □□□□

□□□□□□□□□□□□

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

□□□□ `runtime.exs` □□□

```
xdp_attach_mode = "offload"
```

□□□

- □□□□□ SmartNIC □□
- □□ eBPF □□□□□
- □□□□ eBPF □□□□□□□□□

---

2. XDP □□□□□□□□□□□□□□□

□□□□□□□□□□□

- eBPF □□□□□□□□□□□□□
- □□□□ SKB□□□□□□□□□□□□□□
- □□□□□□ 10-40 Gbps
- □□□□ XDP □□□□□□□□□□□□

□□□□ `runtime.exs` □□□

```
xdp_attach_mode = "native"
```

□□□

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- □□□□□□□□
- □□□ eBPF □□□

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- □□□□i40e□ice□ixgbe□igb
- Mellanox□mlx4□mlx5
- □□□bnxt
- □□□□ena
- □□□ 10G+ □□□

---

3. XDP [illegible]

[illegible]

- eBPF [illegible] SKB [illegible]
- XDP [illegible]
- [illegible]
- [illegible]

[illegible] `runtime.exs` [illegible]

```
xdp_attach_mode = "generic"
```

[illegible]

- [illegible]
- [illegible] SR-IOV [illegible]
- [illegible]
- [illegible]

[illegible]1-5 Gbps[illegible]/[illegible]

XDP [illegible]

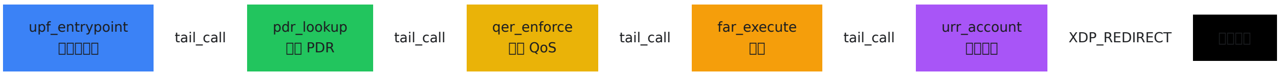
eBPF [illegible] XDP [illegible]

□□□□	□□	**□ OmniUPF □□□□**
`XDP_PASS`	□□□□□□□□□□□□	□□□□□□□□□ICMP□□□□□
`XDP_DROP`	□□□□□□□	□□□□□□□□□□□□□□□
`XDP_TX`	□□□□□□□□□□□□□□	□□□□□
`XDP_REDIRECT`	□□□□□□□□□□□	□□□□□□□N3 ↔ N6□
`XDP_ABORTED`	□□□□□□□□□□□□□	eBPF □□□□

□□□□□□□

□□□□

OmniUPF □□ eBPF □□□□□□□□□□□□□□□□□


upf_entrypoint
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tail_call
pdr_lookup
□□ PDR
tail_call
qer_enforce
□□ QoS
tail_call
far_execute
□□
tail_call
urr_account
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XDP_REDIRECT
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- □□ eBPF □□□□□□ eBPF □□
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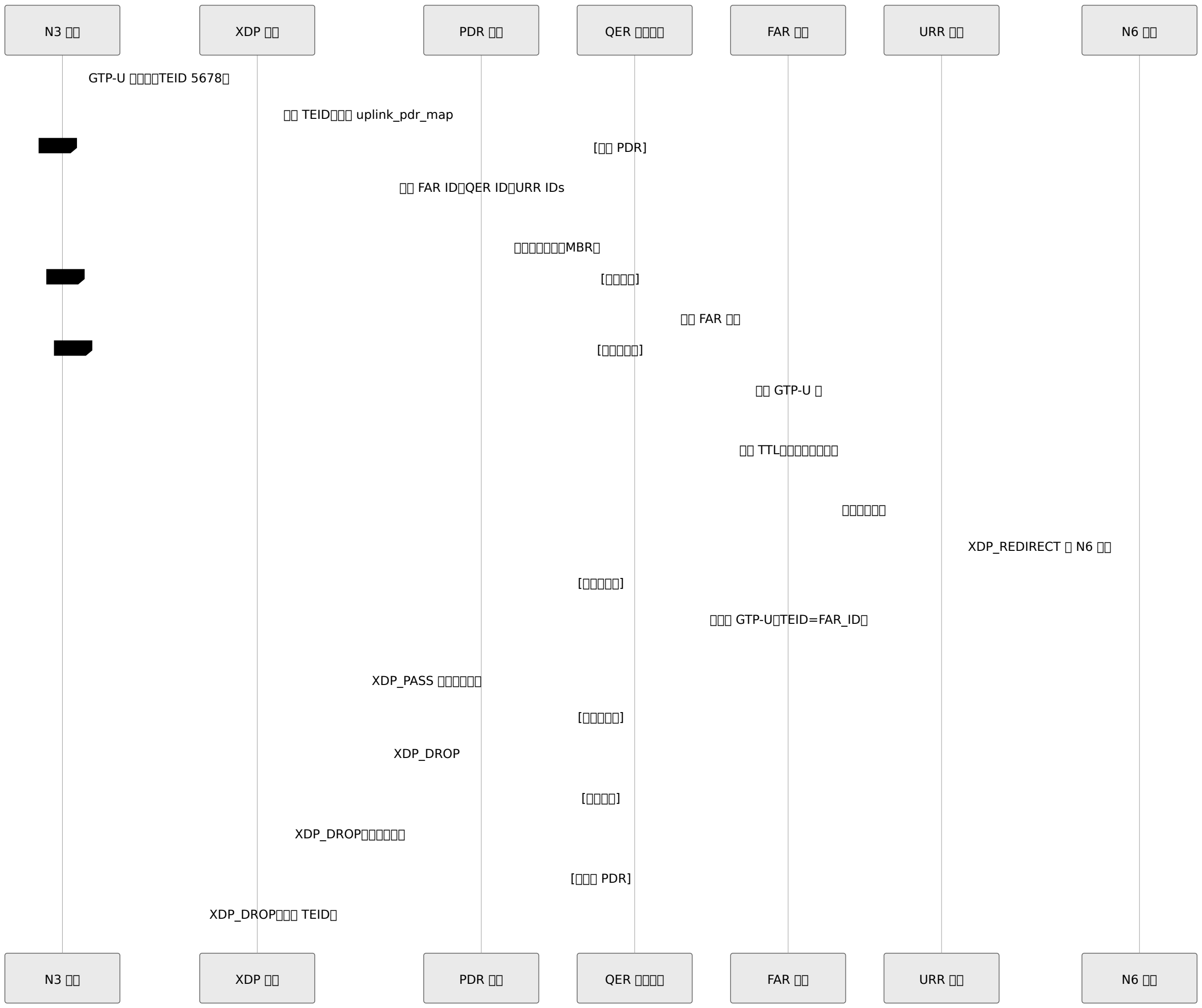
N3 □□
XDP □□
PDR □□
QER □□□□
FAR □□
URR □□
N6 □□
GTP-U □□□□TEID 5678□
□□ TEID□□□ uplink_pdr_map
[□□ PDR]
□□ FAR ID□QER ID□URR IDs
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XDP_REDIRECT □ N6 □□
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□□□ GTP-U□TEID=FAR_ID□
XDP_PASS □□□□□□
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XDP_DROP
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XDP_DROP□□□□□□
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XDP_DROP□□□ TEID□
N3 □□
XDP □□
PDR □□
QER □□□□
FAR □□
URR □□
N6 □□

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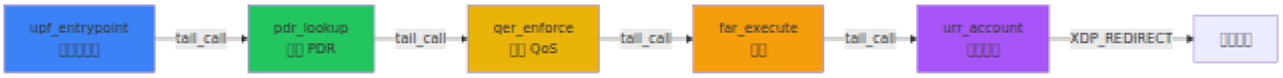
upf_entrypoint
□□□□□
tail_call
pdr_lookup
□□ PDR
tail_call
qer_enforce
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tail_call
far_execute
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tail_call
urr_account
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XDP_REDIRECT
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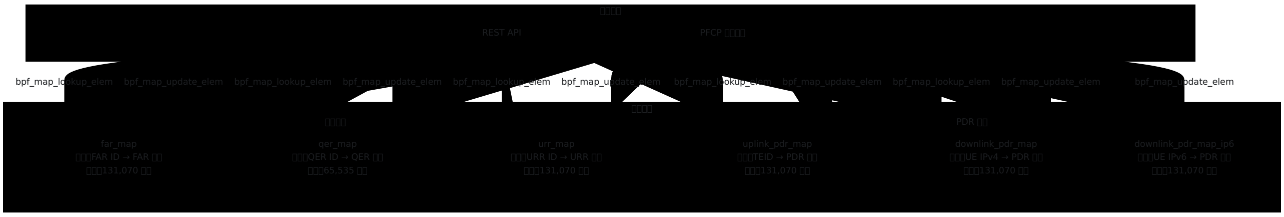
eBPF [illegible]

[illegible]


REST API
PFCP [illegible]
bpf_map_lookup_elem
bpf_map_update_elem
bpf_map_lookup_elem
bpf_map_update_elem
bpf_map_lookup_elem
bpf_map_update_elem
bpf_map_lookup_elem
bpf_map_update_elem
bpf_map_lookup_elem
bpf_map_update_elem
bpf_map_update_elem
PDR [illegible]
far_map
[illegible]FAR ID → FAR [illegible]
[illegible]131,070 [illegible]
qer_map
[illegible]QER ID → QER [illegible]
[illegible]65,535 [illegible]
urr_map
[illegible]URR ID → URR [illegible]
[illegible]131,070 [illegible]
uplink_pdr_map
[illegible]TEID → PDR [illegible]
[illegible]131,070 [illegible]
downlink_pdr_map
[illegible]UE IPv4 → PDR [illegible]
[illegible]131,070 [illegible]
downlink_pdr_map_ip6
[illegible]UE IPv6 → PDR [illegible]
[illegible]131,070 [illegible]

[illegible]

OmniUPF [illegible] `max_sessions` [illegible]

```
PDR [illegible] = 2 × max_sessions  ([illegible] + [illegible])
FAR [illegible] = 2 × max_sessions  ([illegible] + [illegible])
QER [illegible] = 1 × max_sessions  ([illegible])
URR [illegible] = 3 × max_sessions  ([illegible] URR)
```

[illegible]max_sessions = 65,535[illegible]

- PDR [illegible] 131,070 [illegible]
- FAR [illegible]131,070 [illegible]
- QER [illegible]65,535 [illegible]
- URR [illegible]131,070 [illegible]

[illegible]

```
PDR [illegible]3 × 131,070 × 212 B = ~83 MB
FAR [illegible] 131,070 × 20 B = ~2.6 MB
QER [illegible] 65,535 × 36 B = ~2.3 MB
URR [illegible] 131,070 × 20 B = ~2.6 MB
[illegible]~91 MB [illegible]
```

□□□□

□□□□

OmniUPF □□□□□□□□□□□□□□□□□□□□□□□□□ GTP-U □□□□ UDP □□□□□□□□□□□□□

□□□□

Parse error on line 10: ...□□□<br/>□□□FAR_ID → []□□□□] end ----------------------^
Expecting 'SQE', 'DOUBLECIRCLEEND', 'PE', '-)', 'STADIUMEND', 'SUBROUTINEEND', 'PIPE', 'CYLINDEREND', 'DIAMOND_STOP', 'TAGEND', 'TRAPEND', 'INVTRAPEND', 'UNICODE_TEXT', 'TEXT', 'TAGSTART', got 'SQS'

□□

□□□□□□

□□□□□□□FAR □□□ 2 □□□□eBPF □□□

1. □□□□□□□□□□

   ```
   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** □□

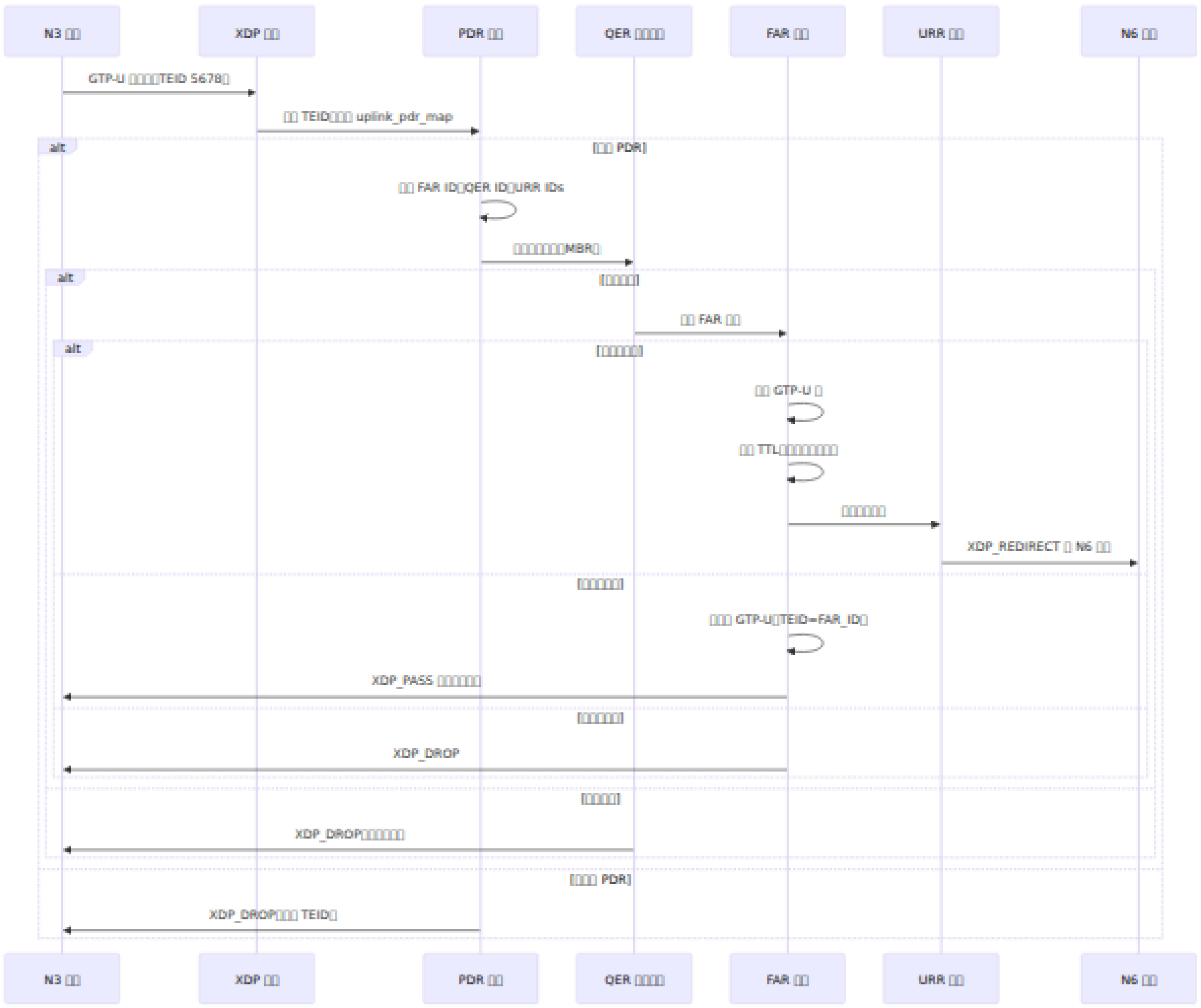
```
gtp->version = 1;
gtp->message_type = GTPU_G_PDU;
gtp->teid = htonl(far_id | (direction << 24));  // □□ FAR ID □□□
gtp->message_length = htons(orig_packet_len);
```

6. □□ **XDP_PASS**□

   - □□□□□□□□□□□ UDP □□□□□□□ 22152
   - □□□□□□□□□□□□□□□□□

□□□□□□

□□□□□□□SMF □□ FAR □□□ BUFFER □□□□□□□□□□□□□


N3 □□
XDP □□
PDR □□
QER □□□□
FAR □□
URR □□
N6 □□
GTP-U □□□□TEID 5678□
□□ TEID□□□ uplink_pdr_map
alt
[□□ PDR]
□□ FAR ID□QER ID□URR IDs
□□□□□□□MBR□
alt
[□□□□□]
□□ FAR □□
alt
[□□□□□□]
□□ GTP-U □
□□ TTL□□□□□□□□□
□□□□□□
XDP_REDIRECT □ N6 □□
[□□□□□□]
□□□ GTP-U□TEID=FAR_ID□
XDP_PASS □□□□□□
[□□□□□□]
XDP_DROP
[□□□□□]
XDP_DROP□□□□□□
[□□□ PDR]
XDP_DROP□□□ TEID□

□□□□□□

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

QoS [illegible]

[illegible]

OmniUPF [illegible] [illegible] [illegible] QoS [illegible]

Parse error on line 5: ...= packet_size × 8 × (NSEC_PER_SEC / rate -----------------------^ Expecting 'SQE', 'DOUBLECIRCLEEND', 'PE', '-)', 'STADIUMEND', 'SUBROUTINEEND', 'PIPE', 'CYLINDEREND', 'DIAMOND_STOP', 'TAGEND', 'TRAPEND', 'INVTRAPEND', 'UNICODE_TEXT', 'TEXT', 'TAGSTART', got 'PS'

[illegible]

[illegible]

[illegible] `qer.h`[illegible]

```
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 [illegible]

    // [illegible] = 0 [illegible]
    if (rate == 0)
        return XDP_PASS;

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

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

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

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

[illegible]

- [illegible]5ms[illegible]5,000,000 [illegible]
- [illegible]
- [illegible]
- **MBR = 0**[illegible]

QoS □□□□

□□□MBR = 100 Mbps□□□□□□ = 1500 □□

1. □□□□□

   ```
   tx_time = 1500 □□ × 8 □/□□ × (1,000,000,000 ns/sec ÷
   100,000,000 bps)
   tx_time = 1500 × 8 × 10 = 120,000 ns = 120 µs
   ```

2. □□□□□

   - □□□□□□□□□ `t=0` □□□□□□□□□□□□□ `t=120µs` □□
   - □□□□□□ `t=100µs` □□□□□□□□□□□
   - □□□□□□ `t=150µs` □□□□□□□□□□□□□□

3. □□□□□□□□

   ```
   Max PPS = (100 Mbps ÷ 8) ÷ 1500 □□ = 8,333 □□□/□
   □□□□□ = 120 µs
   ```

□□□□

□□□

□□	□□□	□□□/□	□□
XDP □□□SmartNIC□	100 Gbps	148 Mpps	< 1 µs
XDP □□□10G NIC□□□□□	10 Gbps	8 Mpps	2-5 µs
XDP □□□10G NIC□4 □□□	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** □□□

Setting SMF as parent of SMF would create a cycle

□□

□□□□□

- SMF □ UPF □□□□□□
- □□ UPF □□□□□ UE □□
- □□□ UPF □□□□□□□□□□

□□□□

CPU □□□

1. □ XDP □□□□ CPU □□□
2. □□ RSS□□□□□□□□□ RX □□
3. □ eBPF □□□□□□□□□

NIC □□□

1. □□ RX □□□□□□□
2. □□□□□ NIC□RSS□
3. □□□□□□□□□□□

□□□□□

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

# □□ IRQ □□□□□ XDP □□
systemctl stop irqbalance

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

# □□□□□□□□□
sysctl -w net.core.rmem_max=134217728
sysctl -w net.core.wmem_max=134217728
```

□□□□

□□□

```
□□ CPU □□ = (□□ PPS ÷ 10,000,000) × 1.5  (50% □□)
□□□□ = (□□□□ × 212 B × 3) + 100 MB (eBPF □□ + □□)
□□□□ = (□□□□□ × 2) + 10 Gbps (□□)
```

□□□100 □□□□□□ 20 Gbps□□

- CPU: (20 Gbps ÷ □□□ 10 Gbps) × 1.5 = 3-4 □□
- □□: (1M × 212 B × 3) + 100 MB ≈ 750 MB
- □□: (20 Gbps × 2) + 10 Gbps = 50 Gbps □□

□□□□

- **UPF □□□□** - □□ UPF □□□□□
- **□□□□□□** - PDR□FAR□QER□URR □□□□
- **□□□□** - □□□□□□□
- **Web UI □□□□** - □□□□□□
- **□□□□□□** - □□□□□□□
- **□□□□□□** - □□□□□□□□□□□□□□□□□□□□□□□□□

OmniUPF □□□□

□□

1. □□
2. □□□□
3. XDP □□□□
4. □□□□
5. □□□□
6. □□□□□□□□□□
7. NIC □□□
8. □□□□
9. □□□□□□□□□

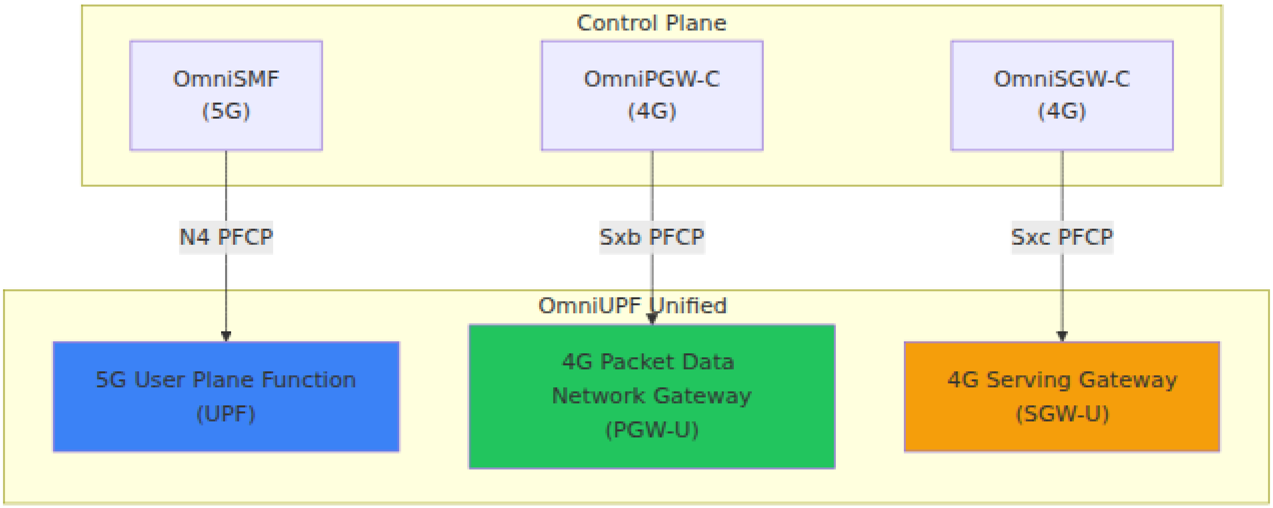
□□

OmniUPF □□□□□□□□□□□□□□□□□□□□□□□□□□□□ 4G (EPC) □ 5G □□□□□□□□□□□ Elixir/OTP □□□□□□□ Elixir □□□□ (`runtime.exs`) □□□

□□□□□□□□□□□□□ `/etc/omniupf/runtime.exs`□□□□□□□□□□□□□□□□□□□□□□ UPF□

□□□□

OmniUPF □□□ □□□□□□□□□□□□


Control Plane
OmniSMF
(5G)
OmniPGW-C
(4G)
OmniSGW-C
(4G)
N4 PFCP
Sxb PFCP
Sxc PFCP
OmniUPF Unified
5G User Plane Function
(UPF)
4G Packet Data
Network Gateway
(PGW-U)
4G Serving Gateway
(SGW-U)

□□□□

□□□□□ □□□□ (SMF□PGW-C □ SGW-C) □□□□□□□□□ OmniUPF □□ PFCP □□□□□□□□□□□□ □ OmniUPF □□□

□□□□□

- OmniUPF □□□□□□□□□□□□□□□ PFCP □□
- □□ OmniUPF □□□□□□□□ UPF□PGW-U □ SGW-U
- □□□□□□□□□□□□□□□□□□□□□

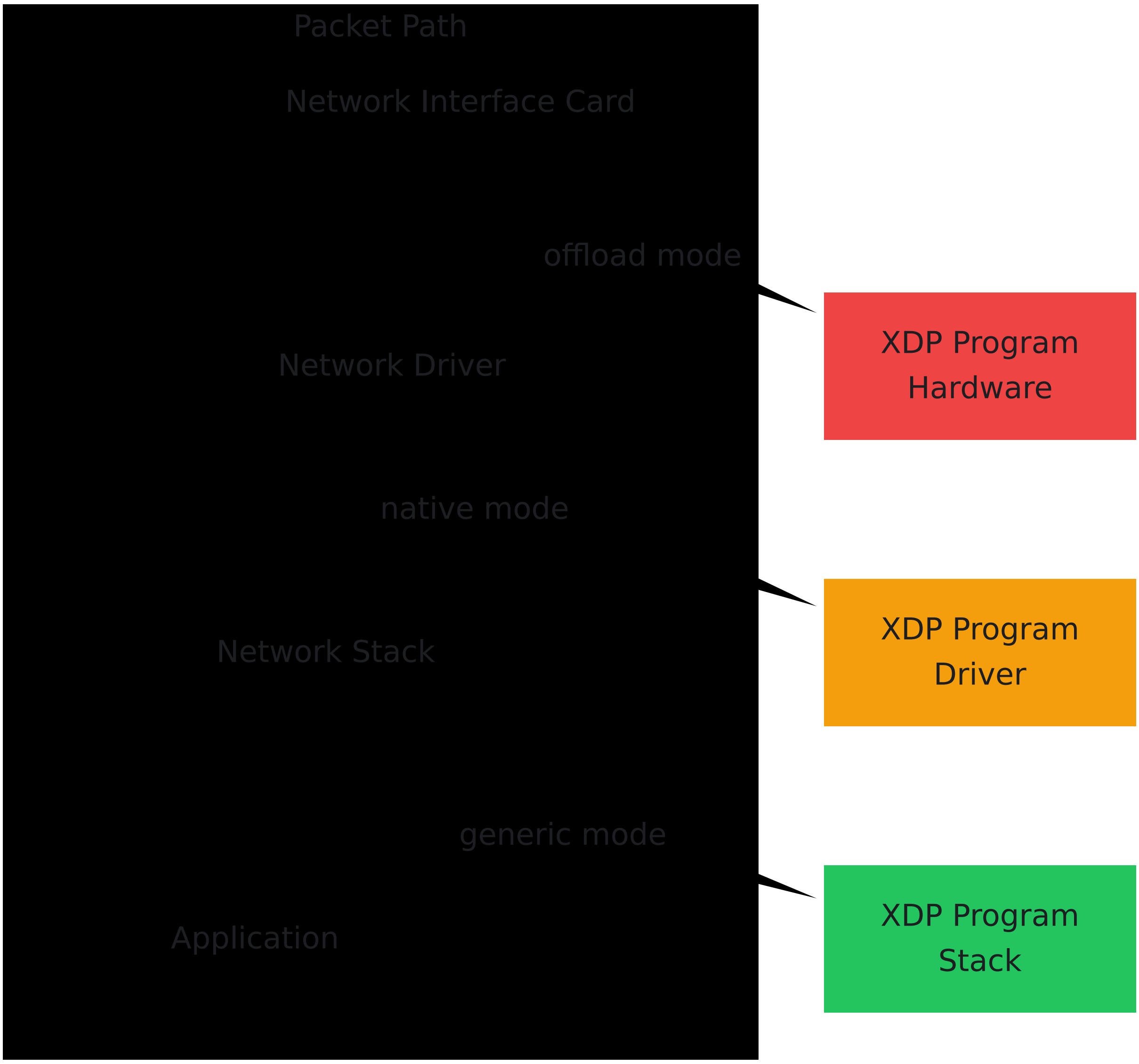
XDP □□□□

OmniUPF □□ XDP (eXpress Data Path) □□□□□□□□□□□□□□□□□□□□

□□□□□ **XDP** □□□□□□□□□□ **Proxmox** □□□□□□□□□□□□□□ **XDP □□□□**□

□□□□

□ □	□□□	□□	□□	**NIC □□**
□ □	□□□ (□□)	~1-2 Mpps	□□□□□□□□□	□□ NIC
□ □	□□□□ (□□)	~5-10 Mpps	□□ (□□□□□ SR-IOV □□□□)	□□ XDP □□□
□ □	NIC □□ (SmartNIC)	~10-40 Mpps	□□□□□□	□□ XDP □□□ SmartNIC


Packet Path
Network Interface Card
offload mode
Network Driver
native mode
Network Stack
generic mode
Application
XDP Program Hardware
XDP Program Driver
XDP Program Stack

□□□□ (□□)

□□□XDP □□□□□□□□□□□

□□□

- □□□ □□ □□□□
- □□□□□□□□□□□
- □□□□□□□□□□
- □□□□□□□□□□□□□□□□□□

□□□

- □□□□ (~1-2 Mpps □□□)
- □□□□ XDP □□□□□□□□□□

□□ (□ `runtime.exs` □)□

```
xdp_attach_mode = "generic"
```

□□□□□

- □□ SR-IOV □□□□
- □□□□□□□
- □□□ XDP □□□ NIC
- □ Proxmox□VMware□VirtualBox □□□□□□□□□□

□□□□ (□□)

□□□XDP □□□□□□□□□□□

□□□

- □□□ (~5-10 Mpps □□□)
- □□□□□□□□□□□□□
- □□□□□□□□□□

- □□□□□□□ SR-IOV □□□

□□□

- □□□□ XDP □□□□□
- □□□□ NIC/□□□□□□ XDP

□□ (□ `runtime.exs` □)□

```
xdp_attach_mode = "native"
```

□□□□□

- □□□□□□□□□
- □ SR-IOV □□□□□□
- □□ XDP □□□□□ NIC (Intel□Mellanox □)

□□□

- □□ XDP □□□□□ (□ NIC □□□)
- □□ XDP □□□ Linux □□ 5.15+

□□□□ (□□□□)

□□□XDP □□□□□ SmartNIC □□□□□

□□□

- □□□□ (~10-40 Mpps)
- □□□□□□ CPU □□□□
- □□□□□
- □□ CPU □□□□□□□□

□□□

- □□□□□ SmartNIC □□
- SmartNIC □□□□□

- □□□□□□□□

□□ (□ `runtime.exs` □)□

```
xdp_attach_mode = "offload"
```

□□□□□

- □□□□□□□□□□
- □□□□□□□□□□□□
- CPU □□□□□□□

□□□

- □□ XDP □□□ SmartNIC (Netronome Agilio CX□Mellanox BlueField)
- □□□���□□□

□□□□

□□□□

□□	□□	□□	□□
`xdp_interfaces`	N3/N6/N9 □□□□□□□ (□□□□□□□ `"auto"` □□□□□□□)	□□□	`"auto"`
`gtpu_interface`	□□□□ GTP-U (N3/N9/S5-S8) □ NIC□□ `sgi_interface` □□□□□□ GTP-U □□□ XDP □□□□□□ NIC□□□□□□□□□□	□□□	`nil`
`sgi_interface`	□□□ IP SGi/N6 □ NIC□□ `gtpu_interface` □□□□□□□□□□ XDP □□□□□□ NIC	□□□	`nil`
`n3_address`	N3 □□□ IPv4 □□ (□□ RAN □ GTP-U)	IP	`"127.0.0.1"`
`n9_address`	N9 □□□ IPv4 □□ (UPF □ UPF □ ULCL)	IP	□ `n3_address` □□

□□ (□ `runtime.exs` □)□

```
xdp_interfaces = "eth0,eth1"
n3_address = "10.100.50.233"
n9_address = "10.100.50.234"
```

□ **NIC** □□□□□□□ □ GTP-U □ SGi □□□□□ NIC □□□□□□□□ NIC □□□□□□□□ NIC □□□□□□□ XDP □□ (□ `gtpu_interface` □□□ GTP-U□□ `sgi_interface` □□□□□)□□□□□□□ "on-a-stick" □□□□□□□□□□□□□ `xdp_interfaces` □□□□□□□□ (□□) □□□□□□□□□□��□□□

```
xdp_interfaces = "eth1,eth2"
gtpu_interface = "eth1"   # [illegible] GTP-U (N3/N9/S5-S8)
sgi_interface  = "eth2"   # [illegible] IP SGi/N6
```

PFCP [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`pfcp_address`	PFCP [illegible] (N4/Sxb/Sxc [illegible])	IP [illegible]	`"127.0.0.1"`
`pfcp_port`	PFCP [illegible]	[illegible]	`8805`
`node_id`	PFCP [illegible] ID	IP [illegible]	`"127.0.0.1"`
`heartbeat_interval_ms`	PFCP [illegible] ([illegible])	[illegible]	`5000`
`heartbeat_timeout_ms`	PFCP [illegible] ([illegible])	[illegible]	`5000`
`heartbeat_retries`	[illegible]	[illegible]	`3`
`association_setup_timeout`	[illegible] UPF [illegible] PFCP [illegible] ([illegible])	[illegible]	`5000`
`pfcp_remote_nodes`	UPF [illegible] IP [illegible] (UPF [illegible])[illegible] UPF [illegible]	[illegible]	`[]`

[illegible] ([illegible] `runtime.exs` [illegible])[illegible]

```
pfcp_address = "10.100.50.241"
pfcp_port = 8805
node_id = "10.100.50.241"
heartbeat_interval_ms = 10_000
heartbeat_retries = 5
association_setup_timeout = 5_000
pfcp_remote_nodes = []                # □□□ ["10.100.50.20",
"10.100.50.22"]
```

API □□□

□□	□□	□□	□□
`api_port`	REST API □□□ (Phoenix) □□□□□	□□	`8080`
`log_level`	□□□□ (`:debug`, `:info`, `:warning`, `:error`)	□□	`:info`

□□ (□ `runtime.exs` □)□

```
api_port = 8080
log_level = :debug
```

GTP □□□□

□□	□□	□□	□□
`gtpu_port`	GTP-U □□	□□	`2152`
`gtp_echo_interval`	□□□□□□□□□	□□	`10`
`gtp_echo_retries`	□□□□□□□□□□□□□□□□	□□	`3`
`gtp_peers`	GTP □□□□□□□□□□□□□□□□□	□□	`[]`

□□ (□ `runtime.exs` □)□

```
gtp_echo_interval = 15
gtp_echo_retries = 3
gtp_peers = [
  %{address: parse_ip.("10.100.50.50"), echo: true, echo_interval:
10},
  %{address: parse_ip.("10.100.50.60"), echo: false},
]
```

□□□□ GTP-U

GTP-U □□□□□□□□□□□ 36 □□□□□□□□□□□□□□ 1500 □□□□□□□ 1536 □□□ GTP-U □□□□□□□□ 1500 □□ N3 □□□GTP-U □□□□□□□□□□□□□□□□□ (TS 29.281 §4.2.4)□□□ UE □□□□□□ PCO ��□□□□□ MTU□□□□□□□□□□□□□□□□□

XDP □□□□□□□□□□□□ GTP-U □□□□□□□ MTU □□□□□□□□□□□□□□□□□□□□□□□□□□ UDP □□□□ □□□□□□□□□□□□□□□□□□□□□□□ UPF □□ (N6 □ N3) □□ GTP-U □□□□□□ (SGW-U) □□

□□	□□	□ □	□□
`gtpu_oversize_punt_enabled`	`true`□□□□□ GTP-U □□□□□□□□□□□□□□□`false`□□□□	□ □	□□□ □

□□□□□□□□UPF □□ MTU □□□□□□□□□□□□□ (□□□□□□ PCO MTU □□□□□□□□□□) □□□□□□□□□□□□□□□□ `upf_gtpu_oversize_punted_total` (□ METRICS.md)□□□□□□□□ `false` □□□□□□□□□ □□□□□□□□

□□ (□ `runtime.exs` □)□

```
gtpu_oversize_punt_enabled = true
```

□ RAN □□□□□□□ GTP-U □□□□□□□□□□□□□□□□□□□□□□□□

TCP MSS □□

□□ PCO □□□ MTU (□□□□□□□) □□□□□ TCP □□□□□ 1460 □□□ MSS□��□□□□□ 1500 □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ MSS □□□□□□□□□□□□□□□

□□	□□	□□	□□
`tcp_mss_clamp`	□□□ UPF □□□□□□□ TCP MSS (IPv4)□□□□□□□□□□□□IPv6 □□□ 20 □□□`false` □□ MSS □□	`false` □□□ 536-1460	□□ □□

□□□ SYN □ SYN-ACK □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□UE □ SYN □□□□□□□□UE □□□□□□□□□ SYN-ACK □□ UE □□□□□□TCP □□□□□□□□□□□□□□□ UPF □□□□□□□□□□□□□□□(PGW-U / UPF)□□□□□□□□ SGW-U □□□

□□□□□ PCO □□□□ IPv4 □□ MTU □□ 40 □□□□□ 1350 MTU□□□□ `1310`□

□□ (□ `runtime.exs` □)□

```
tcp_mss_clamp = 1310
```

□□□□□□ TCP□UDP □□□□□□□ MTU □□□□□□□□□□□□□□□□□ UPF □□□ TCP □□□□□

---

eBPF □□□□

□□	□□	□□	□□
`max_sessions`	□□□□□□□	□□	`1_000_000`
`far_map_size`	FAR eBPF □□□□□	□□	`131_070`
`qer_map_size`	QER eBPF □□□□□	□□	`65_535`
`urr_map_size`	URR eBPF □□□□□	□□	`65_535`

[illegible] ([illegible] `runtime.exs` [illegible])[illegible]

```
max_sessions = 100_000
far_map_size = 131_070
qer_map_size = 65_535
urr_map_size = 131_070
```

[illegible]

[illegible] UE [illegible] UE [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`buffer_port`	[illegible] eBPF [illegible] UDP [illegible]	[illegible]	`22152`
`buffer_max_total`	[illegible] FAR [illegible] ([illegible])	[illegible]	`10_000`
`buffer_max_per_far`	[illegible] FAR [illegible]	[illegible]	`100`
`buffer_ttl_ms`	[illegible] ([illegible])	[illegible]	`30_000`
`buffer_cleanup_interval_ms`	[illegible] ([illegible])	[illegible]	`5_000`

[illegible] ([illegible] `runtime.exs` [illegible])[illegible]

```
buffer_port = 22152
buffer_max_total = 10_000
buffer_max_per_far = 100
buffer_ttl_ms = 30_000
buffer_cleanup_interval_ms = 5_000
```

[illegible] `upf_buffer_packets_dropped_total` [illegible] ([illegible] `global_limit`, `far_limit`, `expired`)[illegible] Metrics Reference[illegible]

□□□□

□□	□□	□□	□□
`feature_ueip`	□□ OmniUPF □ UE IP □□	□□	`false`
`ueip_pool`	UE IP □□□ IP □ (□□ `feature_ueip`)	CIDR □ □□	`"10.60.0.0/24"`
`feature_ftup`	□□ OmniUPF □ F-TEID □□	□□	`true`
`teid_pool_start`	TEID □□□□□□	□□	`1`
`teid_pool_end`	TEID □□□□□□	□□	`10_000_000`

□□ (UE IP □□) (□ `runtime.exs` □)□

```
feature_ueip = true
ueip_pool = "10.45.0.0/16"
```

□□ (F-TEID □□) (□ `runtime.exs` □)□

```
feature_ftup = true
teid_pool_start = 1
teid_pool_end = 1_000_000
```

□□□□□□□

□□□ FRR (Free Range Routing) □□□□□□ UE □□□□□□□□□□□□□ □□□□□□□

□□	□□	□□	□□
`route_manager_enabled`	□□□□ UE □□□□	□□	`true`
`route_manager_type`	□□□□□□□□ (`"frr"` □ `"static"`)	□□□	`"frr"`
`route_manager_nexthop`	□□□ UE □□□□□□□□ (□ = □□□□)	□□□	`""`
`route_manager_vtysh_path`	FRR `vtysh` □□□□□□□□ (□ `route_manager_type` □ `"frr"` □□□)	□□□	`"/usr/bin/`
`route_manager_sync_interval_ms`	□□□□□□□□□□□□□□□□□□□□□ (□□)	□□	`600_000`
`route_batch_interval_ms`	□□□□□□□□/□□□□□□□□□□ (□□)	□□	`1_000`

□□ (□ `runtime.exs` □)□

```
route_manager_enabled = true
route_manager_type = "frr"
route_manager_nexthop = ""
route_manager_vtysh_path = "/usr/bin/vtysh"
route_manager_sync_interval_ms = 600_000
route_batch_interval_ms = 1_000
```

□□□□□

- □□□□□□□□ UPF □□

- □ OSPF □ BGP □□□□□
- □□□□□□ FRRouting □□□□

---

eBPF / XDP □□

□□	□□	□ □	□□
`xdp_interfaces`	□□ XDP □□□□□□□□□□□ `"auto"` □□□□□□	□ □ □	`"auto"`
`xdp_attach_mode`	XDP □ □□`"generic"`□`"native"` □ `"offload"`	□ □ □	`"generic"`
`ebpf_pin_path`	BPF □□□□ pin □□	□ □ □	`"/sys/fs/bpf/upf_pipeli`
`xdp_obj_path`	□□□□ eBPF □□□□	□ □ □	`"/etc/omniupf/ipentrypo`
`ebpf_backend`	□□□���□□□□`:nif` (□□ NIF□□□)□`:port` (□□□□□□)□□ `:mock` (□□□□□□□ eBPF □□□)	□ □	`:nif`

□□ (□ `runtime.exs` □)□

```
xdp_interfaces = "auto"              # [illegible] "eth0,eth1" [illegible]
xdp_attach_mode = "native"
ebpf_pin_path = "/sys/fs/bpf/upf_pipeline"
xdp_obj_path = "/etc/omniupf/ipentrypoint_bpf.o"
ebpf_backend = :nif
```

[illegible]

Elixir [illegible] (runtime.exs)

[illegible]`/etc/omniupf/runtime.exs`

[illegible] Elixir [illegible] `config :upf_ex, ...` [illegible]

```
import Config

parse_ip = fn str ->
  {:ok, addr} = :inet.parse_address(String.to_charlist(str))
  addr
end

#
=====================================================================
# PFCP (N4/Sx) □□
#
=====================================================================
pfcp_address = "10.100.50.241"        # □□ PFCP □□□ IP □□
pfcp_port = 8805                       # PFCP □□ (□□: 8805)
node_id = "10.100.50.241"             # □□□□□□□□□□□ ID

#
=====================================================================
# GTP-U □□□□□□
#
=====================================================================
n3_address = "10.100.50.233"          # N3 □□ IP (GTP-U □□ RAN)
n9_address = n3_address                # N9 □□ IP (□□□ N3)
gtpu_port = 2152                       # GTP-U □□ (□□: 2152)
buffer_port = 22152                    # □□□□□□

#
=====================================================================
# eBPF / XDP □□
#
=====================================================================
xdp_interfaces = "auto"               # "auto" □□□□□□□□□□□□□□□□□
xdp_attach_mode = "native"            # XDP □□: "generic"□"native" □ '
ebpf_pin_path = "/sys/fs/bpf/upf_pipeline"
xdp_obj_path = "/etc/omniupf/ipentrypoint_bpf.o"

#
=====================================================================
# □□□□□□□□
#
=====================================================================
max_sessions = 100_000
teid_pool_start = 1
```

```
teid_pool_end = 10_000_000
far_map_size = 131_070
qer_map_size = 65_535
urr_map_size = 65_535

#
====================================================================
# □□□□
#
====================================================================
feature_ueip = true
feature_ftup = true
ueip_pool = "10.45.0.0/16"

#
====================================================================
# □□□□
#
====================================================================
route_manager_enabled = true
route_manager_type = "frr"

#
====================================================================
# □□□□
#
====================================================================
heartbeat_interval_ms = 10_000
heartbeat_timeout_ms = 5_000
heartbeat_retries = 5

#
====================================================================
# GTP-U □□□□□□□
#
====================================================================
gtp_echo_interval = 10
gtp_echo_retries = 3
gtp_peers = [
  %{address: parse_ip.("10.100.50.50"), echo: true, echo_interval: 1
]

#
====================================================================
# HTTP API □□□
#
=====================================================================
api_port = 8080
log_level = :info

#
=====================================================================
# □□□□ (□□□□□□□□□)
#
=====================================================================
config :upf_ex,
  pfcp_address: parse_ip.(pfcp_address),
  pfcp_port: pfcp_port,
  n3_address: parse_ip.(n3_address),
  n9_address: parse_ip.(n9_address),
  node_id: parse_ip.(node_id),
  api_port: api_port,
  ebpf_pin_path: ebpf_pin_path,
  xdp_obj_path: xdp_obj_path,
  interface_names: String.split(xdp_interfaces, ","),
  xdp_attach_mode: xdp_attach_mode,
  feature_ueip: feature_ueip,
  feature_ftup: feature_ftup,
  ueip_pool: ueip_pool,
  teid_pool_start: teid_pool_start,
  teid_pool_end: teid_pool_end,
  far_map_size: far_map_size,
  qer_map_size: qer_map_size,
  urr_map_size: urr_map_size,
  max_sessions: max_sessions,
  route_manager_enabled: route_manager_enabled,
  route_manager_type: route_manager_type,
  buffer_port: buffer_port,
  gtpu_port: gtpu_port,
  heartbeat_interval_ms: heartbeat_interval_ms,
  heartbeat_timeout_ms: heartbeat_timeout_ms,
  heartbeat_retries: heartbeat_retries,
  gtp_echo_interval: gtp_echo_interval,
  gtp_echo_retries: gtp_echo_retries,
  gtp_peers: gtp_peers

config :logger, level: log_level
```

[illegible]

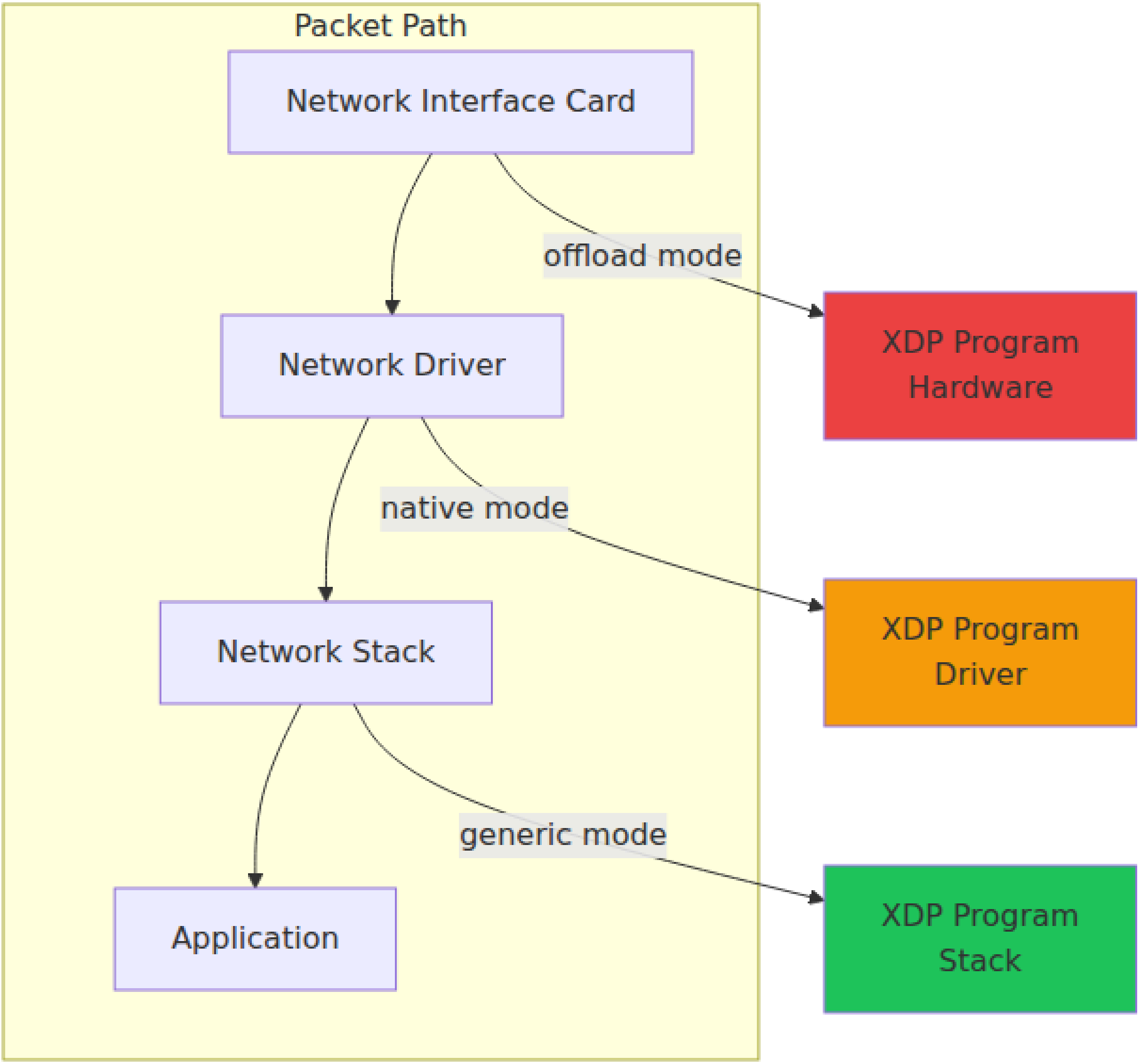
```
# [illegible] UPF
sudo systemctl start omniupf

# [illegible] UPF
sudo systemctl stop omniupf

# [illegible]
sudo systemctl restart omniupf

# [illegible]
sudo systemctl status omniupf

# [illegible]
sudo journalctl -u omniupf -f

# [illegible]
sudo /opt/omniupf/bin/upf_ex start
sudo /opt/omniupf/bin/upf_ex stop
sudo /opt/omniupf/bin/upf_ex daemon   # [illegible]
```

[illegible]

[illegible]

OmniUPF [illegible]XDP [illegible]

[illegible] **Proxmox** [illegible] **XDP** [illegible] **XDP [illegible]**[illegible]


Packet Path
Network Interface Card
offload mode
XDP Program Hardware
Network Driver
native mode
XDP Program Driver
Network Stack
generic mode
XDP Program Stack
Application

Proxmox VE

[illegible]

1. [illegible] XDP[illegible]

[illegible]

[illegible]

- [illegible]VirtIO [illegible] E1000
- XDP [illegible]`generic`
- [illegible]~1-2 Mpps

Proxmox □□□□□□

```
□□□□□net0
□□□VirtIO□□□□□□
□□□vmbr0
```

OmniUPF □□□□ `runtime.exs` **□□□**

```
xdp_interfaces = "eth0"
xdp_attach_mode = "generic"
```

---

2. SR-IOV □□□□□ XDP□

□□□□□□□□□□

□□□

- □□□□□SR-IOV □□□□
- XDP □□□`native`
- □□□~5-10 Mpps

□□□

- □□ SR-IOV □□□□□ NIC□Intel X710□Mellanox ConnectX-5□
- □ BIOS □□□ SR-IOV
- □□ IOMMU□□ GRUB □□□ `intel_iommu=on` □ `amd_iommu=on`□

□ Proxmox □□□ SR-IOV□

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

# □□□ GRUB_CMDLINE_LINUX_DEFAULT□
intel_iommu=on iommu=pt

# □□ GRUB □□□
update-grub
reboot

# □ NIC □□□ 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 □□□□ `runtime.exs` **□□□**

```
xdp_interfaces = "ens1f0"    # SR-IOV VF □□
xdp_attach_mode = "native"
```

---

3. PCI □□□□□ XDP□

□□□□□□□□□□□□□ NIC

□□□

- □□□□ NIC □□□□□□

- XDP □□□`native` □ `offload`□□□□ SmartNIC□
- □□□~5-40 Mpps□□□□ NIC□

Proxmox □□□□□□

```
□□ -> □□ -> PCI □□
□□□□□ NIC□□□□0000:01:00.0□
□□□□□□
□□ GPU□□
PCI-Express□□
```

OmniUPF □□□□ `runtime.exs` □□□

```
xdp_interfaces = "ens1f0"
xdp_attach_mode = "native"    # □ "offload" □□ SmartNIC
```

KVM/QEMU

□□□□□

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

SR-IOV □□□

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

VMware ESXi

□□ vSwitch□□□ XDP□□

- □□□□□□VMXNET3
- XDP □□□`generic`

SR-IOV□□□ XDP□□

- □ ESXi □□□□□□□ 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

NIC □□□

□□ 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 □□ x 1,000,000 pps x 8 □/□□ = 520 Mbps
```

□□ GTP-U □□□□N3□1500 MTU□□

- **□□ IP MTU**□1500 □□□□□□□ IP □□□□
- **□□ GTP-U □□**□36 □□
- □□□□□□□1536 □□

□ 1 Mpps □□□□□□□□□ GTP-U □□□□

```
1536 □□ x 1,000,000 pps x 8 □/□□ = 12,288 Mbps ~ 12.3 Gbps
```

□□ IP □□□□N6 □□□□

□ N6□□□□□□□□□□□□□□ IP□□□ GTP-U□

□□ N6 □□□□

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

□ 1 Mpps □□□□□□□□□ N6 □□□□

```
29 □□ x 1,000,000 pps x 8 □/□□ = 232 Mbps
```

□□ N6 □□□□1500 MTU□□

- **IP MTU□**1500 □□
- □□��1500 □□

□ 1 Mpps □□□□□□□□□ N6 □□□□

```
1500 □□ x 1,000,000 pps x 8 □/□□ = 12,000 Mbps = 12 Gbps
```

□□□□□□□□

Intel X710 NIC□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□

□□□□□□□

□ 1200 □□□□□□□□□□□□□□□□□□□□□□□□

NIC Mpps □□	**N3 □□□□GTP-U□**	**N6 □□□□□□ IP□**	**□□□□**
1 Mpps	~1.0 Gbps	~1.0 Gbps	□□□□□□□□□□□
5 Mpps	~4.9 Gbps	~4.8 Gbps	□□□□□□□
10 Mpps	~9.9 Gbps	~9.6 Gbps	□□□□□□□□
20 Mpps	~19.7 Gbps	~19.2 Gbps	□□□□□□□□
40 Mpps	~39.4 Gbps	~38.4 Gbps	□□□□□□□□□

□□ XDP □□□□□□□

OmniUPF □□□□ XDP □□□□□□□□□□ □□ □ □□ □□□□□□□□□□ □□ NIC□

Intel NICs

□□	□□□□	**XDP □□**	□□	□□
Intel X710	i40e	□	□□	~10 Mpps
Intel XL710	i40e	□	□□	~10 Mpps
Intel E810	ice	□	□□	~15 Mpps
Intel 82599ES	ixgbe	□	���□	~8 Mpps
Intel I350	igb	□□	□□	~1 Mpps
Intel E1000	e1000	□	□□□	~1 Mpps

Mellanox/NVIDIA NICs

□□	□□□□	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 NICs

□□	□□□□	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

□□ NIC XDP □□

□□□□□□□□□□ XDP□

```
# □□ NIC □□□□
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
```

□□□□□□□□ NIC

□ 1200 □□□□□□□□□□□□□□□□□□

[illegible]	[illegible] NIC	[illegible]	**Mpps [illegible]**	[illegible]**N3**[illegible]	[illegible]
[illegible]/[illegible]	[illegible] NIC[illegible]VirtIO[illegible]E1000[illegible]	[illegible]	1-2 Mpps	1-2 Gbps	[illegible]
[illegible]	Intel X710[illegible]Mellanox CX-5	[illegible]	5-10 Mpps	5-10 Gbps	[illegible]
[illegible]/[illegible]	Intel E810[illegible]Mellanox CX-6	[illegible]	10-20 Mpps	10-20 Gbps	[illegible]
[illegible]	Mellanox CX-6[illegible]Intel E810[illegible]	[illegible]	20-40 Mpps	20-40 Gbps	[illegible]
[illegible]	Mellanox BlueField[illegible]Netronome Agilio	[illegible]	40+ Mpps	40+ Gbps	[illegible]
Proxmox [illegible]	VirtIO	[illegible]	1-2 Mpps	1-2 Gbps	[illegible]
Proxmox [illegible]SR-IOV[illegible]	Intel X710/E810 VF[illegible]Mellanox CX-5 VF	[illegible]	5-10 Mpps	5-10 Gbps	[illegible]

[illegible]

[illegible] XDP [illegible]

- XDP [illegible]
- [illegible] XDP [illegible]

NIC [illegible]

- Cilium XDP [illegible]
- IO Visor XDP [illegible]

□□□□

□□ 1□□□□□□□□□□□

□□□□□□ SR-IOV □□□□□□□□□□□□□ OmniUPF

```
# □□□□ (/etc/omniupf/runtime.exs)
xdp_interfaces = "eth0"
xdp_attach_mode = "generic"
api_port = 8080
pfcp_address = "127.0.0.1"
pfcp_port = 8805
node_id = "127.0.0.1"
n3_address = "127.0.0.1"
log_level = :debug
max_sessions = 1_000
```

□□ 2□□□□□□□□□□□

□□□□□□ Intel X710 NIC □□□□□□□□□ UPF

```
# □□□□□□ (/etc/omniupf/runtime.exs)
xdp_interfaces = "ens1f0,ens1f1"    # N3 □ ens1f0□N6 □ ens1f1
xdp_attach_mode = "native"
api_port = 8080
pfcp_address = "10.100.50.241"
pfcp_port = 8805
node_id = "10.100.50.241"
n3_address = "10.100.50.233"
n9_address = "10.100.50.234"
log_level = :info
max_sessions = 500_000
gtp_echo_interval = 30
gtp_peers = [
  %{address: parse_ip.("10.100.50.10"), echo: true, echo_interval:
30},
  %{address: parse_ip.("10.100.50.11"), echo: true, echo_interval:
30},
]
heartbeat_interval_ms = 10_000
feature_ueip = true
ueip_pool = "10.45.0.0/16"
```

□□ 3□Proxmox □□□□ SR-IOV□□□□□□

□□□□ Proxmox □□□□□□ SR-IOV □□□□□ UPF

```
# Proxmox SR-IOV [illegible] (/etc/omniupf/runtime.exs)
xdp_interfaces = "ens1f0"           # SR-IOV VF
xdp_attach_mode = "native"
api_port = 8080
pfcp_address = "192.168.100.10"
pfcp_port = 8805
node_id = "192.168.100.10"
n3_address = "192.168.100.10"
log_level = :info
max_sessions = 100_000
gtp_echo_interval = 15
gtp_peers = [
  %{address: parse_ip.("192.168.100.50"), echo: true},
]
```

[illegible] 4[illegible]PGW-U [illegible]4G EPC[illegible]

[illegible]OmniUPF [illegible] 4G EPC [illegible] PGW-U

```
# PGW-U [illegible] (/etc/omniupf/runtime.exs)
xdp_interfaces = "eth0"
xdp_attach_mode = "native"
api_port = 8080
pfcp_address = "10.200.1.10"
pfcp_port = 8805
node_id = "10.200.1.10"
n3_address = "10.200.1.10"          # S5/S8 [illegible]GTP-U[illegible]
log_level = :info
max_sessions = 200_000
gtp_echo_interval = 20
gtp_peers = [
  %{address: parse_ip.("10.200.1.50"), echo: true, echo_interval: 20},
]
heartbeat_interval_ms = 5_000
```

□□ 5□□□□□UPF + PGW-U □□□

□□□OmniUPF □□□ 5G □ 4G □□□□□□□

```
# □□□□□ (/etc/omniupf/runtime.exs)
xdp_interfaces = "eth0,eth1"
xdp_attach_mode = "native"
api_port = 8080
pfcp_address = "10.50.1.100"
pfcp_port = 8805
node_id = "10.50.1.100"
n3_address = "10.50.1.100"
n9_address = "10.50.1.101"
log_level = :info
max_sessions = 300_000
gtp_echo_interval = 15
gtp_peers = [
  %{address: parse_ip.("10.50.2.10"), echo: true, echo_interval: 15},
  %{address: parse_ip.("10.50.2.20"), echo: true, echo_interval: 15},
]
heartbeat_interval_ms = 10_000
feature_ueip = true
ueip_pool = "10.60.0.0/16"
```

□□ 6□SmartNIC □□□□

□□□□□ Netronome Agilio CX SmartNIC □□□□□□□□□

```
# SmartNIC □□□□ (/etc/omniupf/runtime.exs)
xdp_interfaces = "enp1s0np0"        # SmartNIC □□
xdp_attach_mode = "offload"
api_port = 8080
pfcp_address = "10.10.1.50"
pfcp_port = 8805
node_id = "10.10.1.50"
n3_address = "10.10.1.50"
log_level = :warning
max_sessions = 1_000_000
far_map_size = 2_000_000
qer_map_size = 1_000_000
gtp_echo_interval = 30
gtp_peers = [
  %{address: parse_ip.("10.10.2.10"), echo: true},
  %{address: parse_ip.("10.10.2.20"), echo: true},
  %{address: parse_ip.("10.10.2.30"), echo: true},
]
heartbeat_interval_ms = 15_000
```

□□□□□□□□□

□□□□□□

□□ `max_sessions` □□□□□□□□□□□□□

```
max_sessions = 100_000
far_map_size = 131_070
qer_map_size = 65_535
```

□□□□□~91 MB □□ 100K □□

□□□□

□□□□□□□□

```
□□□□□ = 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 x 212 B = 424 B
- FAR□2 x 20 B = 40 B
- QER□1 x 36 B = 36 B
- URR□2 x 20 B = 40 B
- □□□□□□ ~540 B

□□ **100K** □□□□□□□ ~52 MB

□□□□□□□□□□□□□ 2 □□□□□□

```
# □□□□□□
ulimit -l

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

□□□□

- **□□□□** - eBPF/XDP □□□□□□□□□
- **□□□□□□** - PDR□FAR□QER□URR □□
- **□□□□** - □□□□□□□□□□
- **□□□□** - □□□ Prometheus □□□□
- **Web UI □□** - □□□□□□
- **□□□□** - UPF □□□□□□□
- **□□□□□□** - □□□□□□□□□□□□□□□□□□

□□□□□□ IPv6 / □□

OmniUPF □□□□ IPv6 □□□□□□□ IPv6 □ IPv4v6 PDN □□□□□□□□□□UE □□□□□ PFCP □□ IPv6 □□□□□□□□□ OSPFv3 □□□□□ UE □□□□□

□□□□ □□□□ □□□□□□□□□PDN □□□□□PAA□Gx□□□□□ PFCP □ UPF □□ UE IPv6 □□□□ SMF/PGW-C □□□□□□□ □□□□ □ □□□□□

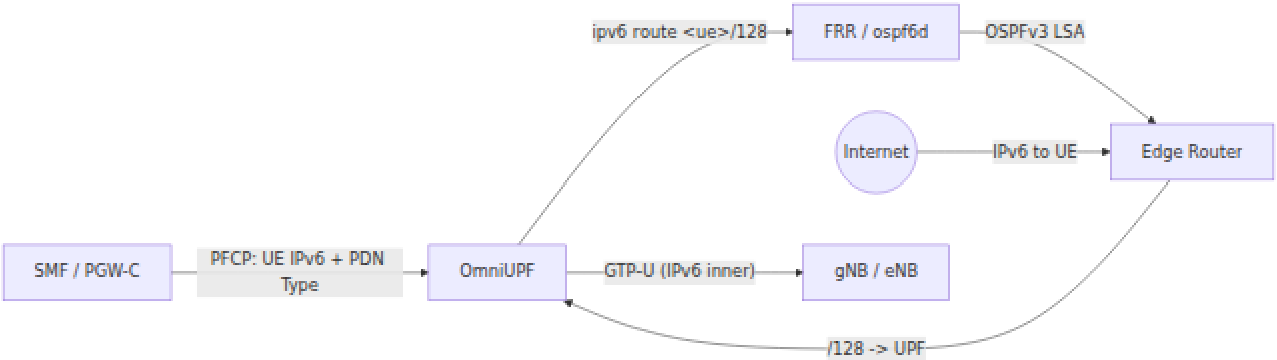
□□

- □□
- □□□□□□
- UE IPv6 □□□
- OSPFv3 □□□□
- □□□□□□
- □□□□

□□

□□□ IPv6□□ IPv4v6□PDN □□□□SMF/PGW-C □□ PFCP □ UE □ IPv6 □□□ PDN □□□□□ UPF□□□□UPF□

1. □□ **IPv6** □□□□□□□□□□ UE □□□□□□□□□□□□□
2. □ UE □□□□ `/128` □□□□□□□□ **OSPFv3** □□□□□□□□□□□□□□□□□□□□□□ UPF□
3. □□□□□□□□□□□□□□□□□□□□□ GTP-U □□□□□□ IPv6 □□□□□□


ipv6 route <ue>/128
FRR / ospf6d
OSPFv3 LSA
Internet
IPv6 to UE
Edge Router
SMF / PGW-C
PFCP: UE IPv6 + PDN Type
OmniUPF
GTP-U (IPv6 inner)
gNB / eNB
/128 -> UPF

[illegible]

[illegible] IPv6 [illegible] sysctl drop-in [illegible] `/etc/sysctl.d/` [illegible]

[illegible]	[illegible]	[illegible]
`net.ipv6.conf.all.disable_ipv6`	`0`	[illegible] IPv6[illegible]UPF [illegible] IPv6 [illegible]
`net.ipv6.conf.default.disable_ipv6`	`0`	[illegible] IPv6 [illegible]
`net.ipv6.conf.all.forwarding`	`1`	[illegible] IPv6 [illegible] UE [illegible]

[illegible] IPv6 [illegible] OSPFv3 [illegible]

UE IPv6 [illegible]

[illegible] UPF [illegible] UE [illegible] SMF [illegible] `runtime.exs` [illegible] IPv6 [illegible] SMF/PGW-C [illegible] PFCP [illegible] UE [illegible]

```
# /etc/omniupf/runtime.exs
config :upf_ex,
  ueip_pool: "2001:db8:6f85:70::/64"
```

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
`ueip_pool`	[illegible] [illegible]CIDR[illegible]	[illegible]	-	[illegible] UPF [illegible] UE IP [illegible] IPv4 [illegible] IPv6 CIDR[illegible]

OSPFv3 □□□□

□□□□□ UE IPv6 □□□□ `/128` □□□□□□□□□□□□□□□□□□□ IPv4 `/32` □□□□□□□□□□□□□□□□□□□ FRR □□□□□ OSPF□

```
# /etc/omniupf/runtime.exs
config :upf_ex,
  route_manager_enabled: true,
  route_manager_type: "frr"
```

□□	□□	□□	□□	□□
`route_manager_enabled`	□□□	□	`false`	□□ UE □□□□□□□□□□ `true` □□□□ UE □□□
`route_manager_type`	□□□	□	-	□□□□□`"frr"` □□ FRR/`vtysh` □□□□□□□□□□□□□□□□ `ip`/`ipv6` □□□□□□□ `"frr"` □□ OSPFv3 □□□

FRR □□□□□□□□□□□□ **OSPFv3** (`ospf6d`) □□□□□□□□□□□□ UE `/128` □□□□□□□□□□□□□□ IPv6 □□□□□□ `ipv6 route <addr>/128` □□□□□□ - IPv4 `ip route` □□□□□ IPv6 □□□□□□□□□□□□□□□□□□□□□□□□ □□□□□

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□□	□□
□□□□□ → UE□	□□ IPv6 □□□□ PFCP □□□□□ IPv6 □□□□□□□□□□□□□□□ GTP-U □□□ gNB/eNB□□□□□□□□□ BUFF□□□□□□
□□□UE → □□□	GTP-U □□□□□□□ IPv6 □□□□□□□ IPv6 FIB □□□ N6 □□□□□□□□□ sysctl□□
□□□BUFF□	□□□ IPv6 □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ IPv4 □□□

□□□□□□□ `accept_local` / □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ martians□

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IPv6 □□□□□□□ UE

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- UE `/128` □□□□□□□□□□□□□□□□□□ UPF □□□□ OSPFv3□□
- UPF □□□□□□□□□ OSPFv3 □□□□□□
- □□□□□□□□□ `/128`□□□□□□□

□□□□□

1. □□ `route_manager_enabled: true` □ `route_manager_type: "frr"`□
2. □□ UPF FRR □□□□□□□□□□ OSPFv3 □□□□□□□□□□
3. □□ OSPFv3 □□□□□□□□□□□□□□□□□ OSPF □□□ UE `/128`□

IPv6 □□□□□□□□□

□□□□□□□□□□□□ IPv6 □□□□□□□□□□□□□

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- □□□□□□ IPv6□□□□□□□
- □□□□□□□□□□ IPv6 □□□

□□□□□

1. □□ □□□□□□□`disable_ipv6=0`□`forwarding=1`□□
2. □□□□□□□□□□□□□□□□□ IPv6 □□□

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□□□□□□ OmniUPF □ `/api/metrics` □□□□□□□□ Prometheus □□□HTTP API □□□ `api_port` □□□□□□ `8080`□□□□□ `/api` □□ - □□ API □□□□□□□□□□□

□□□□□□□□□□□□□□□□ OmniUPF □□□□□□

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1. **PFCP □□** - □□□□□□□□□□□□□□□□□□
2. □□□□□□□□ - □□□□/□□/□□□□□□□□□□
3. □□□□□□□□□□□□ - □□□□□□□□□□□□ TEID □□□□□□□□□□
4. □□□□□□ **(DLDR)** □□ - PFCP □□□□□□□□□ FAR □□□□
5. **GTP-U □□** - □□□□□□□□□□□□
6. **URR □□** - □□□□□□□□□□ URR □□□
7. **eBPF □□□□** - □□□□□□□□□□
8. □□□□□□□ - □□□□ (N3/N6) `_total` □□□□□ `expose_xdp_metrics` □□ (#57)□□□□□ □ `/api/v1/xdp_stats` □□□□
9. □□/□□□□ - TEID/FAR-ID □□ UE □□□□
10. □□□□□□ - □□□□□□□□□□ DNS □□□□□

PFCP □□

UPF □□ PFCP □□□□SMF / PGW-C / SGW-C□□□□□□□□□□□□□□

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`upf_pfcp_associations`	Gauge	none	□□□□□ PFCP □□
`upf_pfcp_sessions`	Gauge	none	□□□□□ PFCP □□
`upf_pfcp_peer_restarts_total`	Counter	`peer`	□□□□□□□□□□□□□
`upf_pfcp_duplicate_requests_total`	Counter	none	□□□□□□□□□ PFC
`upf_orphaned_sessions_deleted_total`	Counter	none	□□□□□□□□□□□□□
`upf_pfcp_messages_rx_total`	Counter	`type`, `peer`	□□□□□□□□□□□□□
`upf_pfcp_messages_tx_total`	Counter	`type`, `peer`	□□□□□□□□□□□□□

`upf_pfcp_errors_total`	Counter	`type`	PFCP □□□□□□□□
			`session_conte`
			`mandatory_ie_`

[illegible]

[illegible]	[illegible]	[illegible]
`upf_sessions_created_total`	Counter	none
`upf_sessions_deleted_total`	Counter	none
`upf_sessions_modified_total`	Counter	none
`upf_session_establishment_duration_microseconds`	Histogram	none

[illegible]

eBPF [illegible]UDP [illegible] `22152`[illegible]��[illegible] [illegible] UE [illegible] ���[illegible] UE [illegible] [illegible] **TEID** [illegible] G-PDU [illegible] GTP-U [illegible] `buffered`/`flushed`/`current` □□□□□□□□□□□□□□□□□□□□ `upf_walled_garden_*` □□□□□ TEID □□□ `upf_gtpu_error_indications_sent_total`□

□□□□	□□	□□	
`upf_userspace_punt_received_total`	Counter	none	□□□□□□□□□□□□ □ + □□ TEID□
`upf_gtpu_oversize_punted_total`	Counter	none	□□□□□□□□□□□□ □□□□□ MTU□□ □□□□□□□□□□□□ □□□□□ `gtpu_oversi`
`upf_buffer_packets_buffered_total`	Counter	none	□□□□□□□□□□□□
`upf_buffer_packets_flushed_total`	Counter	none	□□□□□□□□□□□□
`upf_buffer_packets_dropped_total`	Counter	`reason`	□��□□□□/□□
`upf_buffer_packets_current`	Gauge	none	□□□□□□□□□□□□
`upf_buffer_flush_operations_total`	Counter	none	□□□□□□□□□□□□
`upf_buffer_flush_packets_sent_total`	Counter	none	□□□□□□□□□□□□
`upf_buffer_flush_errors_total`	Counter	`reason`	□□□□□□□□□□□

`upf_buffer_packets_dropped_total` **`reason`** □□□□□□□□□□□□□□□□□□□□□□□□

- `global_limit` - □□□□□□□□□ (`buffer_max_total`)
- `far_limit` - □□□□□ FAR □□□□□□ (`buffer_max_per_far`)
- `expired` - □□□□□□ TTL (`buffer_ttl_ms`) □□
- `read_error` - □□□□□□□□□□□□□
- `too_small` - □□□□□□ GTP □□□
- `invalid_gtp_type` - □ G-PDU GTP □□□□
- `not_buffering_far` - FAR □□ BUFF □□

- `error_indication_failed` - □□□□□□ TEID □□□ GTP-U □□□□

> □□ TEID □□ □□ □□□□□□□□□□ GTP-U □□□□□□□□□□□□ `upf_gtpu_error_indications_sent_total` □□□□□□□□□□□□���□□□□□□□□□

`upf_buffer_flush_errors_total` `reason` □□

- `far_lookup_failed` - □□□ eBPF □□□□□ FAR □□
- `no_forw_action` - FAR □□□□ FORW □□
- `connection_failed` - □□□□□□□□□□ UDP □□□

□□□□□□ (DLDR) □□

□□ PFCP □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ SMF/PGW-C □□ UE□

□□□□	□□	□□	□□
`upf_dldr_sent_total`	Counter	`peer`	□□□□□□□□□□□ SMF/PGW-C □□□□
`upf_dldr_errors_total`	Counter	none	DLDR □□/□□□□
`upf_dldr_skipped_total`	Counter	none	□□ FAR □□□□□□□□□□ DLDR
`upf_far_index_size`	Gauge	none	□ FarIndex □□□□ FAR □□□□□ DLDR □□

GTP-U □□

GTP-U □□□□□□□□□□□□□□□□□□□□□□□ TEID □□□□□□□□□□□□□

[illegible]	[illegible]	[illegible]	[illegible]
`upf_gtpu_echo_responses_tx_total`	Counter	none	[illegible] GTP-U [illegible]
`upf_gtpu_error_indications_sent_total`	Counter	none	[illegible] GTP-U [illegible] TEID[illegible]
`upf_gtpu_error_indications_rx_total`	Counter	none	[illegible] GTP-U [illegible]
`upf_error_indication_sessions_deleted_total`	Counter	none	[illegible]

[illegible] UPF [illegible] TEID [illegible] GTP-U [illegible]

[illegible] UPF [illegible] TEID[illegible]UPF [illegible]

URR (□□□□□□) □□

□□□□	□□	□□	□□
`upf_urr_reports_sent_total`	Counter	`trigger`	□□□ URR □□□□□□□□□□□□
`upf_urr_report_errors_total`	Counter	none	URR □□□□/□□□□
`upf_urr_active_timers`	Gauge	none	□□□ URR □□□□□□□/□□□□/□□□□□□

`trigger` □□□□ URR □□□□□□ - □□ `periodic` (PERIO), `volume_threshold` (VOLTH), `time_threshold` (TIMTH), `quota_validity` (QUVTI)□

□□ URR □□□□□□□□□□ Prometheus □□□□□□□□□□□□□□□ REST API □ `/api/v1/urr_map` □□□□ URR □□□□□

---

eBPF □□□□

□□□□□□□□□□□□□□□□□□□□□

□□□□	□□	□□	□□
`upf_ebpf_far_entries`	Gauge	none	eBPF □□□□ FAR □□
`upf_ebpf_pdr_uplink_entries`	Gauge	none	eBPF □□□□□□□ PDR □□□□ TEID □ PDR□
`upf_ebpf_pdr_downlink_entries`	Gauge	none	eBPF □□□□□□□ PDR □□□□ UE IP □□□ PDR□

`upf_ebpf_far_entries` □□□□□□ FAR-id □ (`upf_far_ids_allocated`)□□□ far_map □□□□��� FAR id □□□□□□□PDR □□□□□□□□□□□□□□□□□□□□□□□□□ O(□□□)□□

[illegible] (N3/N6)

[illegible] (**N3** = GTP-U [illegible] gNB/eNB[illegible] **N6** = SGi [illegible]) [illegible] eBPF `upf_ext_stat` [illegible] CPU [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`upf_n3_rx_packets_total` / `upf_n3_tx_packets_total`	Counter	none	N3 (GTP-U) [illegible] XDP [illegible]
`upf_n6_rx_packets_total` / `upf_n6_tx_packets_total`	Counter	none	N6 (SGi) [illegible] XDP [illegible]
`upf_n3_rx_bytes_total` / `upf_n3_tx_bytes_total`	Counter	none	N3 (GTP-U) [illegible]
`upf_n6_rx_bytes_total` / `upf_n6_tx_bytes_total`	Counter	none	N6 (SGi) [illegible]

[illegible] **`expose_xdp_metrics`** [illegible] **#57**[illegible] `upf_ext_stat` [illegible] `virtio_net` [illegible] XDP **TX-ring wedge**[illegible] `Sampler` [illegible]���[illegible] `config :upf_ex, expose_xdp_metrics: true` [illegible]

[illegible] `_total` [illegible] `upf_ext_stat` [illegible] omniupf [illegible] eBPF `.o` [illegible] `rate()` [illegible] `rate()`[illegible]

[illegible] **JSON**[illegible] `GET /api/v1/xdp_stats` [illegible] eBPF[illegible]`rx_n3` / `tx_n3` / `rx_n6` / `tx_n6`[illegible] `rx_n3_bytes` / `tx_n3_bytes` / `rx_n6_bytes` / `tx_n6_bytes`[illegible]

[illegible]/[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
`upf_routes_total`	Gauge	none	[illegible] UE IP [illegible]
`upf_teid_allocated`	Gauge	none	[illegible] TEID
`upf_far_ids_allocated`	Gauge	none	[illegible] FAR ID

[illegible]

[illegible]/[illegible] [illegible][illegible]

□□□□	□□	□□	□□
`upf_walled_garden_active_redirects`	Gauge	none	□□□□□□□□□□□□
`upf_walled_garden_packets_intercepted_total`	Counter	none	□□□□□□□□□□□
`upf_walled_garden_packets_dropped_total`	Counter	none	□□□□□□□□□□□
`upf_walled_garden_packets_forwarded_total`	Counter	`dst_ip`	□□□□□□□□□□□□□□ IP
`upf_walled_garden_bytes_forwarded_total`	Counter	`dst_ip`	□□□□□□□□□□□□□ IP
`upf_walled_garden_dns_spoofed_total`	Counter	`domain`	□□□□□□□ DNS □□□□□□

□□□□	□□	□□	□□
`upf_walled_garden_dns_forwarded_total`	Counter	`domain`	□□□□DNS□□□□□□□□□□□□□

> □□□□□□□ `dst_ip` □ `domain` □□□

□□ Prometheus □□

□□□□

□□□ HTTP API □□□□ `/api/metrics` □□□□□□□□□□□□ `api_port`□□□ `8080`□□□□□ `/api` □□ - □□ API □□□□□□□□□□□

```
# □□□□□□
curl http://localhost:8080/api/metrics

# □□□□
upf_pfcp_sessions 42
upf_pfcp_associations 2
upf_dldr_sent_total{peer="10.100.50.241"} 17
```

Prometheus □□

□ OmniUPF □□□□□□□ `prometheus.yml`□

```yaml
scrape_configs:
  - job_name: 'omniupf'
    metrics_path: /api/metrics
    static_configs:
      - targets: ['localhost:8080']
```

Grafana [illegible]

[illegible]

- [illegible] (`upf_pfcp_sessions`, `upf_pfcp_associations`)
- [illegible] N3/N6 [illegible] `/api/v1/xdp_stats` [illegible] #57[illegible]
- [illegible] (`upf_buffer_packets_current`, [illegible] `reason` [illegible])
- DLDR / [illegible] (`rate(upf_dldr_sent_total[5m])`)
- [illegible]

[illegible]

- [illegible] - [illegible]
- [illegible] - [illegible] `api_port`[illegible] UPF [illegible]
- **Web UI [illegible]** - [illegible]
- [illegible] - eBPF [illegible]
- [illegible] - [illegible] PDR[illegible]FAR[illegible]QER[illegible]URR [illegible]
- [illegible] - [illegible]
- [illegible] - [illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]

[illegible]

[illegible] OmniUPF [illegible]OmniUPF [illegible] Web UI [illegible] REST API [illegible]

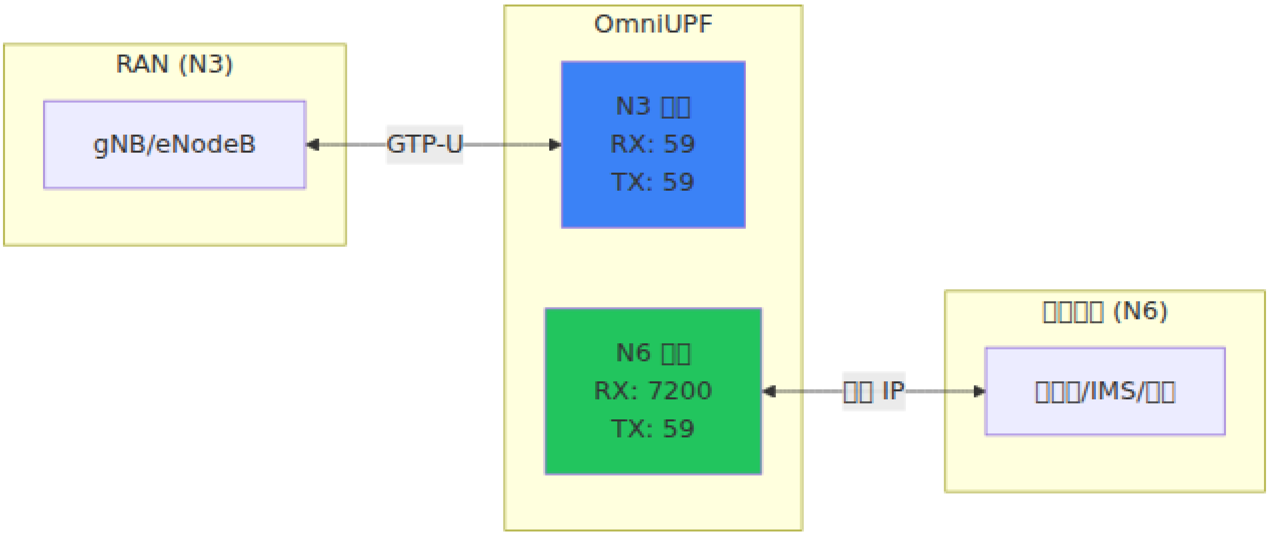
[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	RX/TX [illegible]
[illegible]	[illegible] N3/N6 [illegible]	[illegible]	N3 RX/TX, N6 RX/TX
XDP [illegible]	[illegible]	[illegible]	XDP [illegible]
[illegible]	[illegible]	[illegible]	FIB [illegible]/[illegible]
eBPF [illegible]	[illegible]	[illegible] 10 [illegible]	[illegible]
[illegible]	[illegible]	[illegible] 5 [illegible]	[illegible]FAR [illegible]

□□□□

N3/N6 □□□□

N3/N6 □□□□□□ RAN (N3) □□□□□ (N6) □□□□□□□□□□□



RAN (N3)
gNB/eNodeB
GTP-U
OmniUPF
N3 □□
RX: 59
TX: 59
N6 □□
RX: 7200
TX: 59
□□ IP
□□□□ (N6)
□□□/IMS/□□

□□□

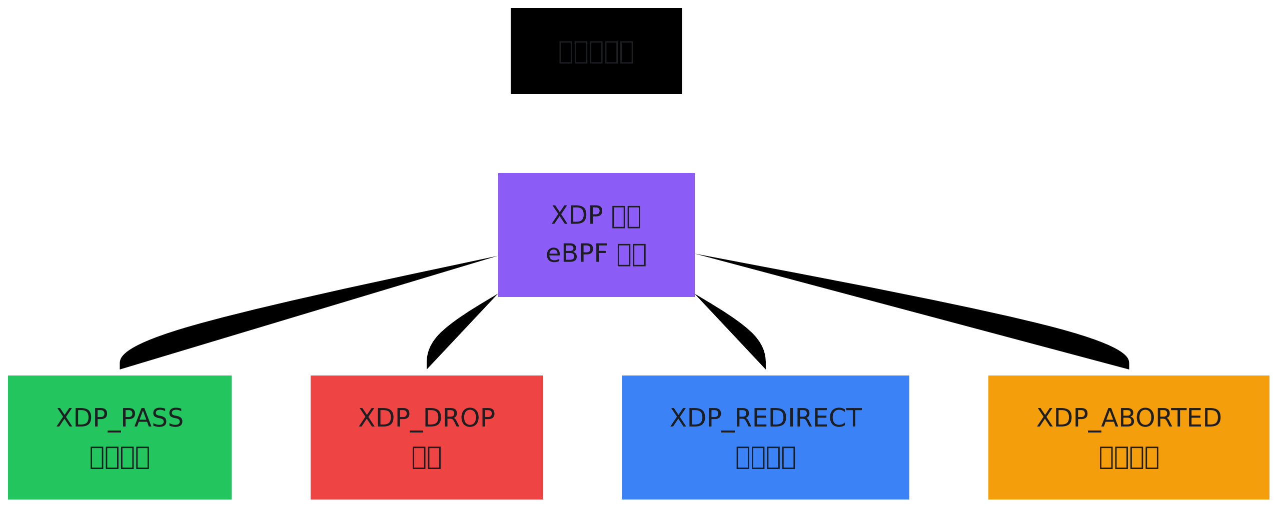
- **RX N3**□□□ RAN □□□□□□□□□ GTP-U □□□
- **TX N3**□□□□ RAN □□□□□□□ GTP-U □□□
- **RX N6**□□□□□□□□□□□□□□□□□□ IP□
- **TX N6**□□□□□□□□□□□□□□□□□ IP□
- □□□□□□□□□□□□□□□

□□□□□

- **RX N3 ≈ TX N6**□□□□□□□ RAN □□□□□□
- **RX N6 ≈ TX N3**□□□□□□□□□□□□□ RAN
- □□□□□□□□□□□
  - □□□□□□□□ >> □□□
  - □□□□□□□□□□
  - □□□��□□

XDP □□

XDP (eXpress Data Path) □□□□□□□□□□□□□□□


□□□□□
XDP □□
eBPF □□
XDP_PASS
□□□□
XDP_DROP
□□
XDP_REDIRECT
□□□□
XDP_ABORTED
□□□□

□□□

- □□□XDP □□□□□□□□□□□ 0□

- [illegible]XDP [illegible]
- [illegible]
- [illegible]
- **TX**[illegible] XDP [illegible]

[illegible]

- **[illegible] > 0**[illegible]eBPF [illegible]
- **[illegible] > 0**[illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

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

[illegible]

- [illegible] **GTP-U PDU** [illegible]
- [illegible] **ICMP** [illegible]

- **□□ TCP □ UDP □□□□□□□□□**
- □□□□□□□□□□□□□□□□

□□□□

FIB (□□□□□) □□□□□□□□□□□

IPv4 FIB □□□

- □□□□□□□□□□□□□□□□
- □□□□□□□□□□

IPv6 FIB □□□

- □□□□□□ IPv6 □□□□
- □□□□□□ IPv6 □□□□

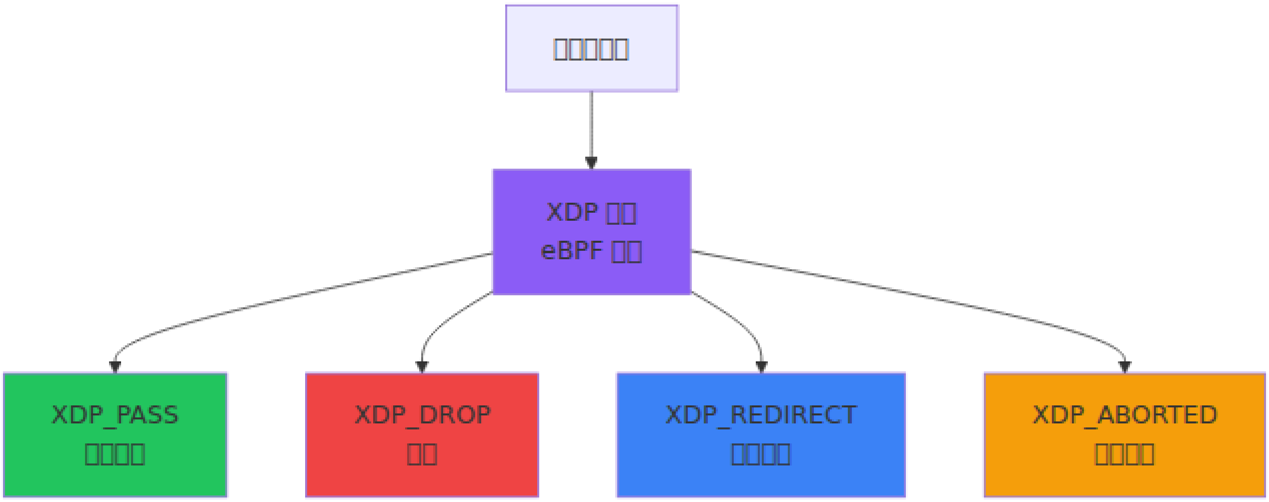
□□□□□

- □□□□□□□□□□□□□□□□□□
- □□□□□□□□□□□□□□□
- □□□□□□□□□□□□□□□□□□□□

□□□□

eBPF □□□□

eBPF □□□□□□□□□□□□□□□□□□□□□□□□


□□□□□
XDP □□
eBPF □□
XDP_PASS
□□□□
XDP_DROP
□□
XDP_REDIRECT
□□□□
XDP_ABORTED
□□□□

□□ eBPF □□

far_map (□□□□□□□)□

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

pdr_map_downlin (□□ PDRs - IPv4)□

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

pdr_map_downlin_ip6 (□□ PDRs - IPv6)□

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

pdr_map_teid_ip (□□ PDRs)□

- □□□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
- □□□□□ - □□□□□

[illegible]

[illegible]	[illegible]
0-50% ([illegible])	[illegible] - [illegible]
50-70% ([illegible])	[illegible] - [illegible]
70-90% ([illegible])	[illegible] - [illegible] 1 [illegible]
90-100% ([illegible])	[illegible] - [illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]

3. □□□□□□

□□□□□□□□□□

1. □□ OmniUPF □□
2. □□□□□□□□□ UPF □□□□
3. □□□□ OmniUPF □□
4. □□□□□□□□□□□
5. □□□□□□□□□□

□□□□□ eBPF □□□□□□□□□□ UPF□□□□□□□□□□□

□□□□

□□ OmniUPF □□□□□□ Prometheus □□□□□□□□□□□ □□□□□

□□□□□□

□□□

```
□□□□□ (pps) = (□□□□□□□) / (□□□□□□□)
```

□□□

- □□ RX □□□□7,000
- 10 □□□17,000
- □□□□□ = (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 □□□□
- □□□□□□□
- □□□□

□□□□□

□□□

```
□□□ (Mbps) = (□□□□□□ × 8) / (□□□□□□□ × 1,000,000)
```

□□□

- □□ RX □□□500 MB
- 60 □□□800 MB
- □□□ = (300 MB × 8) / (60 × 1,000,000) = 40 Mbps

□□□□□□□□□□□ `expose_xdp_metrics` □□□ `_total` □□□□□□`upf_n3_rx_packets_total`□`upf_n3_rx_bytes_total`□... N6 □□□□□N3 □ GTP-U □□gNB□□N6 □ SGi □□□□□□□□eBPF `upf_ext_stat` □□□□□□□□ `Sampler` □□□□□□□□□□□□□□□□□□□□□ `virtio_net` TX-ring-wedge □□□□□□ #57□□□□□□□□□□□□□□□□□□□□□JSON □ `/api/v1/xdp_stats` □□□□□□ □□□□□□□□□□ □□□□□

□□□□□

- □□□□□□□□□□□□□□□□□□
- □□□□□□N3/N6 □□□□□□□□□
- □□ 2 □□□□□□□□□□□

□□□

□□□

```
□□□ (%) = (□□□□□□ / □ RX □□□) × 100
```

□□□□□□□

- **< 0.1%**□□□□□□□□□□□□□□□□□
- **0.1% - 1%**□□□□□□□□□□□□□□
- **1% - 5%**□□□□□ QoS □□□□□□
- **> 5%**□□□□□□□□□□□□□□

□□□□□□□

- QER □□□□□MBR □□□
- eBPF □□□□□□
- □□□ TEID □ UE IP
- □□□□

□□□□□

□□□□

□□□□□□□□□□□□□

- eBPF □□□□ > 90%
- XDP □□□□ > 0
- □□□ > 5%
- UPF □□□□□□

□□□□□1 □□□□□□□

- eBPF □□□□ > 70%
- □□□ > 1%
- □□□□□□□□□□□
- □□□ TTL □□□□□□□□ 30 □□

□□□□□□□□□□□

- eBPF □□□□ > 50%

- □□□□□□□□□
- □□ PFCP □□□/□□
- URR □□□□□□

□□□□

□□□□□□□□□□□□□

1. **Prometheus** □□□□□□□□□□□□□□□□□□□□□□□□ □□□□□
2. □□□□□□□ OmniUPF □□□□□□□□□
3. **REST API** □□□□□□□ `/map_info`□`/packet_stats` □□
4. **Web UI** □□□□□□□□□□□□□□□□□□

□□□□

□□□□□□

□□□□□□□□

```
□□□□□ = min(
  PDR □□□□ / 2,  # □□ + □□ PDR □□□
  FAR □□□□ / 2,  # □□ + □□ FAR □□□
  QER □□□□       # □□□□□□□□ QER
)
```

□□□

- PDR □□□□□131,070
- FAR □□□□□131,070
- QER □□□□□65,535

□□□□□ = min(131,070 / 2, 131,070 / 2, 65,535) = **65,535** □□

[illegible]

[illegible] **eBPF** [illegible]

```
[illegible] = Σ ([illegible] × ([illegible] + [illegible]))
```

[illegible]

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

[illegible]

- [illegible]`ulimit -l`[illegible]
- [illegible] 2 [illegible]
- [illegible]

[illegible]

[illegible]

1. [illegible]
   - [illegible]~5 Mbps
   - [illegible]~1 Mbps
   - VoIP[illegible]~0.1 Mbps
2. [illegible]

   ```
   [illegible] = [illegible] × [illegible]
   ```

3. [illegible]

```
□□□□ = □□□□ × 2  # 100% □□
```

□□□

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

□□□□

□□□□□

1. □□□□□□□□□
2. □□□□□□□
3. □□□□□□□

□□□□□□

```
□□□□□□□ = (□□ - □□□□) / (□□□□)
```

□□□

- □□□□□30,000
- □□□65,535 □□
- □□□□□2,000 □□
- □□□□□□□□ (65,535 - 30,000) / 2,000 = **17.8** □

□□□□□□ 12 □□□□□□□□□□□ 5 □□□□□□

[illegible]

[illegible]

[illegible] > 1%[illegible]

[illegible]

1. [illegible] → [illegible]
2. [illegible]
3. [illegible] XDP [illegible] XDP [illegible]

[illegible]

- **QER** [illegible] QER MBR [illegible]
- [illegible] **TEID**[illegible] PDR TEID [illegible] gNB [illegible]
- [illegible] **UE IP**[illegible] PDR [illegible] UE IP
- [illegible]

[illegible]

- [illegible] QER MBR
- [illegible] SMF [illegible] PDR
- [illegible]

XDP [illegible]

[illegible]XDP [illegible] > 0

[illegible]

1. [illegible] → XDP [illegible]
2. [illegible]
3. [illegible] OmniUPF [illegible] eBPF [illegible]

[illegible]

- eBPF [illegible]
- [illegible]
- eBPF [illegible]
- [illegible]

[illegible]

- [illegible] OmniUPF [illegible]
- [illegible]Linux 5.4+[illegible]
- [illegible] eBPF [illegible]
- [illegible]

[illegible]

[illegible] 100%

[illegible]

1. [illegible]
2. [illegible] 100%
3. [illegible]

[illegible]

1. [illegible]
2. [illegible] SMF [illegible]
3. [illegible] FAR [illegible]

[illegible]

1. [illegible] eBPF [illegible]
2. [illegible] UPF [illegible]
3. [illegible]

[illegible]

[illegible]CPU [illegible]

[illegible]

1. [illegible]
2. [illegible] XDP [illegible]
3. [illegible] UPF [illegible] CPU [illegible]
4. [illegible] N3/N6 [illegible]

[illegible]

- [illegible] UPF [illegible]
- [illegible] CPU [illegible]
- [illegible]
- eBPF [illegible]

[illegible]

- [illegible] UPF[illegible]
- [illegible] CPU [illegible] RSS[illegible]
- [illegible]
- [illegible] eBPF [illegible]

[illegible]

- [illegible] - [illegible] Prometheus [illegible]
- **UPF [illegible]** - [illegible] UPF [illegible]
- [illegible] - PDR[illegible]FAR[illegible]QER[illegible]URR [illegible]
- **Web UI [illegible]** - [illegible]
- [illegible] - [illegible]
- [illegible] - eBPF [illegible]

PFCP [illegible]

[illegible]

PFCP[illegible] OmniUPF [illegible] PFCP [illegible]

[illegible] **3GPP TS 129.244** [illegible] PFCP [illegible]

[illegible]

OmniUPF [illegible] Prometheus [illegible] PFCP [illegible] PFCP [illegible]

```
upf_pfcp_rx_errors{message_name="...", cause_code="...",
peer_address="..."}
```

[illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible] [illegible] [illegible] PFCP [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
1	**RequestAccepted**	[illegible]/[illegible]/[illegible]

□□□□□□□

□□	□□	□□□□
64	**RequestRejected**	□□□□□□□□□□□□□□□□□□□□□□□□□□
65	**SessionContextNotFound**	□□□□□□□□□ SEID □□□□□□□□□□□UPF □□□□□
66	**MandatoryIEMissing**	□□□□□□□□□□□□□□□□□□□□NodeID□□□□□□□□ F-SEID□□□RecoveryTimeStamp□
67	**ConditionalIEMissing**	□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
69	**MandatoryIEIncorrect**	□□□□□□□□□□□□□□□□□□□□□□□□□NodeID □□□□□□RecoveryTimeStamp □□□□□□□F-SEID□
72	**NoEstablishedPFCPAssociation**	□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ PFCP □□□
73	**RuleCreationModificationFailure**	□ PDR□FAR□QER □ URR □□□□□eBPF □□□□□□□□□□□□□□eBPF □□□□□□□□□□□□□□□□□□□□□□

[illegible]/[illegible]

[illegible]	[illegible]	[illegible]
74	**PFCPEntityInCongestion**	UPF [illegible]
75	**NoResourcesAvailable**	[illegible]��[illegible]eBPF [illegible]TEID [illegible]
77	**SystemFailure**	[illegible]eBPF [illegible]

[illegible]

[illegible]	[illegible]	[illegible]
68	**InvalidLength**	[illegible]OmniUPF [illegible]
70	**InvalidForwardingPolicy**	UPF [illegible] OmniUPF [illegible]
71	**InvalidFTEIDAllocationOption**	[illegible] F-TEID [illegible] OmniUPF [illegible]
76	**ServiceNotSupported**	[illegible] OmniUPF [illegible]
78	**RedirectionRequested**	UPF [illegible] UPF [illegible]OmniUPF [illegible]

[illegible]

[illegible]

[illegible] NodeID

```
SMF → UPF: □□□□□□□□ NodeID□
UPF → SMF: □□□□□□□□□□MandatoryIEMissing□
```

□□□□□□□ SMF □□□□□□□□□□□□ NodeID □□□□□

□□□□□□ **NodeID** □□

```
SMF → UPF: □□□□□□□NodeID="invalid"□
UPF → SMF: □□□□□□□□□□MandatoryIEIncorrect□
```

□□□□□NodeID □□□□□□ FQDN □ IPv4/IPv6 □□□

□□□□□□□□□□

```
SMF → UPF: □□□□□□□□ RecoveryTimeStamp□
UPF → SMF: □□□□□□□□□□MandatoryIEMissing□
```

□□□□□□□□□□□□□□□ RecoveryTimeStamp□

□□□□□□

□□□□□□□□

```
SMF → UPF: □□□□□□
UPF → SMF: □□□□□□□□□□NoEstablishedPFCPAssociation□
```

□□□□□□□□□□□□□□ PFCP □□□

□□□□□□□□□

```
SMF → UPF: □□□□□□
UPF □□□□ FAR□QER□URR
UPF □□□□ PDR□eBPF □□□□□
UPF → SMF: □□□□□□□□□□RuleCreationModificationFailure□
```

[illegible]

- [illegible] eBPF [illegible]
- [illegible] UPF [illegible]
- [illegible]

[illegible] **F-SEID**

```
SMF → UPF: [illegible] CP F-SEID[illegible]
UPF → SMF: [illegible]MandatoryIEMissing[illegible]
```

[illegible] CP F-SEID[illegible]

[illegible]

[illegible] **SEID**

```
SMF → UPF: [illegible]SEID=12345[illegible]
UPF [illegible] SEID 12345 [illegible]
UPF → SMF: [illegible]SessionContextNotFound[illegible]
```

[illegible]

- [illegible] SEID [illegible]
- [illegible]
- [illegible] UPF [illegible]N9 [illegible]

[illegible]

[illegible] **SEID**

```
SMF → UPF: [illegible]SEID=67890[illegible]
UPF [illegible] SEID 67890 [illegible]
UPF → SMF: [illegible]SessionContextNotFound[illegible]
```

[illegible]SEID [illegible]

[illegible]

[illegible] Prometheus [illegible]

[illegible] Prometheus [illegible]

```
# [illegible]
rate(upf_pfcp_rx_errors{cause_code!="RequestAccepted"}[5m])

# [illegible]
topk(5, sum by (cause_code) (upf_pfcp_rx_errors))

# [illegible] SMF [illegible]
sum by (peer_address, cause_code)
(upf_pfcp_rx_errors{cause_code!="RequestAccepted"})

# [illegible]
upf_pfcp_rx_errors{message_name="SessionEstablishmentRequest",
cause_code!="RequestAccepted"}
```

[illegible] Web [illegible]

[illegible]

- [illegible]
- [illegible]/[illegible]
- [illegible]

[illegible]

- eBPF [illegible]RuleCreationModificationFailure [illegible]
- [illegible]

[illegible] Web UI [illegible] [illegible]

[illegible]

[illegible] MandatoryIEMissing [illegible]

1. □□ SMF □□□□□□□□□□
2. □□ PFCP □□□□□□
3. □□ SMF □□□□□□□□□□□□□

□□□ RuleCreationModificationFailure□

1. □□ eBPF □□□□□ `GET /api/v1/map_info`
2. □□□□□□□□□ `upf_ebpf_map_used / upf_ebpf_map_capacity`
3. □□□□□ > 70%□□□□□□□□□□□□
4. □□□ □□□□

NoEstablishedPFCPAssociation □□□

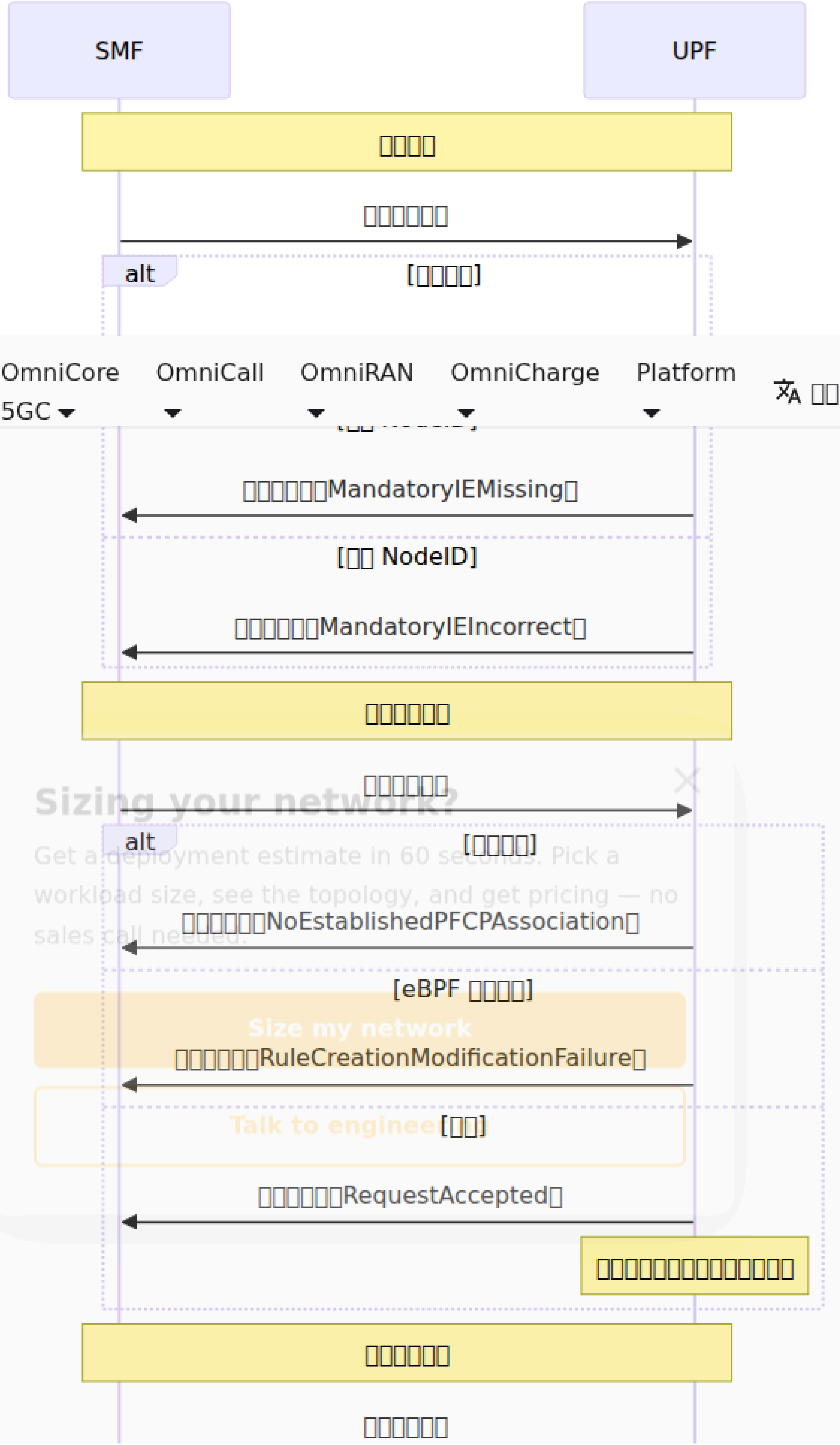
1. □□□□□□□□□ `GET /api/v1/pfcp_associations`
2. □□□□□□□□
3. □□□□□□□□
4. □□ SMF □ UPF □□□□□□

□□□□□□ SessionContextNotFound□

1. □□□□□□□□□□ SEID
2. □□□□□□□□□□
3. □□ N9 □□□□□□□□□□□□ UPF □□
4. □□□□□□□ `GET /api/v1/pfcp_sessions`

[illegible]

[illegible]

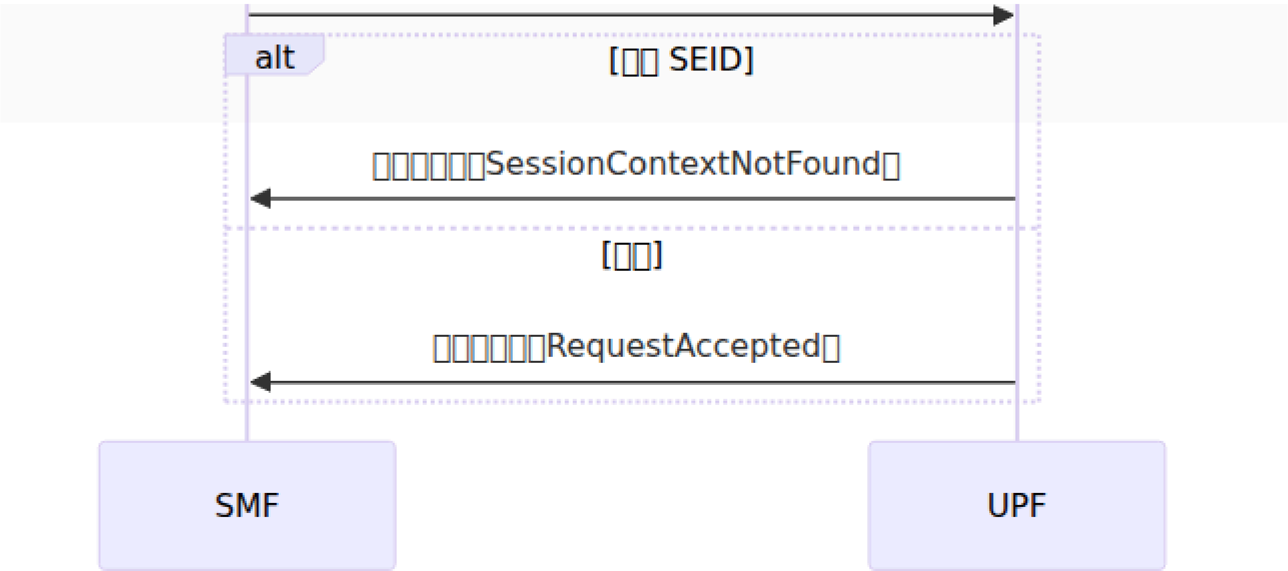

SMF
UPF
□□□□
□□□□□□
alt
[□□□□]
[□□ NodeID]
□□□□□□MandatoryIEMissing□
[□□ NodeID]
□□□□□□MandatoryIEIncorrect□
□□□□□□
□□□□□□
alt
[□□□□]
□□□□□□NoEstablishedPFCPAssociation□
[eBPF □□□□]
□□□□□□RuleCreationModificationFailure□
[□□]
□□□□□RequestAccepted□
□□□□□□□□□□□□□□
□□□□□□
□□□□□□

Sizing your network?

Get a deployment estimate in 60 seconds. Pick a workload size, see the topology, and get pricing — no sales call needed.

Size my network

Talk to engineer


alt
[□□ SEID]
□□□□□□SessionContextNotFound□
[□□]
□□□□□□RequestAccepted□
SMF
UPF

□□□□□

□□□□□

```
# □□□□□□□
- alert: PfcpHighRejectionRate
  expr: |
    rate(upf_pfcp_rx_errors{cause_code!="RequestAccepted"}[5m]) > 0.1
  annotations:
    summary: "□ PFCP □□□□{{ $value }}/s"

# □□□□□□□
- alert: PfcpRuleCreationFailures
  expr: |

rate(upf_pfcp_rx_errors{cause_code="RuleCreationModificationFailure"}
[5m]) > 0
  annotations:
    summary: "□□□ PFCP □□□□□□"

# □□□□□□□
- alert: PfcpNoAssociation
  expr: |

rate(upf_pfcp_rx_errors{cause_code="NoEstablishedPFCPAssociation"}
[5m]) > 0
  annotations:
    summary: "□□□□□□□□□□□ PFCP □□"
```

3GPP [illegible]

OmniUPF [illegible]

- **3GPP TS 129.244 v16.4.0** - PFCP [illegible]
- **[illegible] 8.2.1 [illegible]** - [illegible]
- **[illegible] 8.19 [illegible]** - [illegible]

[illegible]

- **PFCP [illegible]** - PFCP [illegible]
- [illegible] - upf_pfcp_rx_errors [illegible]
- [illegible] - [illegible]
- [illegible] - PFCP [illegible]
- **Web UI [illegible]** - [illegible]

□□□□□□

□□

1. □□
2. □□□□□□□ (PDR)
3. □□□□□□ (FAR)
4. QoS □□□□ (QER)
5. □□□□□□ (URR)
6. □□□□
7. □□□□
8. □□□□

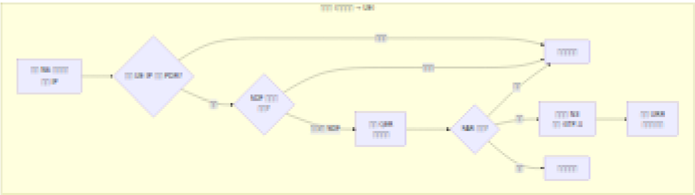
□□

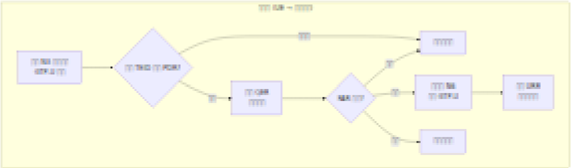
OmniUPF □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ SMF □□ PFCP □□□□□□□ eBPF □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ UPF □□□□□

□□□□

□□□□	□□	□□□□	□□□
PDR (□□□□□□□)	□□□□□□□□	TEID □ UE IP	SMF □□ PFCP □□□□/□□
FAR (□□□□□□)	□□□□□□	FAR ID	SMF □□ PFCP □□□□/□□
QER (QoS □□□□)	□□□□□□□□□	QER ID	SMF □□ PFCP □□□□/□□
URR (□□□□□□)	□□□□□□□□	URR ID	SMF □□ PFCP □□□□/□□

□□□□□□



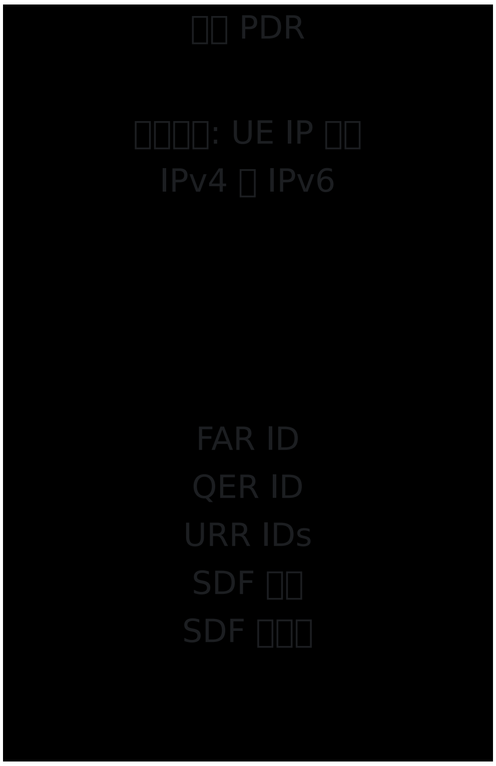


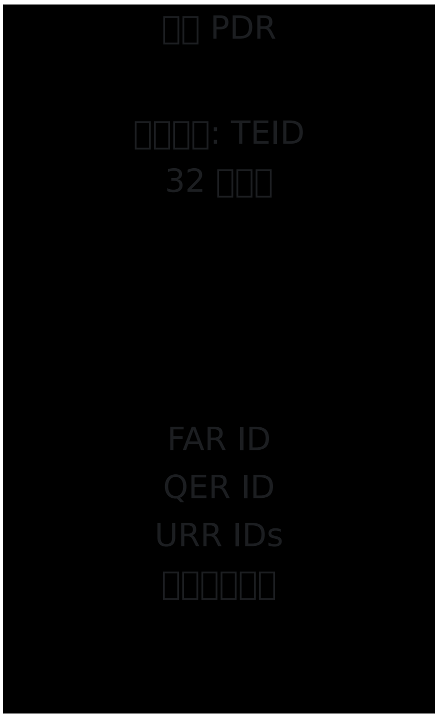
□□□□□□□ (PDR)

□□

PDR □□□□□□□□□□□□□□□ UPF □□□□□□□□□□□□□

PDR [illegible]


[illegible] PDR
[illegible]: UE IP [illegible]
IPv4 [illegible] IPv6
FAR ID
QER ID
URR IDs
SDF [illegible]
SDF [illegible]


[illegible] PDR
[illegible]: TEID
32 [illegible]
FAR ID
QER ID
URR IDs
[illegible]

[illegible] PDR

[illegible] PDR [illegible] RAN [illegible] N3 [illegible]

□□□□: 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
□□□□□□: False
SDF □□: No SDF
```

□□ PDR

□□ PDR □□□□□□□□□ N6 □□□□□□□□□□

□□□□: UE IP □□

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

□□□:

- **FAR ID**: □□□□□□□□□
- **QER ID**: QoS □□□□□□□□□□□
- **URR IDs**: □□□□□□□□□□□□□
- **SDF □□**: □□□□□□□□□□
    - `No SDF`: □□□□□□□□□□
    - `SDF Only`: □□□ SDF □□□□□

    - `SDF + Default`: SDF □□□□□□□□□□□□□□□□□□□□ FAR
- **SDF □□□**: □□□□□□□□□□□□□□□IP □□□

□□□□:

1. □□□□□□□□□□ IP
2. □ `downlink_pdr_map` (IPv4) □ `downlink_pdr_map_ip6` (IPv6) □□□□□□□
3. □□□□□□□□□□ SDF □□□□□□□□□
4. □□ FAR ID□QER ID □ URR IDs
5. □□□□□□□□□□□□□

□□:

```
UE IP: 10.45.0.1
FAR ID: 1
QER ID: 1
□□□□□□: False
SDF □□: No SDF
```

SDF □□□ (□□□□□)

SDF □□□□□□□□□□□□□□□□

□□:

- □□ YouTube □□□□□□□
- □ VoIP □□□□□□□□□□□□ QoS
- □□□□□□□□□□□□□□□□

□□□□:

- □□: TCP, UDP, ICMP
- □□□□: □□□□□□□□HTTPS □ 443□SIP □ 5060□
- **IP □□□□**: □□□□□□
- □□□: 3GPP □□□□□□

□□ **SDF** □□:

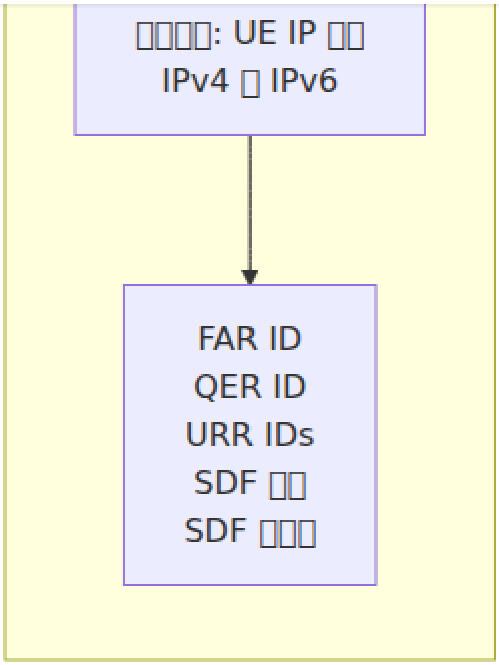
```
PDR ID: 10
UE IP: 10.45.0.1
SDF □□: SDF Only
SDF □□□:
  - □□: UDP, □□: 5060-5061 → FAR ID 5 (VoIP FAR)
  - □□: TCP, □□: 443 → FAR ID 1 (□□ FAR)
```

□□□□□□ (FAR)

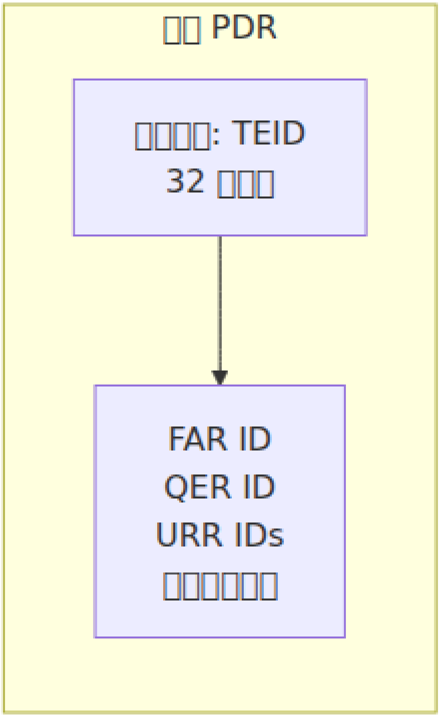
□□

FAR □□□□□ PDR □□□□□□□□□□□□□□□□□□□□GTP-U □□□□□□□□□□

FAR [illegible]



[illegible]: UE IP [illegible]
IPv4 [illegible] IPv6
FAR ID
QER ID
URR IDs
SDF [illegible]
SDF [illegible]



[illegible] PDR
[illegible]: TEID
32 [illegible]
FAR ID
QER ID
URR IDs
[illegible]

[illegible]

FAR [illegible]

□□	□	□	□□
FORWARD	1	2	□□□□□□□□□
BUFFER	2	4	□□□□□□□□□□
DROP	0	1	□□□□□
NOTIFY	3	8	□□□□□□□□□
DUPLICATE	4	16	□□□□□□□□□□□

□□□□□□:

- `Action: 2 (FORWARD)` - □□□□□□□□□
- `Action: 6 (FORWARD + BUFFER)` - □□□□□□□□□□
- `Action: 4 (BUFFER)` - □□□□□□□□□□□□
- `Action: 1 (DROP)` - □□□□□□□□□□□□□□□□□□

□□□□

BUFFER □□□□ 2□□□□□□□□□□□□□□□□□□□□ UPF □□□□□□□□□□□□□ UE □□□□□□□□□□□□

□□□□□□□

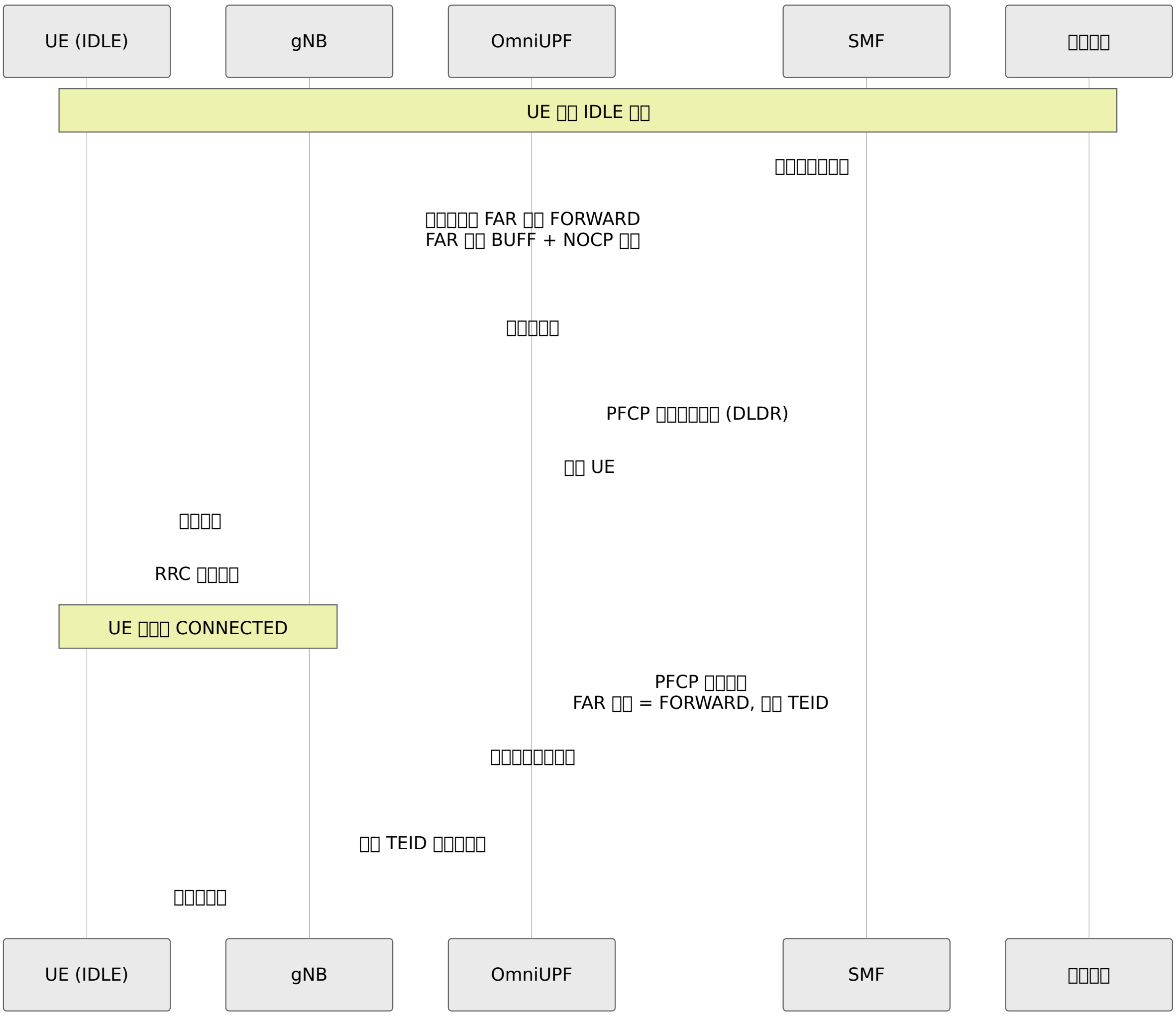
□□□□□□□□□: □□□□□□□□□□ IDLE □□□□□□□ gNB□□ UE □□UPF□

1. □□□□□
2. □ SMF □□□□□□□□ (DLDR)
3. SMF □ UE □□□□□□□□□□
4. □□□��□SMF □□ FAR □ FORWARD □□
5. UPF □□□□□□□□□□ UE

□□□□□□□□□: □ gNB □ gNB □□□□□□UPF □□□□□□□□□□□□□

1. □□ gNB □□□□□
2. SMF □ FAR □□□□□ BUFFER

3. □□□□□□□□□□□□□
4. UE □□□□□ gNB
5. SMF □□ FAR□□□□□ TEID □ FORWARD □□
6. UPF □□□□□□□□□ gNB


UE (IDLE)
gNB
OmniUPF
SMF
□□□□
UE □□ IDLE □□
□□□□□□□
□□□□□ FAR □□ FORWARD
FAR □□ BUFF + NOCP □□
□□□□□
PFCP □□□□□□ (DLDR)
□□ UE
□□□□
RRC □□□□
UE □□□ CONNECTED
PFCP □□□□
FAR □□ = FORWARD, □□ TEID
□□□□□□□□
□□ TEID □□□□□
□□□□□
UE (IDLE)
gNB
OmniUPF
SMF
□□□□

□□□□□□□

□□□□□□:

- □□□□□□□: 100,000□□□□□
- □□□□□□: □□□□□□
- **TTL (□□□□)**: 60 □□□□□□
- □□ **TTL** □□□□: □□□□

□□ **FAR** □□:

- □□ **FAR** □□□□□□□: 10,000□□□□□

- □□: □□□□ FAR □□□□□□

□□□□□□:

- □□□□□□□□ FAR □□□□□□□□□□□□
- □□□□□□□□□`reason="global_limit"` □ `reason="far_limit"`
- □□□□□□□□□□□□□□□ TTL □□□□□□□□

□□□□□□ (DLDR)

□ UPF □ IDLE UE □□□□□□□□□ SMF □□ PFCP □□□□□□□

DLDR □□:

- □□□□: □□□□□□ (DLDR)
- **FAR ID**: □□□□□ FAR
- □□□□□□□□: □□ QFI□□□□□□□□

SMF □ DLDR □□□:

1. □□ AMF → gNB □□ UE
2. □□ UE □□ RRC □□
3. □□ PFCP □□□□□□□□ FAR
4. FAR □□□ `BUFF+NOCP` □□□ `FORW`
5. UPF □□□□□□□□

DLDR □□□:

- `upf_dldr_sent_total`: □□□□ DLDR
- `upf_dldr_send_errors`: □□□ DLDR
- `upf_buffer_notify_to_flush_duration_seconds`: □ DLDR □□□□□□□□

□□□ □□□□ □□□□□□□

□□□□

□□□□□□□ BUFF □□□:

- FAR □□ `|= 0x04`□□□□ 2□

- □□: `Action: 2 (FORW)` → `Action: 6 (FORW+BUFF)`
- □□□□□□□□

□□□□□□□BUFF □ FORW□:

- FAR □□ `= 0x04`□□ BUFF□
- □□□□□□□□□□
- □□ IDLE UE □□□□□□□

□□□□□□□ BUFF □□□:

- FAR □□ `&= ~0x04`□□□□ 2□
- □□: `Action: 6 (FORW+BUFF)` → `Action: 2 (FORW)`
- □□□□□□□□□□□□□□□□□□

□□□□:

- □□ □□ FAR □□□□□□□□□□□□
- □□□□□□□□□ TEID/□□□□□□
- □□□□□□□□□□
- FAR □□□□ FORW □□

□□□□:

- □□□□□□□□□□□□□□
- □□□□□□□□□□□□□□
- □□□□ `reason="cleared"`

□□□□□□□□

□□□□□Web UI□: □□□ □□ □□□

- □□□□□□
- □□□□□
- □□□□□□□□ FAR □□
- □□ FAR □□□□□□
- □□□□□□□□□
- □□/□□□□ FAR □□□

- □□□□□□□

□□□□:

- □□□ **> 10 □**: □□□□□□□
- □□□ **> 30 □**: □□□□□□□□□□□□
- □□□□□□: □□□□□□□□□□□□□□□

Prometheus □□:

- `upf_buffer_packets_current`: □���□□□□□□
- `upf_buffer_bytes_current`: □□□□□□□
- `upf_buffer_fars_active`: □□□□□□□□ FAR
- `upf_buffer_packets_dropped{reason}`: □□□□□□□□

□□□ □□□□ □□□□□□□□□□

□□□□□□

□□ 1: IDLE UE □□□□

```
□□□□:
- UE □□ IDLE □□□□□ gNB □□□
- FAR □□: 0x04 (□ BUFF)

□□□□:
1. DN □□□□□□□
2. UPF □□ PDR□□□ FAR
3. FAR □□ BUFF □□ → □□□□□□
4. UPF □ SMF □□ DLDR
5. SMF □□ UE
6. UE □□□ gNB
7. SMF □□ FAR: Action = 0x02 (FORW)
8. UPF □□□ TEID □□□□□□□□
```

□□ 2: □□□□

```
□□□□:
- UE □□□ gNB-1 (TEID 1234)
- FAR □□: 0x02 (FORW)

□□□□:
1. SMF □□ FAR: Action = 0x06 (FORW+BUFF)
2. □□□□□□ gNB-1 □□□
3. UE □□□ gNB-2
4. SMF □□ FAR: TEID = 5678, Action = 0x02 (FORW)
5. UPF □□□□□□□□□□ gNB-2□□□□ TEID
6. □□□□□□□□□□□
```

□□ 3: □□□□

```
□□□□:
- UE □□□□□□□□

□□□□:
1. SMF □□ FAR: Action = 0x04 (□ BUFF)
2. □□□□□□□□□□□□□□□□
3. □□□□□□□□
4. SMF □□ FAR: Action = 0x02 (FORW)□□□□
5. UPF □□□□□□□□□□□□□□□
```

□□□□□□

□□□□□□□ GTP-U □□□

□□ **FAR** (N3 → N6):

- □□□□□□: False
- □□: □□ GTP-U□□□□□ IP □□□

□□ **FAR** (N6 → N3):

- □□□□□□: True
- □□ IP: gNB IP □□□□□□198.51.100.10□
- TEID: UE □□□□□ ID
- □□: □□ GTP-U □□□□□□ gNB

Web UI □□ FAR □□

□□□□□□□□□ ID □□ FAR □□□□

[illegible]:

1. [illegible] → FARs [illegible]
2. [illegible] FAR ID
3. [illegible] "[illegible]" [illegible] FAR [illegible]

[illegible]:

- FAR ID
- [illegible] + [illegible]
- [illegible]/[illegible]
- [illegible]
- [illegible] IP [illegible]
- TEID
- [illegible]

QoS [illegible] (QER)

[illegible]

QER [illegible]

QER [illegible]

QER
QFI
QoS
QER ID
MBR
MBR
GBR
GBR

QoS □□

QFI (QoS □□□□):

- 5G QoS □□ 6 □□□□
- □ 1-9 □□□□□□□□□QFI 9 = □□□□□
- □□ 5GC □□□□□□□

□□□:

- **□□ (0)**: □□□□
- **□□ (□□)**: □□□□

□□□□□ (MBR):

- □□□□□□□□□□
- □ kbps □□□□□
- **MBR = 0**: □□□□□□□□□□
- □□ MBR □□□□□□□

□□□□□ (GBR):

- □□□□□□□□□□□
- □ kbps □□□□□
- **GBR = 0**: □□□□□□□□□
- **GBR > 0**: □□□□□□□□□□

QoS □□□

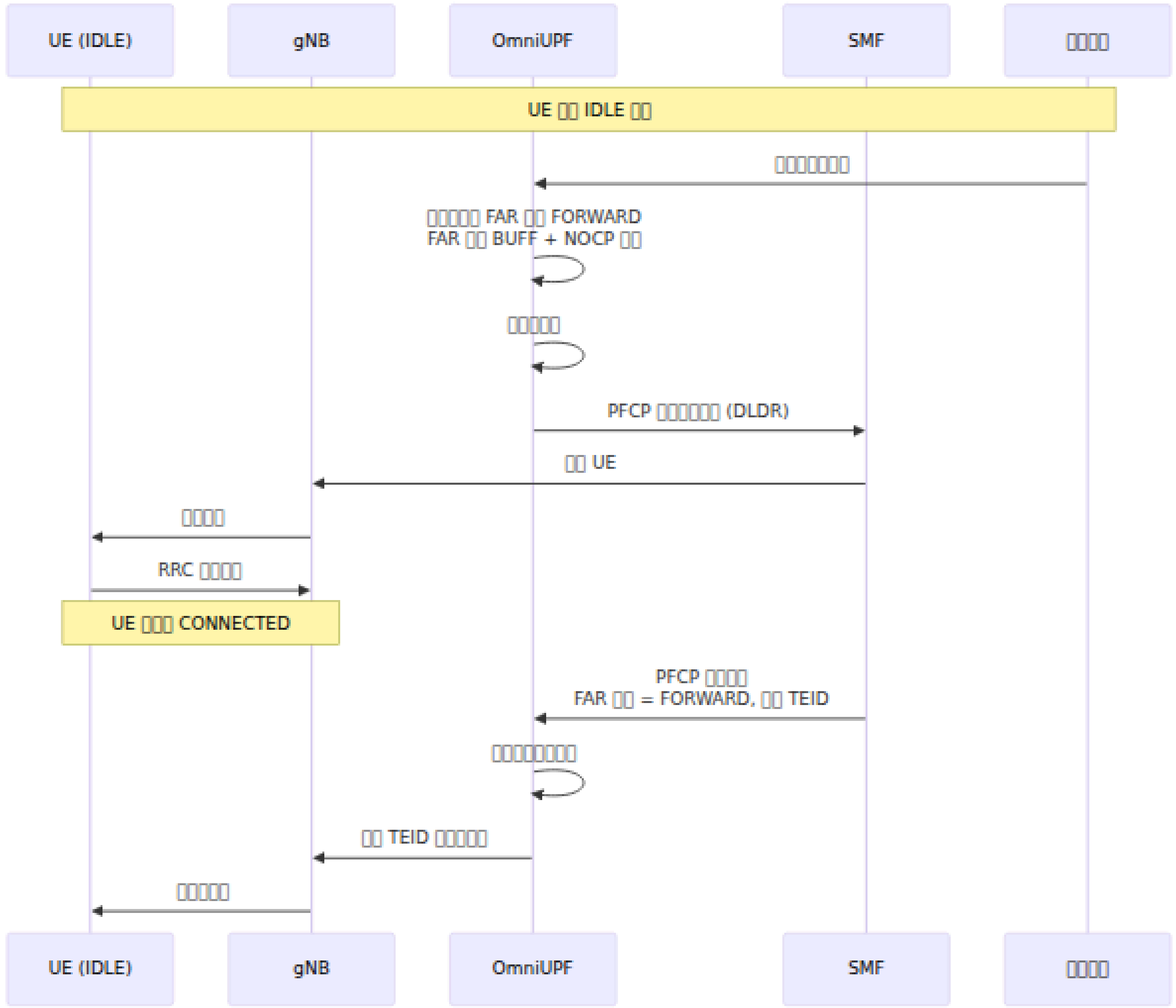
□□□□□ (GBR = 0):

```
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 □□□□


UE (IDLE)
gNB
OmniUPF
SMF
□□□□
UE □□ IDLE □□
□□□□□□□
□□□□□ FAR □□ FORWARD
FAR □□ BUFF + NOCP □□
□□□□□
PFCP □□□□□□ (DLDR)
□□ UE
□□□□
RRC □□□□
UE □□□ CONNECTED
PFCP □□□□
FAR □□ = FORWARD, □□ TEID
□□□□□□□□
□□ TEID □□□□□
□□□□□
UE (IDLE)
gNB
OmniUPF
SMF
□□□□

MBR □□□□

OmniUPF □□ □□□□□□□□□ □□□□□ MBR□□□□□□□□□□□□□□□ eBPF □□□□□□□□□□□□□□□□□□□ □ XDP □□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□

□□: □□□□□□□□□

□□□□□□□□□UPF □□□□□□□

1. □□□□□: □□□□□□ `CLOSED`□□□□□□□□□□□□□
2. **MBR** □□: □□ MBR = 0□□□□□□□□□□□□□□
3. □□□□□□:

```
tx_time = (packet_size_bytes × 8) × (1,000,000,000 ns/sec) /
MBR_kbps
```

4. [illegible]: [illegible] 5ms [illegible]
5. [illegible]: [illegible] `tx_time` [illegible]

[illegible]:

[illegible]:

- MBR = 100,000 kbps (100 Mbps)
- [illegible] = 1500 [illegible]
- [illegible] = 5,000,000 ns (5 ms)

```
[illegible] 1: [illegible] 100 Mbps [illegible]
tx_time = (1500 [illegible] × 8 [illegible]/[illegible]) × (1,000,000,000 ns/sec) /
100,000,000 bps
        = 12,000,000,000 / 100,000,000
        = 120 ns

[illegible] 2: [illegible]
current_time = 1000000000 ns
window_start = 999990000 ns
if (window_start + tx_time > current_time):
    [illegible]

[illegible] 3: [illegible]
window_start = window_start + 120 ns
[illegible]
```

[illegible]

5ms [illegible]:

- [illegible] 5 [illegible]
- [illegible] 5ms[illegible]
- [illegible]

[illegible]:

- □□□□□ 5ms □□□□□□□
- □□□□□□ MBR □□□□□□□
- □□□□□□□□□□□□

□□□□□□□□□:

- □□ MBR □□ `qer->ul_start` □□□
- □□ MBR □□ `qer->dl_start` □□□
- □□□□□□□□□□□□

□□□□□□□

□□ **(N3 → N6)**:

1. □□□□□ N3 □□□□□ gNB□
2. □□ TEID □□ PDR
3. □□ QER ID □□ QER
4. □□ `ul_gate_status` → □□□□□□□
5. □□ `limit_rate_sliding_window()`□□□ `ul_maximum_bitrate`
6. □□□□□□□□ N6 □□□ URR □□□

□□ **(N6 → N3)**:

1. □□□□□ N6 □□□□□□□□□□
2. □□ UE IP □□□□ PDR
3. □□ QER ID □□ QER
4. □□ `dl_gate_status` → □□□□□□□
5. □□ `limit_rate_sliding_window()`□□□ `dl_maximum_bitrate`
6. □□□□□□□ GTP-U □□□□□□ N3

N9 □□ (SGWU ↔ PGWU):

- □ N9 □□□□□□□□□□□□□□□□□□□ QER
- □□ QER □ SGWU □ PGWU □□□□□□

MBR □□□□□□□□

□□□□□□□□□□□□□□ **MBR** □□:

- [illegible]: GTP-U[illegible]UDP[illegible]IP [illegible] ~50-60 [illegible]
- [illegible]: [illegible] = [illegible]
- [illegible]: [illegible]
- [illegible]: 5ms [illegible] MBR

[illegible]:

```
[illegible] MBR: 100 Mbps
[illegible]: ~95-98 Mbps[illegible] GTP-U/UDP/IP [illegible]
```

[illegible]:

1. [illegible] URR [illegible]: `upf_urr_*_volume_bytes`
2. [illegible]: `(volume_delta_bytes × 8) / time_delta_seconds / 1000` = kbps
3. [illegible] QER [illegible] MBR [illegible]

GBR ([illegible])

[illegible]: OmniUPF [illegible] GBR [illegible]GBR [illegible] QER [illegible]��[illegible]

GBR [illegible]:

- GBR [illegible] PFCP [illegible] SMF [illegible]
- GBR [illegible] QER [illegible] API [illegible]
- [illegible] GBR [illegible]
- GBR [illegible]

[illegible]:

- GBR [illegible]
- [illegible] eBPF QoS [illegible]

[illegible] (URR)

[illegible]

URR [illegible] SMF [illegible]

URR [illegible]

URR [illegible]
[illegible]
[illegible] UE [illegible]
[illegible]
[illegible] UE [illegible]
URR ID
[illegible]
[illegible]
[illegible] + [illegible]
[illegible]
[illegible]
[illegible]
[illegible]

□□□□

□□□□:

- □ UE □□□□□□□□□□
- □ GTP-U □□□□□□
- □□ IP □□□□□□

□□□□:

- □□□□□□□□ UE □□□
- □ GTP-U □□□□□
- □□ IP □□□□□□

□□□:

- □□□□□□□□□□
- □□□□□□□

□□□□□□□

URR □□□□□□□□□□□□□

□□□□:

- □□□□□□□□□□□□□
- □□: □ 1 GB □□□□□□

□□□□:

- □□□□□□□
- □□: □ 5 □□□□□□

□□□□:

- □□□□□□□□
- □ QoS □□□□□
- □□□□□□

[illegible]

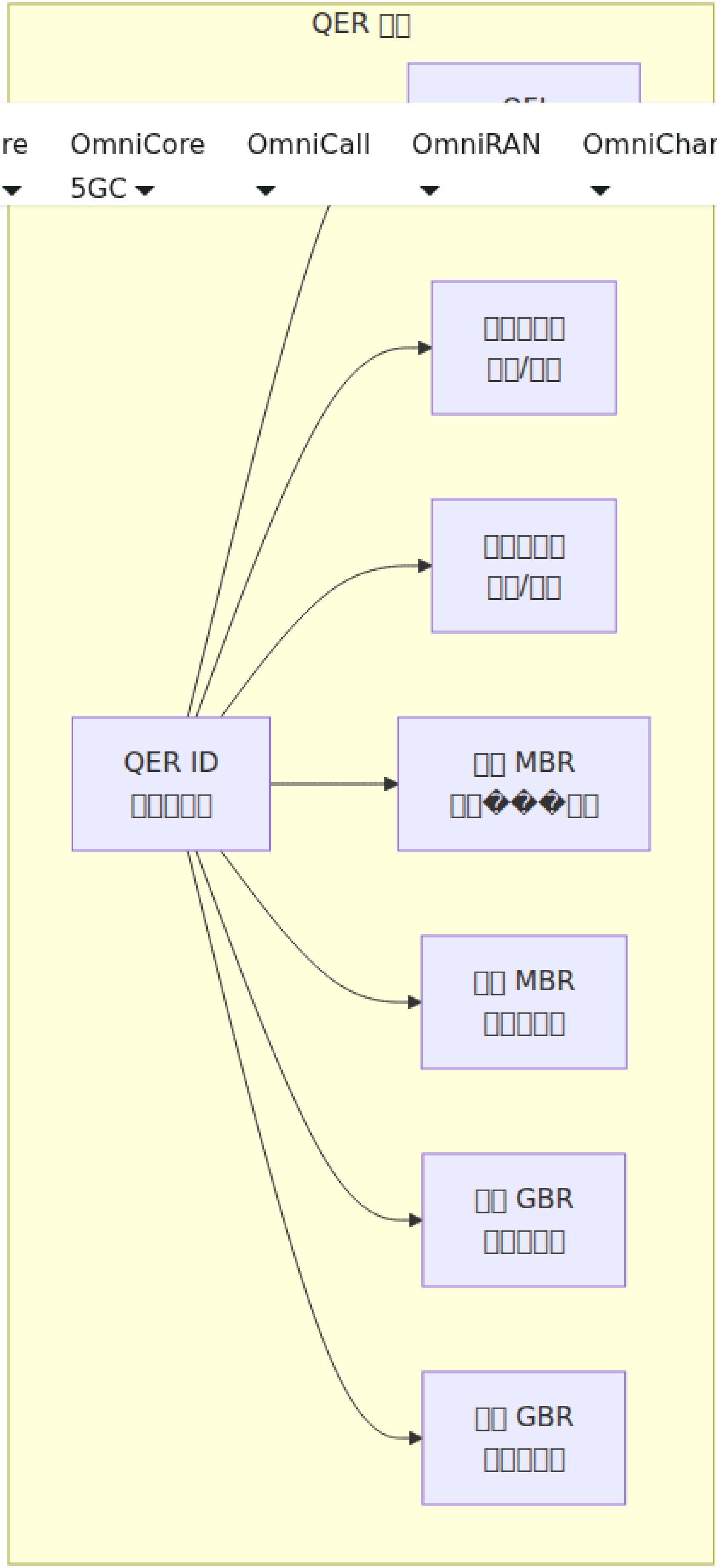
Web UI [illegible]

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

[illegible]:

```
URR ID: 0
[illegible]: 12.3 KB
[illegible]: 9.0 KB
[illegible]: 21.3 KB
```

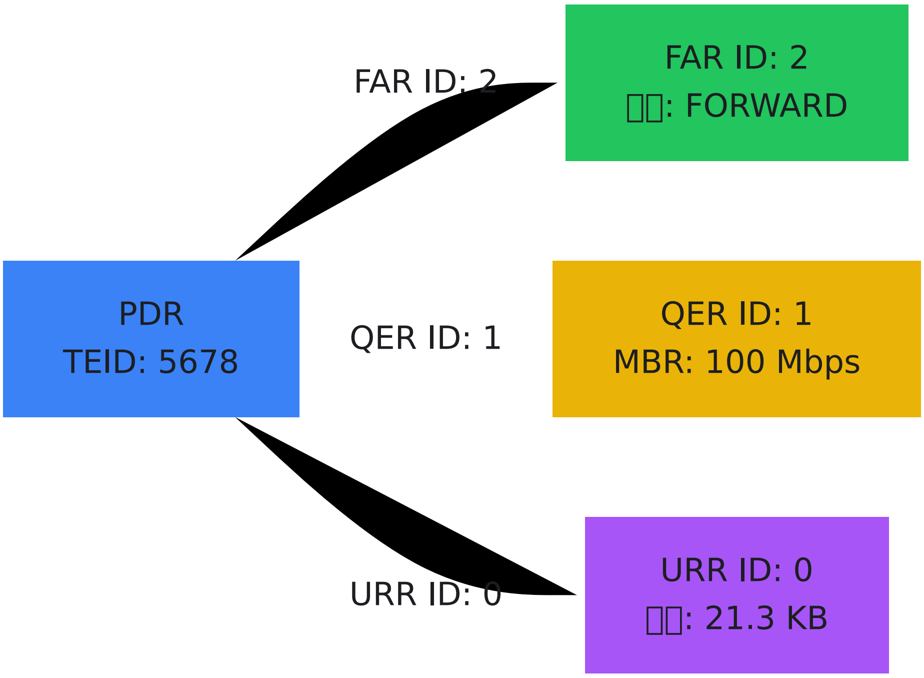
URR [illegible]


QER
QER ID
MBR
MBR
GBR
GBR

□□□□

PDR → FAR → QER → URR □

□□ PDR □□□□ FAR□FAR □□□□□□ QER □□□□□□ URR□


FAR ID: 2
FAR ID: 2
□□: FORWARD
PDR
TEID: 5678
QER ID: 1
QER ID: 1
MBR: 100 Mbps
URR ID: 0
URR ID: 0
□□: 21.3 KB

□□□□□□

□□ **PDR**:

```
TEID: 5678
FAR ID: 2
QER ID: 1
URR IDs: [0]
□□□□□□□: False
```

□□ **PDR**:

```
UE IP: 10.45.0.1
FAR ID: 1
QER ID: 1
URR IDs: [0]
SDF □□: No SDF
```

FAR ID 1 (□□):

```
□□: 2 (FORWARD)
□□□□□□: True
□□ IP: 198.51.100.10
TEID: 5678
```

FAR ID 2 (□□):

```
□□: 2 (FORWARD)
□□□□□□: False
```

QER ID 1:

```
QFI: 9
□□ MBR: 100000 kbps
□□ MBR: 100000 kbps
□□ GBR: 0 kbps
□□ GBR: 0 kbps
```

URR ID 0:

```
□□□□: 12.3 KB
□□□□: 9.0 KB
□□□: 21.3 KB
```

□□□□

□□□□□□□

□□□□□□:

1. □□□□□
2. □□ IP □ TEID □□ UE
3. □□ "□□" □□□□□□ (PDR, FAR, QER, URR)

□□□□□□:

1. □□□□□
2. □ PDR □□□□□□ TEID□□□□□ UE IP□□□□□□
3. □□ FAR ID, QER ID, URR IDs
4. □□□ FAR/QER/URR □□□□□□□□□□

□□/□□□□

□□: □□□□□□□□□□□□□□□□

□□:

1. □□□□□ → FARs
2. □□□□□□□□ FAR ID
3. □□ "□□"
4. □□□□□□□□□□ "□□□□"
5. □□ FAR □□□ 2 □□□□□□□□□□ 4□

□□□□□□□□□□□:

1. □□□□□
2. □□□□□□□ FAR
3. □□□□□□□ "□□□□"

[illegible] QoS [illegible]

[illegible]:

1. [illegible] → QERs
2. [illegible] UE [illegible] QER ID
3. [illegible] MBR [illegible] MBR [illegible]
4. [illegible] URR [illegible]

[illegible]:

```
[illegible] (kbps) = ([illegible] × 8) / ([illegible] × 1000)
```

[illegible] MBR[illegible]

[illegible]

[illegible] **URR** [illegible]:

1. [illegible]�� → URRs
2. [illegible]
3. [illegible]
4. [illegible]

[illegible]:

- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible] **PDR**:

1. [illegible] TEID[illegible] UE IP[illegible] PDR
2. [illegible] FAR ID [illegible]
3. [illegible] SDF [illegible]

[illegible] **FAR**:

1. [illegible] FAR [illegible] FORWARD[illegible] DROP [illegible] BUFFER[illegible]
2. [illegible]
3. [illegible] IP [illegible] TEID [illegible]

[illegible] **QER**:

1. [illegible] (0)
2. [illegible] MBR [illegible]

[illegible]

[illegible] **QER** [illegible]:

1. [illegible] → QERs
2. [illegible] MBR [illegible]
3. [illegible] URR [illegible]

[illegible] **FAR** [illegible]:

1. [illegible] → FARs
2. [illegible] FORWARD[illegible] DROP
3. [illegible] BUFFER [illegible]

[illegible]

[illegible]:

1. [illegible]
2. [illegible]
3. [illegible] > 30 [illegible]
4. [illegible]

5. □ FAR □□□□□

□□□□:

1. □□□□□□□□□□□□□□□ 100,000□
2. □□□□ FAR □□□□□□□□ FAR □□□□□□□ 10,000□
3. □□□□□□□□
4. □□□□□□□□□

URR □□□

□□□□□□□:

1. □□ PDR □□□□ URR ID
2. □□□□□□□□□ PDR
3. □□ FAR □□□□□□□□□□□□□□
4. □□ URR ID □□□□□ URR □□□

□□□□□□ **SMF**:

1. □□ PFCP □□□□□□
2. □□ URR □□□□□□□□/□□□□□
3. □□ PFCP □□□□□□□□□

□□□□

- **UPF □□□□** - OmniUPF □□□□□□□
- **Web UI □□□□** - □□□□□□□□□□□
- □□□□ - □□□□□□□
- □□□□□□ - □□□□□□□

OmniUPF [illegible]

[illegible]

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

[illegible]

[illegible] OmniUPF [illegible]

[illegible]

[illegible]

```
# 1. □□ OmniUPF □□□□□□
systemctl status omniupf

# 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
```

[illegible] XDP [illegible]

```
bpftool net list
```

[illegible] XDP [illegible]

```
bpftool prog show
```

[illegible] XDP [illegible]

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

[illegible]

[illegible] N4 [illegible] PFCP [illegible]

```
# PFCP [illegible] XDP [illegible]tcpdump [illegible]
tcpdump -i eth0 -n udp port 8805 -w /tmp/pfcp_traffic.pcap
```

[illegible] N3 [illegible] GTP-U [illegible]

```
# □□□UPF □□□□□□ tcpdump □□□□ XDP □□□□□□□
# XDP □□□□□□□□□□□□□□□□ GTP-U□

# □□□□□□□□
# 1. gNB □ UPF □□□□□ TAP
# 2. □□□□□□□/SPAN □□ N3 □□
# 3. □□□□□□□□□□□□ VM

# □□□/□□□□□□□□□□ UPF □□□
# tcpdump -i <mirror_interface> -n udp port 2152 -w
/tmp/n3_capture.pcap

# □□□□□ API □□□□□□□□
curl http://localhost:8080/api/v1/packet_stats
curl http://localhost:8080/api/v1/n3n6_stats
```

□□□□□□□□□

```
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 □□□□□□□”

□□□

```
ERRO[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
```

□□□□□□□□□

□□□

```
ERRO[0000] kernel version 5.4.0 is too old, minimum required is
5.15.0
```

□□□Linux □□□□□□□□□□

□□□□□

```
# □□□□□□
uname -r

# □□□□□□Ubuntu/Debian□
sudo apt update
sudo apt install linux-generic-hwe-22.04
sudo reboot

# □□□□□
uname -r  # □□ >= 5.15.0
```

□□□□□ libbpf □□

□□□

```
error while loading shared libraries: libbpf.so.0: cannot open
shared object file
```

□□□□□□ libbpf □

□□□□□

```
# □□ libbpf□Ubuntu/Debian□
sudo apt update
sudo apt install libbpf-dev

# □□□□
ldconfig -p | grep libbpf
```

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□□□

```
ERRO[0000] unable to read config file: unmarshal errors
```

[illegible]Elixir [illegible]

[illegible]

```
# [illegible]
cd /opt/omniupf && bin/upf_ex eval "IO.puts(:ok)"

# ���[illegible]
# - [illegible]
# - Elixir [illegible] : [illegible] =[illegible]
# - [illegible]

# [illegible] /etc/omniupf/runtime.exs
# [illegible]
# xdp_interfaces = "eth0"
# xdp_attach_mode = "generic"
# api_port = 8080
# pfcp_address = "10.0.0.1"
```

[illegible]

[illegible]

```
ERRO[0000] interface eth0 not found
```

[illegible]

[illegible]

```
# □□□□□□□□
ip link show

# □□□□□□
ip addr show eth0

# □□□□□□□□□□□□ /etc/omniupf/runtime.exs□
# xdp_interfaces = "ens1f0"  # □□□□□□□□

# □□□□□□□□□□□□□□
ls /sys/class/net/
```

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□□□

```
ERRO[0000] failed to start API server: address already in use
```

□□□□□ 8080□8805 □ 9090 □□□□□□□□

□□□□□

```
# □□□□□□□□□
sudo lsof -i :8080
sudo netstat -tulpn | grep :8080

# □□□□□□
sudo kill <PID>

# □□ /etc/omniupf/runtime.exs □□□ OmniUPF □□
# api_port = 8081
# pfcp_port = 8806
```

□□□□□□ PFCP □□ ID

□□□

```
ERRO[0000] invalid pfcp_node_id: must be valid IPv4 address
```

□□□PFCP □□ ID □□□□□ IPv4 □□

□□□□□

```
# □ /etc/omniupf/runtime.exs □
# □□□□□ IP □□□□□□□□□□
node_id = "10.100.50.241"

# □□□
# node_id = "localhost"
# node_id = "upf.example.com"
```

PFCP □□□□

□□□□□□ PFCP □□

□□□

- Web UI □□“□□□□”
- SMF □□□□“PFCP □□□□□□”

□□□

```
# 1. □□ PFCP □□□□□□□□
sudo netstat -ulpn | grep 8805

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

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

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

□□□□□□□□□□

□□□□□ PFCP

□□□□□

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

PFCP □□ ID □□

□□□□□

```
# □ /etc/omniupf/runtime.exs □□□□□ ID □□□□□□ N4 □□ IP
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 □□□□□□ UPF IP

□□□□□

- □□ SMF □□□□ UPF □□
- □□ SMF □□□ UPF □ `pfcp_node_id` IP
- □□ SMF □□□□□ UPF □ N4 □□

□□□PFCP □□□□

□□□

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

□□□

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

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

□□□□□□□□

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□□□□□

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

# □□□□□□□□□□□□□
# - □□□□□□
# - □□□□□/□□□□□□□
# - □□□□□□
```

□□□□□□□□

□□□□□

```
# □ /etc/omniupf/runtime.exs □
heartbeat_interval_ms = 30_000    # □ 5000 □□□ 30000 □□
heartbeat_retries = 5             # □□□□□□
heartbeat_timeout_ms = 10_000     # □□□□□□
```

□□□□□□□

□□□□□□□□□□□□□□RX/TX □□□ 0□

□□□

- □□□□□□□ 0 RX/TX □□□
- UE □□□□□□□□□

□□□

```
# 1. [illegible] XDP [illegible]
ip link show eth0 | grep xdp

# 2. [illegible] UP [illegible]
ip link show eth0

# 3. [illegible]XDP [illegible]
# [illegible]tcpdump [illegible] XDP [illegible] GTP-U [illegible]
curl http://localhost:8080/api/v1/packet_stats
```

[illegible]

XDP [illegible]

[illegible]

```
# [illegible] OmniUPF [illegible] XDP
sudo systemctl restart omniupf

# [illegible]
ip link show eth0 | grep xdp
bpftool net list
```

[illegible]

[illegible]

```
# [illegible]
sudo ip link set eth0 up

# [illegible]
ethtool eth0 | grep "Link detected"

# [illegible]
```

[illegible]

[illegible]

```
# □ /etc/omniupf/runtime.exs □
xdp_interfaces = "ens1f0"    # □□ 'ip link show' □□□□□□□□
```

□□□□□□□□□□□□□□□□□□□

□□□

- RX □□□□□ TX □□□□□
- □□□ > 1%

□□□

```
# □□□□□□□□
curl http://localhost:8080/api/v1/xdp_stats | jq '.drop'

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

# □□□□□□□
watch -n 1 'curl -s http://localhost:8080/api/v1/packet_stats | jq
".total_rx, .total_tx, .total_drop"'
```

□□□□□

□□ PDR □□□□□ TEID □ UE IP□

□□□□□

```
# [illegible]
curl http://localhost:8080/api/v1/sessions

# [illegible]
# - PFCP [illegible]
# - SMF [illegible]
# - [illegible]

# [illegible] PDR [illegible]
bpftool map dump name pdr_map_teid_ip | grep -c key
bpftool map dump name pdr_map_downlin | grep -c key
```

[illegible]

[illegible]

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

# [illegible] UE IP [illegible]
ip route get 10.45.0.100

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

QER [illegible]

[illegible]

- [illegible]
- [illegible]
- URR [illegible]
- [illegible] XDP [illegible]

[illegible]

1. [illegible] **MBR** [illegible]

```
# □□□□□ QER ID
curl http://localhost:8080/api/v1/pfcp_sessions | jq '.data[] |
select(.ue_ip == "10.45.0.1")'

# □□ QER □□
curl http://localhost:8080/api/v1/qer_map | jq '.data[] |
select(.qer_id == 1)'
```

2. □□□□□□□

```
# □□□□□□□□□□□□ 0□□□□
curl http://localhost:8080/api/v1/qer_map | jq '.data[] |
{qer_id, ul_gate: .ul_gate_status, dl_gate: .dl_gate_status}'
```

3. □ **URR** □□□□□□□□

```
# □□□□□□□□ URR □□□□□
curl http://localhost:8080/api/v1/urr_map | jq '.data[] |
select(.urr_id == 0)'

# □□□□□□□□□□
# throughput_kbps = (volume_delta_bytes × 8) /
time_delta_seconds / 1000
```

4. □□ **MBR** □□□□□□□
    - □□□□□ ≈ MBR □ 95-98%□□□□□□□□
    - □□□□□□□□□ MBR□□□□□□□□
    - □□□□□□ MBR □□□□□□□□□□□□□□□

□□□□□

- □□ **MBR** □□□□□ SMF □□ PFCP □□□□□□ QER□□□ MBR
- □□□□□□□□□ SMF □□□□□□□□□□□□□□□□□
- □□□□□□□□□□□ SMF □□□□□ QoS □□□□

□□ **MBR** □□□

OmniUPF □□□□□□□□□□□□□□□□ MBR □□□□□□□□□□□□□ □□□□□�� - MBR □□□□□□□□

- □□□□□□□□□□□□□□□□
- □□□□□□□□□□□□□□ MBR □□
- □□□□□□□/□□□□□□□□
- 5ms □□□□□□

□□□□□

- **VoIP** □□□□□□□ MBR □□□□□□□□□□□□□□G.711 = ~80 kbps□
- □□□□□□□□ MBR > □□□□□ + □□□1080p = ~5-10 Mbps□
- □□□□□□ 5ms □□□□□□□□□□□□□□□□□□

□□□□□□□□□□□□□□□□□□□

□□□

- RX N3 □□□□□□ TX N3 □□□□□□□□□
- RX N6 □□□□□□ TX N6 □□□□□□□□□

□□□

```
# □□ N3/N6 □□□□□□□XDP □□□□□
curl http://localhost:8080/api/v1/n3n6_stats
curl http://localhost:8080/api/v1/packet_stats

# □□□□□ tcpdump □□□□ XDP □□□ GTP-U □□
# □□□□ API □ xdpdump □□□□□□
# □□□“□□ XDP □□□□□”□□□□□□□□
```

□□□□□RX N3□□ TX N6□□

□□□□□ FAR □□□□ N6 □□□□□

□□□□□

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

# □□ N6 □□□□□□
ip route get 8.8.8.8  # □□□□□□□□□

# □□□□□□□□□□□□
sudo ip route add default via <N6_GATEWAY> dev eth1
```

□□□□□RX N6□□ TX N3□□

□□□□□□□ PDR □□□ GTP □□

□□□□□

```
# □□ UE IP □□□ PDR □□□□
curl http://localhost:8080/api/v1/sessions | jq '.[].pdrs[] |
select(.pdi.ue_ip_address)'

# □□ FAR □□□□□□□□□
curl http://localhost:8080/api/v1/sessions | jq '.[].fars[] |
.outer_header_creation'

# □□ gNB □□□
ping <GNB_N3_IP>
```

XDP □ eBPF □□

□□□□□ **XDP** □□□□□□□□□□□□□□□□ **XDP □□□□**□

□□□XDP □□□□□□

□□□

```
ERRO[0000] failed to load XDP program: invalid argument
```

[illegible]

```
# [illegible] XDP [illegible]
grep XDP /boot/config-$(uname -r)

# [illegible]
# CONFIG_XDP_SOCKETS=y
# CONFIG_BPF=y
# CONFIG_BPF_SYSCALL=y

# [illegible] dmesg [illegible]
dmesg | grep -i bpf
```

[illegible]

[illegible] XDP [illegible]

[illegible]

```
# [illegible] XDP [illegible]
# Ubuntu 22.04+ [illegible]��[illegible] XDP
sudo apt install linux-generic-hwe-22.04
sudo reboot
```

XDP [illegible]

[illegible]

```
# [illegible] OmniUPF [illegible]
journalctl -u omniupf | grep verifier

# [illegible]
# - eBPF [illegible]
# - [illegible]eBPF [illegible]

# [illegible] eBPF [illegible]
sudo sysctl kernel.bpf_stats_enabled=1
```

□□□XDP □□□□□□

□□□

- XDP □□□□□□ aborted > 0
- □□□□□□□

□□□

```
# □□ XDP □□□□
curl http://localhost:8080/api/v1/xdp_stats | jq '.aborted'

# □□ XDP □□□□
watch -n 1 'curl -s http://localhost:8080/api/v1/xdp_stats'
```

□□□eBPF □□□□□□□□□

□□□□□

```
# □□□□□□□□□ eBPF □□
dmesg | grep -i bpf

# □□ OmniUPF □□□□□ eBPF □□
sudo systemctl restart omniupf

# □□□□□□□□□□□□ 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"'
```

□□□□□□□

```
# □ /etc/omniupf/runtime.exs □
max_sessions = 200_000    # □ 100_000 □□

# □□□□□□□□□
far_map_size = 400_000
qer_map_size = 200_000
```

□□□□□□□□□□□□□ OmniUPF□□□□□□□□□□□□□

□□□□

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□□□

- □□□ < 1 Gbps □□ NIC □□□□
- CPU □□□□

□□□

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

# □□ NIC □□□□
ethtool -S eth0 | grep -i drop

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

□□□□□

□□□□ XDP □□

□□□□□

```
# □ /etc/omniupf/runtime.exs □
xdp_attach_mode = "native"    # □□□□ XDP □ NIC/□□□□
```

□□□□

□□□□□

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

# □□ RSS □□□□
ethtool -l eth0

# □□□□□□□□ CPU
# □□□ /proc/interrupts □□□ irqbalance □□□□□□
```

□□□□

□□□□□

```
□□□□□□ Elixir □□□□□□□
□□ /etc/omniupf/runtime.exs □□□□□□□□
```

□□□□□□

□□□

- Ping □□ > 50ms
- □□□□□□

□□□

```
# □□□ UE □□□
ping -c 100 <UE_IP> | grep avg

# □□□□□□□□
curl http://localhost:8080/api/v1/upf_buffer_info | jq
'.total_packets_buffered'

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

□□□□□

[illegible]

[illegible]

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

# [illegible]
# [illegible] OmniUPF [illegible] PFCP [illegible] FAR[illegible]
```

FIB [illegible]

[illegible]

```
# [illegible]
# [illegible] BPF_ENABLE_ROUTE_CACHE=1 [illegible]

# [illegible]
# [illegible]
```

[illegible]

[illegible]

- [illegible]
- NIC [illegible] RX [illegible]

[illegible]

```
# □□ NIC □□
ethtool -S eth0 | grep -E "drop|error|miss"

# □□□□□□□□□
ethtool -g eth0

# □□□□□□
watch -n 1 'ethtool -S eth0 | grep -E "drop|miss"'
```

□□□□□

```
# □□ RX □□□□□□□
ethtool -G eth0 rx 4096

# □□ TX □□□□□□□
ethtool -G eth0 tx 4096

# □□□□□
ethtool -g eth0
```

□□□□□□□□□□

□□□□□□□□□□□□□□□□□□ **XDP □□□□**□

Proxmox: VM □□ XDP □□□□

□□□

- □□□□□□□□□ XDP □□
- □□□□□□□

□□□VM □□□□□□□□□ SR-IOV

□□□□□

□□ 1□□□□□□□□□□□□

```
# □ /etc/omniupf/runtime.exs □
xdp_attach_mode = "generic"
```

□□ 2□□□ SR-IOV □□

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

# 2. □□ VFs
echo 4 > /sys/class/net/eth0/device/sriov_numvfs

# 3. □ Proxmox UI □□ VF □□□ VM
# □□ → □□ → PCI □□ → □□ VF
```

□ `/etc/omniupf/runtime.exs` □□

```
xdp_interfaces = "ens1f0"    # SR-IOV VF
xdp_attach_mode = "native"
```

VMware: □□□□□□

□□□

- OmniUPF □□□□□□□

□□□vSwitch □��□□□□ MAC □□

□□□□□

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

VirtualBox: □□□□□

□□□

- □□□ < 100 Mbps

□□□VirtualBox □□□ SR-IOV □□□ XDP

□□□□□

```
# □ /etc/omniupf/runtime.exs □
xdp_attach_mode = "generic"    # VirtualBox □□□□□
```

□□ VirtualBox □□□

- □□ VirtIO-Net □□□□□□□□□
- □□“□□□□”□□□□
- □ VM □□□□ CPU □□
- □□□□□□□□□ NAT
- □□□□□ KVM/Proxmox □□□□□□□□

NIC □□□□□□□

□□□NIC □□□□□□□ XDP

□□□

```
ERRO[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□□□□□□□

```
# □ /etc/omniupf/runtime.exs □
xdp_attach_mode = "generic"
```

□□ 2□□□ NIC □□□□

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

# □□□□□□□□□□□□
# Intel □□□□
# □ https://downloadcenter.intel.com/ □□
```

□□ 3□□□ NIC

```
# □□□□ XDP □ NIC□
# - Intel X710, E810
# - Mellanox ConnectX-5, ConnectX-6
# - Broadcom BCM57xxx (bnxt_en □□□□)
```

□□□□□□□□□□□□□□

□□□

- □□ XDP □□□□□
- NIC □□□□

□□□

```
# □□□□□□
dmesg | tail -100

# □□□□□□□□
journalctl -k | grep -E "BUG:|panic:"
```

□□□□□

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

# 2. □ /etc/omniupf/runtime.exs □□□□ XDP □□□□□□□□□
# xdp_attach_mode = "native"

# 3. □□□□□□□□□□□□
# xdp_attach_mode = "generic"

# 4. □ NIC □□□ Linux □□□□□□□□
```

□□□IPv6 SLAAC □□□ / UDP □□□□□□□□-XDP + virtio□

□□□

```
# IPv6 UE □□□□□ 50%□□□□□ SLAAC □□□□□□□
# RA □ UPF □□□□ RAN □□□□□
# □ eNB/gNB□□□□□□��□□□□□□ UDP □□□□□
# □□□□□□□□□□□ RA□
nstat -az | grep UdpInCsumErrors      # □□□□ SLAAC □□□□□□
```

- □□□ **IPv6 SLAAC** / □□□□□ — □□□□□□□□□
- □□□□□□ SGW-U □ PGW-U □□ □□ □□□□□□□□□□□□ □□□□□□□ SGW-U+PGW-U □□□□□□ □□□

□□□□□□□□□□ □□□□□□□□□□□□□□□□□□ □□□□□□□□□□□ TX □□□□□□□`CHECKSUM_PARTIAL`□□□□□ NIC □□ `tx-checksum-ip-generic: on`□□□ □□□□ **XDP** □□□□□□□□□□□□□□ □□ `skb`□□□ □□ SGW-U □□□□□ RA □□□□□□□ IP + TEID □□ `udp->check` □□□□ skb □□□□□□□□□□ `csum_start`/`csum_offset`□ □□□□□virtio□NIC □□□□□□□□□□ UDP □□□□□□ □□□□□□□□□ □□□□□□□□□□□□XDP □□□□□□ □□□□□□□□□□□□□ `CHECKSUM_NONE`□□□□□ □□□□□ eBPF □□ □□□□□ NIC □□□□□□□ — □□□□□□□□ SLAAC □□□□□/□□ XDP □□□□□□□□□□□□ skb□□□□□□ □□□□□□□□□ □□□□□□□□□ **virtio□NIC** □□□□□□□

□□□□□

```
# □□□□□□ NIC □□ TX □□□□□□□□□□□□□□□□□□□□□□□□
# □□□□ UDP □□□XDP
# □□□□□□□□□□□□□□□□□□□□□□□□□□□
ethtool -K <n3_iface> tx off
ethtool -K <n6_iface> tx off

# □□□□□□□“off”□□
ethtool -k <n3_iface> | awk '/^tx-checksumming/{print}'

# □□□□□SLAAC □□□□□□□□□□□UdpInCsumErrors □□□□□□□
```

> □□□□□□□□□□□□□□□□□□□□ NIC □□□□□□□□□□□□□□□□□□□□□□□□ NIC□□□ XDP □□
> □`xdp_attach_mode: native`□ □□□□□□□□□□

□□□□□□

□□□□□□□□□

□□□

- SMF □□□□□□□□
- UE □□□□ PDU □□

□□□ PFCP □□□□□□ □□□□□□□□□□□□□□□

□□□

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

# □□ PFCP □□□□
curl http://localhost:8080/api/v1/sessions | jq 'length'

# □□□□□□□□□ PFCP □□
tcpdump -i any -n udp port 8805 -w /tmp/pfcp_session.pcap
```

□□□□□

□□□□□□

□□□□□

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

# □□□□□□□□□□□ eBPF □□□□□□□
```

□□□ PDR/FAR □□

□□□□□

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

# □□□□□
# - □□□ UE IP □□□0.0.0.0 □□□□
# - □□□ TEID□0 □□□□
# - PDR □□ FAR
# - □□□ FAR □□

# □□ SMF □□□□□□□
```

□□□□□□□UEIP/FTUP□

□□□□□

```
# □ /etc/omniupf/runtime.exs □
feature_ueip = true
ueip_pool = "10.60.0.0/16"

feature_ftup = true
teid_pool_start = 1
teid_pool_end = 100_000
```

□□□□

□□□□□□□□□□□

□□□

- □□□□□□□□□□
- □□□□□□□□□

□□□

```
# □□□□□□□□□
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 □□
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 □ Elixir □□□□□□□□□ `/etc/omniupf/runtime.exs` □□□□□□□

□□□□□

□□□□□ FAR □□□□□□□□

□□□□□ □□□□□ Elixir □□□□□□□□□ `/etc/omniupf/runtime.exs` □□□□□□□

□□□□

□□□□□

```
# □ /etc/omniupf/runtime.exs □
log_level = :debug    # :debug | :info | :warning | :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 □□□□□□□□

XDP □□□□□□ □□ □□□□□□□□□□ `tcpdump` □□□□ **XDP** □□□□□□N3 □□ GTP-U □□□□UDP □□ 2152□□ XDP □□□□□□□□□□ UPF □□□□ tcpdump □□

□□□□□□□□□□

```
# □□ 1□□□□□ API □□□□□□□□
curl http://localhost:8080/api/v1/xdp_stats
curl http://localhost:8080/api/v1/packet_stats | jq
curl http://localhost:8080/api/v1/n3n6_stats

# □□ 2□□□ PFCP □□□□□ XDP □□□
tcpdump -i any -n udp port 8805 -w /tmp/pfcp.pcap

# □□ 3□□□□□□□□□□□□□ GTP-U□
# □□□□ TAP □□□□□□□□□□□□
# □□□
# - gNB □ UPF □□□□□ TAP
# - □□□ SPAN/□□□□□ N3 □□□□□□□□
# - □□□□□□□□□□□□□□□□□
#
# □□□□□□□□□ UPF□□
# tcpdump -i <mirror_interface> -n udp port 2152 -w
/tmp/n3_mirror.pcap
```

□□□□□□□□□

□□□□□

```
# □□□□ TAP □□□□□□□□□□
# □□□Cisco □□□ SPAN □□
(config)# monitor session 1 source interface Gi1/0/1
(config)# monitor session 1 destination interface Gi1/0/24

# □□□□ Gi1/0/24 □□□□□□□
tcpdump -i eth0 -n udp port 2152 -w /tmp/n3_capture.pcap
```

□□□□□VMware, KVM □□□

```
# □□□□□□□□□□□□□ UPF □□□□□□□□ VM
# □□□Linux □□□□□ VM □□□ tcpdump
# □□□□□□□□□□ UPF □ N3 □□□□□□□□□□

# □□□□ VM □□
tcpdump -i eth1 -n udp port 2152 -w /tmp/n3_virtual.pcap
```

□□□□□□□□□□

- XDP □□□□□□□□□
- □□□□ NIC □□□□□□□□□□
- □□□□ tcpdump □ XDP □□□□□□□□□□□□□
- □□□□□ UPF □□□□□□□□□□□

□□□□ **UPF** □□□□□□□□□

- □ PFCP □□□UDP 8805□ - □□□□□□□□ XDP □□
- □ API □□□□□
- □ GTP-U □□□UDP 2152□ - □□□□□□□ XDP □□

□□□□

□□□□□□□□□□□□□□□□□

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 □□□□
   - □□□□□
   - □□□□□□□□□□□□
   - □□□□□□
   - □□□□

□□□□

- □□□□ - □□□□□□□
- □□□□ - eBPF/XDP □□□□□□□
- □□□□ - □□□□□□□□□□
- □□□□ - □□□□□□□ Prometheus □□
- **PFCP □□□□** - PFCP □□□□□□□□□
- □□□□□□ - PDR□FAR□QER□URR □□
- □□□□ - UPF □□□□□

OmniUPF [illegible] / [illegible]

[illegible]

1. [illegible]
2. [illegible]
3. PFCP [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible] URL
8. API
9. Prometheus [illegible]
10. [illegible]

[illegible]

[illegible] [illegible] UPF [illegible]MikroTik [illegible]mangle [illegible] DNAT[illegible]

[illegible]SMF [illegible] `redirect_information` [illegible] PFCP [illegible]OmniUPF [illegible]

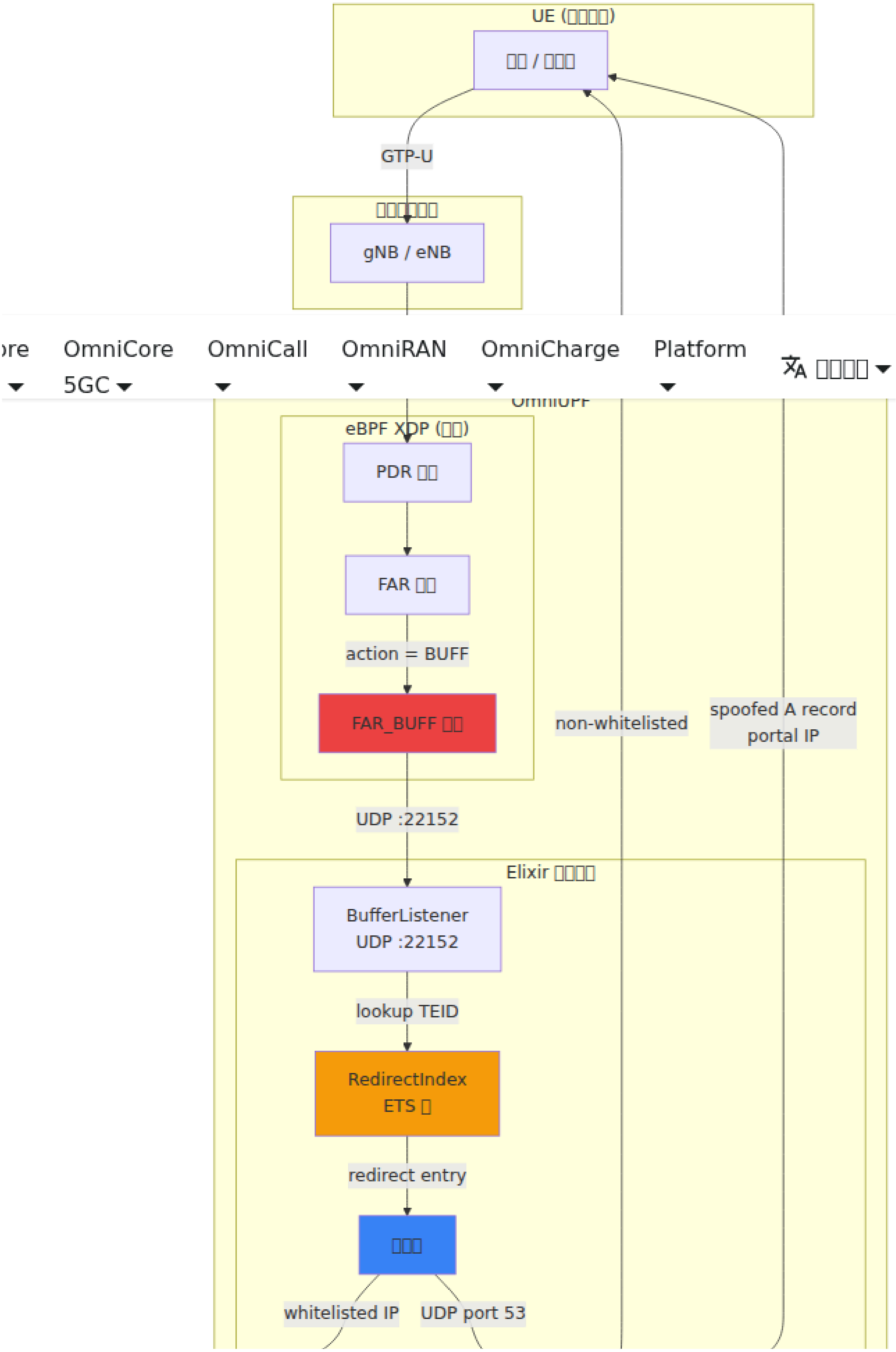
- **DNS [illegible]** [illegible] IP[illegible]Apple[illegible]Android[illegible]Windows[illegible]
- [illegible] **IP**[illegible]
- [illegible] [illegible]

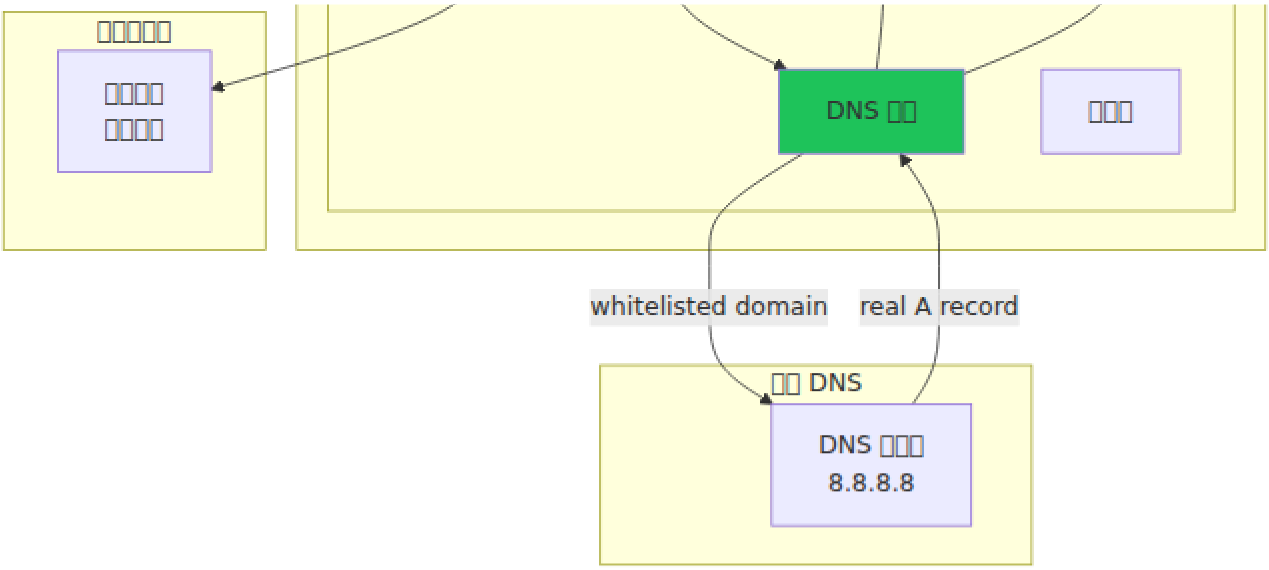
[illegible]/[illegible]SMF [illegible] FAR [illegible] FORW[illegible]

[illegible]

- [illegible] **eBPF** [illegible] -- [illegible] `FAR_BUFF` [illegible]

- □□□□□□ -- □□□□□□□□□□□□ IP □□□□ URL□□ SMF □ `redirect_information` IE □□
- □□□□□ **UPF** -- SMF □□“□□□□□□”□UPF □□□□□□□□□□
- □□□□□ -- □□ FAR □□ FORW□□□□□□□□□□□□ GTP □□□□□□ UE


UE (□□□□)
□□ / □□□
GTP-U
□□□□□□
gNB / eNB
ore
OmniCore 5GC
OmniCall
OmniRAN
OmniCharge
Platform
□□□□
OmniUPF
eBPF XDP (□□)
PDR □□
FAR □□
action = BUFF
FAR_BUFF □□
non-whitelisted
spoofed A record portal IP
UDP :22152
Elixir □□□□
BufferListener UDP :22152
lookup TEID
RedirectIndex ETS □
redirect entry
□□□
whitelisted IP
UDP port 53


□□□□□
□□□□
□□□□
DNS □□
□□□
whitelisted domain
real A record
□□ DNS
DNS □□□
8.8.8.8

□□□□

1. **UE □□ GTP-U** □□□□□□□□DNS □□□HTTP □□□□□ UPF
2. **eBPF PDR** □□ □□□□□ PDR□□□ FAR
3. **FAR** □□□ **BUFF**□□□□□□□□□□ FORW □□□□-- eBPF □□□□□□□ UDP □□ 22152 □ BufferListener
4. **BufferListener** □□ TEID□□□ RedirectIndex ETS □
5. □□ TEID □ RedirectIndex □□**Dispatcher** □□□□ IP □□□
6. □□□□
    - □□□□□□□□□ DNS □□□□□ A □□□□□ IP
    - □□□□□□□□ DNS □□□□□□□□□□□□□□□□□□□ IP
    - □□□□□ IP □□□□ IP□□□□□□□□□□□
    - □□□□□□□□□□□□
7. **DNS/GTP-U** □□ □□□□ GTP-U □□□□□ DL TEID □□□□□□ gNB□□□□ UE

N9 □□□□□SGW + PGW □□□□

□ 4G EPC □□□□OmniUPF □□□□□□ **SGW-U** □ **PGW-U**□SGW-C □ PGW-C □□□□□□□□□□ PFCP □□□SGW □□□□□ N9 FAR□□��□□□□□ PGW □□□□□ TEID□□□ N3 □□□□□□□PGW □□□□□□□□□□□□□□□□□□□

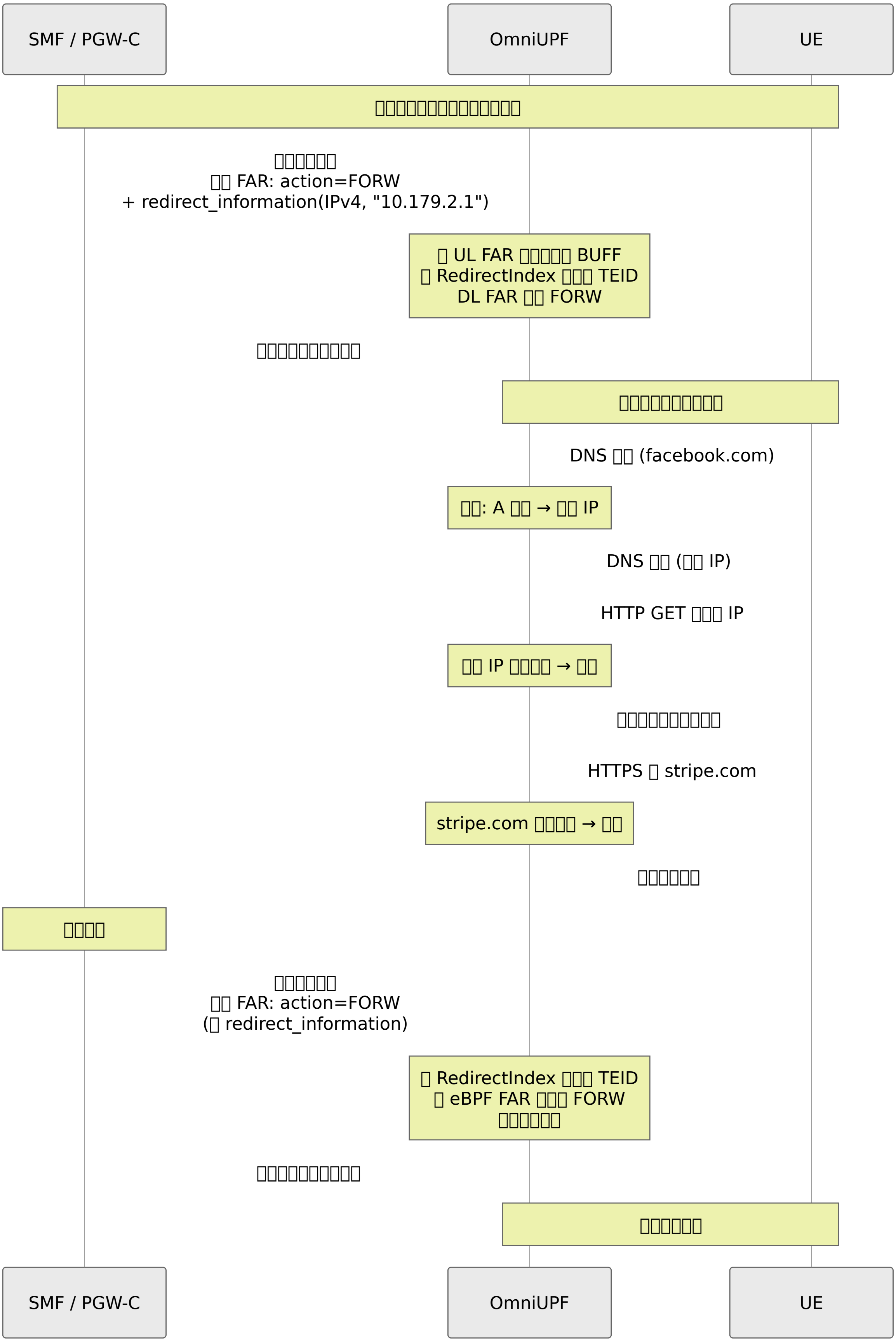
□□ `POST /v1/walled_garden` □□□□□□□□□□□□□□□□□□□□□□□□□□□□

1. **PGW □□ TEID** □□□ SEID □□□ PDR □□□□

2. □□□□□□ PFCP □□□□□□□□□□□SGW □□□□□□□□□□□ FAR□□ `teid` □ PGW UL PDR TEID □□□□□□□□□□ `outer_header_creation`□□ FAR □□□ PGW □ N9 □□ FAR□
3. □□ PGW UL FAR □ SGW □□ gNB □ UL FAR □ eBPF □□□□□□□ `BUFF`□□□□□□□□□ eBPF □□□□□□□□□□ eNB □□□□□ SGW □ TEID□□□□ PGW □ TEID□
4. □□ **SGW** □□ **gNB** □ **UL PDR** □□□□ RedirectIndex□□□□ PGW UL PDR□□SGW UL PDR TEID □ eBPF □□□ eNB □□□□□□□□□□□□□
5. □□ **DL** □□□□□□□□□ UE□□□□□□□ **SGW** □□□ **DL FAR**□□□ eNB □ FAR□`remoteip != n3_address`□□DL TEID □□□□□□□□□□□□□□□□□□□□□□□□ - □□□□□□□□□□□□□□□□□□ □□□□ eNB TEID □□□□

□□□ **UPF** □□□□□□ SGW□SMF □□□ UPF □□□□□□□□□□□ UL FAR □ TEID □□ - SGW □□□□ □□□□□□□□□□□□ UL PDR □□□□□

PFCP □□□


SMF / PGW-C
OmniUPF
UE
□□□□□□□□□□□□□□
□□□□□□
□□ FAR: action=FORW
+ redirect_information(IPv4, "10.179.2.1")
□ UL FAR □□□□□ BUFF
□ RedirectIndex □□□ TEID
DL FAR □□ FORW
□□□□□□□□□□
□□□□□□□□□□
DNS □□ (facebook.com)
□□: A □□ → □□ IP
DNS □□ (□□ IP)
HTTP GET □□□ IP
□□ IP □□□□ → □□
□□□□□□□□□□
HTTPS □ stripe.com
stripe.com □□□□ → □□
□□□□□□
□□□□
□□□□□□
□□ FAR: action=FORW
(□ redirect_information)
□ RedirectIndex □□□ TEID
□ eBPF FAR □□□ FORW
□□□□□□
□□□□□□□□□□
□□□□□□
SMF / PGW-C
OmniUPF
UE

��□□ PFCP IEs

SMF □□□ FAR □ `forwarding_parameters` □□□ `redirect_information` □□□□□□□

IE	□□
`apply_action`	□ SMF □□□ FORW□UPF □□□□□□ BUFF□
`redirect_information`	□□□□□□□□□□
`forwarding_parameters`	□□ `redirect_information` □ `outer_header_creation`

□□□□□□□□□□ 3GPP TS 29.244 □ 8.2.20-1□□

□□	□	**UPF □□**
IPv4	0	□□□□□ IPv4 □□□□□□□□□ IP
IPv6	1	□□□□□ IPv6 □□□□□□□□□ IP
URL	2	□ URL □□□□□□ IP□□□□ IP □□□□ IP□UPF □□□ URL □□ -- □□□□ API □ □□□□□□□□ Web □□□□□□□□□□□□□□□□□
SIP URI	3	□□□□□

□□□□□□

□□□□□□□□ DNS □□□□ □□□ DNS □□□□□□□□□□□□ IP□□□□□□□□□□□□

□□□□□

□□	□□□	□□□□
Apple (iOS/macOS)	`captive.apple.com`	HTTP 200□□□□ `<HTML><HEAD><TITLE>□□</TITLE></HEAD><BODY>□□</BODY></HTML>`
Android	`connectivitycheck.gstatic.com`	HTTP 204
Windows	`www.msftconnecttest.com`	HTTP 200□□□□ `Microsoft Connect Test`
Samsung	`connectivitycheck.samsung.com`	HTTP 200

□□□□□□□□□ IP □□

- □□/□□□□□iOS□Android□
- □□□□□□□□□Windows□

□□□□□ IP □□□□□□□□□□□□□ URL □□□□□□□□□□□□□□□□/□□□□□

□□□□□□□□□□ IP / □□□□□□□

□□□□□□□□□□□□□□ IP □□□ *□□* □□□□□□□□□ HTTP `Host` □□ □□□□□□□□□□□□□ □□□□□ IP□□□□□□□□□□□□□ □□□□□□□

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1. □□□□□□□ DNS □□□□ □□□□□ **IP** -- □□□□□□□□□□ (`connectivitycheck.gstatic.com`□`captive.apple.com`□`www.msftconnecttest.com` □)□
2. UE □□□□ HTTP □□□ IP□□□□□□ □□□ `Host` □□□□ `Host: connectivitycheck.gstatic.com`□□□□□□□□□□□□

3. UPF □□□□□□□□□□□□□□□□□ □□□□ **`Host`** □□□□ □□□□□□□□□

□□□□ IP □ □□□□□□□□□ -- □□□□□□□□□ `Host:` □□□□□□□□□ IP □□□□□□□□□ -- □□□□□□□□□□ □ `Host` □□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□ IP □□□□□□□□□□□□□□□□□CRM□□□□ □□□□□□□□□□□□□□□

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- □□□□□□□ □□□ **IP** □□□□ IP □□□□□□□□□ `Host`□□□
- □□□□□□□□□□□□ □□□□□□□□□□□□□□□ `Host:` □□□□□□□□□□

□□□ □ `walled_garden_portal_ip`□□□□ URL □□□ `redirect_information` □□□□□□□ □□□□ □□ HTTP □□ *□□* □□□□□ IP□UPF □□□□□□□□□□ `Host` □□□□□□□□ `Host` □□□

□□

□□□□□□□□□□□□□□□□□□□□□□□`.deb` □□□□□□□□□□ `/etc/omniupf/runtime.exs`□□□□□ □□ (`rel/env.sh`) □□□□□□□□□□□□□□ `RELEASE_CONFIG_DIR=/etc/omniupf`□□□ Erlang □□□□□□□□□□□ `config/runtime.exs`□□□□□□□□□□ UPF□

```
#
====================================================================
# □□□□ / □□□□□□□
#
====================================================================

# □□□□□□□□□□□□□
walled_garden_enabled = true

# □□□□□ IP□□□□□ / □□□□□
walled_garden_portal_ip = "10.179.2.1"

# □□□ IPv6 □□□□□□□□IPv6 □□□□□□
walled_garden_portal_ip6 = "fd00:179:2::1"

# □□□□□□□□□□□ DNS □□□
walled_garden_dns_resolver = "8.8.8.8"

# □□□□□□□□□□□□□□□□□□□□
# □□□□□□"*.stripe.com" □□ "api.stripe.com"
walled_garden_whitelist = [
  "stripe.com",
  "*.stripe.com",
  "js.stripe.com",
  "hcaptcha.com",
  "*.hcaptcha.com",
  "newassets.hcaptcha.com",
]
```

□□

□□	□□	□□	□□	□□
`walled_garden_enabled`	□□	□	`false`	□□□□□□□□□□□□□ FAR □□ `redirect_inf` □□
`walled_garden_portal_ip`	□□□ □IPv4□	□ □□ □□ □□	`10.179.2.1`	□□□□ / □□□□□□ □ `redirect_in` URL □□□□□□□□□□ SIP URI □□□□□□ IPv4/IPv6 □□□I □□ URL □□□□□□ □□
`walled_garden_portal_ip6`	□□□ □IPv6□	□	`nil`	□□□ IPv6 □□□□□ □□□□□□□□□□□ `walled_garde` □□ IPv4 □□□□□□ □□□□□□□□
`walled_garden_dns_resolver`	□□□ □IPv4□	□	`8.8.8.8`	□□□□□□□□□□□□□ □□□□□□□□□□□□□ □□□□□□□
`walled_garden_whitelist`	□□□□□	□	`[]`	□□□□□□□□□□□□□ □□□□□□ □□□□□□□

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□□□□□□□□□□□□□□□□□□□□□□□□□□□ IP□□□□ UPF □□□□□□□ SMF -- SMF □□□□□□□

[illegible]

[illegible]	[illegible]	[illegible]
`stripe.com`	`stripe.com`[illegible]`api.stripe.com`[illegible] `js.stripe.com`	`evilstripe.com`[illegible] `notstripe.com`
`*.stripe.com`	`api.stripe.com`[illegible] `js.stripe.com`[illegible] `dashboard.stripe.com`	`stripe.com`[illegible] `evilstripe.com`
`hcaptcha.com`	`hcaptcha.com`[illegible] `newassets.hcaptcha.com`	`evihcaptcha.com`

[illegible] [illegible]`stripe.com` [illegible]`foo.stripe.com`[illegible]`evilstripe.com`[illegible]

IP [illegible]

[illegible] DNS [illegible] IP [illegible] [illegible] [illegible]

1. [illegible] `api.stripe.com`
2. DNS [illegible] `203.0.113.7`
3. `203.0.113.7` [illegible] IP [illegible]
4. [illegible] HTTP/HTTPS [illegible] `203.0.113.7` [illegible]

[illegible] IP [illegible]

[illegible]

[illegible] Stripe [illegible] hCaptcha[illegible]

```
walled_garden_whitelist = [
  # □□□□□
  "stripe.com",
  "*.stripe.com",

  # □□□□□
  "hcaptcha.com",
  "*.hcaptcha.com",

  # Google □□□□□□□□□□□
  "fonts.googleapis.com",
  "fonts.gstatic.com",

  # □□□□□ CDN□□□□□□□□
  "cdn.example.com",
]
```

□□□□□□ URLs

□□ PFCP □□□□□□□ □□□□□□□□□SMF □□ FAR □□ `redirect_information` IE □□□□□□

- **IPv4** □□□□□□ IP □□□□□□□□□□□□□□□ IP
- **IPv6** □□□□□□ IPv6 □□□□□□□□□□□□□□□ IP
- **URL** □□□□□□□ FAR □□□□□□□□ DNS □□□□□□ IP □□□□ IP□UPF □□□ URL □□ -- □□□□ □□ API □□□□

□□□□□□□□□□MVNO □□□□□□□□□□□□□□□□□□□□□

□□	SMF redirect_information	□□□□□ IP	□□
□□A	`IPv4: 10.179.2.1`	`10.179.2.1`	`10.179.2.1`
□□B	`IPv6: 2001:db8::1`	`2001:db8::1`	`2001:db8::1`
□□C	`URL: https://topup.mvno.com/recharge`	□□□ `topup.mvno.com` □ IP	`https://topup`

UPF ���□□□□□□□ IP □□□□ URL□□□□□□□□□ API □□□

API

□□□□□□□□□□□□□□ `/v1/walled_garden`□□□ `/api` □□□□□□□□□□□□ `api_port`□□□□ 8080□□□ Phoenix HTTP □□□□□□

GET /v1/walled_garden

□□□□□□□□□□□□□□□□□□□□□ IP□□□□ CIDR □□□□□□□□□□

□□□

```json
{
  "redirect_count": 2,
  "redirects": [
    {
      "teid": "0x4000",
      "session_seid": 1,
      "portal_ip": "10.179.2.1",
      "redirect_url": null,
      "ue_ip": "10.60.0.1",
      "gnb_ip": "10.179.1.21",
      "dl_teid": "0x5000",
      "far_global_id": 42
    },
    {
      "teid": "0x4001",
      "session_seid": 2,
      "portal_ip": "10.179.2.2",
      "redirect_url": "https://topup.mvno.com",
      "ue_ip": "10.60.0.2",
      "gnb_ip": "10.179.1.21",
      "dl_teid": "0x5001",
      "far_global_id": 43
    }
  ],
  "whitelisted_ips": [
    {"ip": "10.179.2.1", "type": "portal"},
    {"ip": "203.0.113.7", "type": "resolved"},
    {"ip": "203.0.113.6", "type": "resolved"}
  ],
  "whitelisted_cidrs": ["192.168.0.0/24"]
}
```

□□□□□

□□	□□
`redirect_count`	□□□□□□□□□□□□□
`redirects[].teid`	□□□□□□ TEID□□□□□□
`redirects[].session_seid`	PFCP □□ SEID
`redirects[].portal_ip`	□□□□□□□□ IP
`redirects[].redirect_url`	SMF □□□□ URL□□□□ URL □□□□□ null
`redirects[].ue_ip`	UE IP □□
`redirects[].gnb_ip`	GTP-U □□□ gNB IP
`redirects[].dl_teid`	GTP-U □□□□□ TEID
`redirects[].far_global_id`	□□ FAR □□ ID
`whitelisted_ips`	□□□□□□□□□ IP□□□ + □□□ DNS □□□
`whitelisted_cidrs`	□□□□□ API □□□ CIDR □□

POST /v1/walled_garden

□□ SEID □□□ PFCP □□□□□□□□□□□□□□□□□□/API □□□□□ - □□□□□□□ PFCP □□□□□FAR □□□ `redirect_information`□API □□□□□□□□□□□□□□□□□□□□ SMF □□□□□□□□□

□□□□

```json
{
  "seid": 1,
  "url": "http://10.179.2.1/"
}
```

□□	□□	□ □	□□
`seid`	□□	□	□□□□□ PFCP □□□□□ SEID
`url`	□□ □	□	□□□□□ - □□ IPv4/IPv6 □□□ URL□��□□□ URL□□□□□□□□□□□□ IP □□□□ IP□□□□ URL □□□□□□□ API □□□□

□□□200 OK□□

```json
{
  "status": "redirect activated",
  "info": {
    "seid": 1,
    "sgw_seid": 7,
    "portal_ip": "10.179.2.1",
    "ue_ip": "10.60.0.1",
    "gnb_ip": "10.179.1.21",
    "ul_teids": ["0x4000", "0x4006"]
  }
}
```

`sgw_seid` □□□□□□ N9 □□□SGW+PGW □□□□□□□□□□ TEID □□ BUFF □□□□□`ul_teids` □□□□□□□□□□□□□□□□ TEID□

□□□□□

□□	□□
404	□□□□□□SEID □□□□□□□ PFCP □□□
400	□□□□□□

DELETE /v1/walled_garden/:seid

□□□□□□□□□□□□□□□□□□□□□□□□□□□□ FAR□□□ N9 □□□□□□□□ SGW □□ FAR□□ eBPF □□□□□□□□ `action=FORW`□□□ TEID □□□□□□□□□□

□□□□□ `:seid` - □□□□□□□□□ SEID□

□□□200 OK□□

```
{"status": "redirect removed", "info": {"seid": 1}}
```

□□□□□

□□	□□
404	□□□□□

GET /v1/walled_garden/whitelist

□□□□□□□□□□□□□ IP□□□ IP □ DNS □□□ IP□□□□□ API □□□□□ CIDR □□□

□□□

```
{
  "ips": [
    {"ip": "10.179.2.1", "type": "portal"},
    {"ip": "203.0.113.7", "type": "resolved"}
  ],
  "cidrs": ["192.168.100.0/24"]
}
```

POST /v1/walled_garden/whitelist

□□□□□ IP □□□ CIDR □□□□□□□□□□□□□□ UPF□□□□□□□□□□□□□□□□□□□□□ - □□□□□□□□ `runtime.exs` □□ `walled_garden_whitelist`□

□□□□□□ IP□□

```json
{"ip": "203.0.113.10"}
```

□□□□□□ CIDR □□□□

```json
{"cidr": "192.168.100.0/24"}
```

□□□□ `ip` □ `cidr` □□□□□□□ CIDR □□□□□□□□□□□□□ IP □□□□□□□□□□□□□□□□ IP □ DNS □□□□□

□□□200 OK - IP □□□□

```json
{"status": "added", "ip": "203.0.113.10"}
```

□□□200 OK - CIDR □□□□

```json
{"status": "added", "cidr": "192.168.100.0/24"}
```

□□□□□

□□	□□
400	□□□ IP□□□□ CIDR □□□□□□□□

Prometheus □□

□□□

□□: `upf_walled_garden_active_redirects` □□: □□□ □□: □□□□□□□□□□□□□□□□□□□

□□□□:

```
# □□□□□□□
upf_walled_garden_active_redirects
```

□□□

□□: `upf_walled_garden_packets_intercepted_total` □□: □□□ □□: □□□□□□□□□□□□□□□□□□□□□□□□□

□□: `upf_walled_garden_packets_dropped_total` □□: □□□ □□: □□□□□□□□□□□□□□□□□□ DNS □□□

□□: `upf_walled_garden_packets_forwarded_total` □□: □□□ □□:

- `dst_ip` - □□□□□□□ IP □□: □□□□□□□□□□□□□□□□□□□□□ IP □□□□□□□□□□□□□

□□: `upf_walled_garden_bytes_forwarded_total` □□: □□□ □□:

- `dst_ip` - □□□□□□□ IP □□: □□□□□ IP □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□: `upf_walled_garden_dns_spoofed_total` □□: □□□ □□:

- `domain` - □□□□□ □□: □□□□□□□ DNS □□□□□□□□□□

□□: `upf_walled_garden_dns_forwarded_total` □□: □□□ □□:

- `domain` - □□□□□□□ □□: □□□□□□□□ DNS □□□□□□□□□□□□□

□□□□

```
# □□□□□□□□□
upf_walled_garden_active_redirects

# □□□□□□□/□□
rate(upf_walled_garden_packets_intercepted_total[5m])

# □□□□□□□□□□□□
rate(upf_walled_garden_packets_dropped_total[5m])

# □□□□□□□□□□/□□
sum by (dst_ip)
(rate(upf_walled_garden_bytes_forwarded_total[5m]))

# □□□□□□□□ 5 □□□□□□
topk(5, sum by (dst_ip)
(rate(upf_walled_garden_bytes_forwarded_total[5m])))

# □□□□□□□□
topk(10, sum by (domain)
(rate(upf_walled_garden_dns_spoofed_total[5m])))

# □□□□□□□
sum by (domain) (rate(upf_walled_garden_dns_forwarded_total[5m]))

# □□□□□□□□
sum(rate(upf_walled_garden_packets_dropped_total[5m]))
  / sum(rate(upf_walled_garden_packets_intercepted_total[5m]))
```

□□□□

□□□□□□□□□□

□□: □□□□□□□ API □□□□□□□□□□□□□□□□

□□□□:

- □□□□□□□□□□□□ IP □□□
- □□□□□□□□□□□□□□□ URL
- DNS ���□□□□ UE□□□ GTP-U □□□

□□□□:

1. □□□□□□□□□□□□□`curl http://<portal_ip>/`
2. □□□□□□□□ URL□□□□Apple □ `GET /hotspot-detect.html`□
3. □□ `GET /v1/walled_garden` □□□□□□□□
4. □□ Prometheus □□□`upf_walled_garden_dns_spoofed_total` □□□□□
5. □□□□ GTP-U □□□□□□□□□DL FAR □□□ FORW□

□□□□□□□

□□: □□□□□□□□□□□□□□□□□□□Stripe □□□

□□□□:

- □□□□□□□□□□□□
- □□□□□□□□ CDN IP □□□□
- □□□□□□□□□□□□

□□□□:

1. □□ `GET /v1/walled_garden` - □□ `whitelisted_ips` □□□□□□□ IP
2. □□ Prometheus: `upf_walled_garden_dns_forwarded_total{domain="stripe.com"}` □□□□□□
3. □□□□□□□□□□□□□□□`js.stripe.com`□`m.stripe.network`□
4. □□ `upf_walled_garden_bytes_forwarded_total` □ `dst_ip` □□□□□□

□□□□□□

□□: SMF □□□□ `redirect_information` □□□□□□□□□□□□□□□□

□□□□:

- `walled_garden_enabled` □ `false`

- `redirect_information` IE □□□□ FAR □□□□□ □□ FAR □□
- FAR □□□□□□□ BUFF

□□□□:

1. □□□□□`walled_garden_enabled = true`
2. □□ `GET /v1/pfcp_sessions` - □□□□□ FAR □□□□□ FAR □□□□□ `0x04`□BUFF□
3. □□ `GET /v1/walled_garden` - □□□ TEID □□□□□□□□□□
4. □□ UPF □□□□□□□□□□□□ `redirect_info` □□

□□□□□□□□□□

□□: □□□□□□□□□□□□□□

□□□□:

- SMF □□□□□□□□□□□□□□
- BUFF->FORW □□□□□□□

□□□□:

1. □□ `GET /v1/walled_garden` - □□□□□□□□□□
2. □□ `GET /v1/pfcp_sessions` - □□ FAR □□□□□□ `0x02`□FORW□
3. □□ SMF □□□□□□□□□□□□□
4. □□ UPF □□□□□“□□□□□□□□□□□□□”□□

□□□□□ TEID□□□□□□□□□

□□: DNS □□□□□□□□□□□□ UE□GTP-U □□□□□□□□□ gNB IP□□ eNB □□□□□□□ TEID□

□□: □ 4G/SGW+PGW □□□□SGW DL FAR □□ eNB TEID □□□□□□□□□□□□□□□□□□□ TEID □□□□`□□□□□□□` □□□□□□□□□□□□□ eNB □□□ TEID □□□□□□□□□□□□□□□SGW □□□□ DL FAR □□□□ - □□□□□□□□□□□□□□□□□□□ TEID□

□□□□: □□□□□□□ □□ □□ DL TEID□□□□□ SGW □□□□□ DL FAR□□□□ `outer_header_creation` □ `remoteip != n3_address` □ FAR□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□ TEID □□□□□ DNS □□□□□□□□□□□□□□□□□□□□□□□ TEID□

1. [illegible] `GET /v1/walled_garden` - [illegible] `dl_teid` [illegible]
2. [illegible] `GET /v1/pfcp_sessions` - [illegible] SGW [illegible] FAR [illegible] gNB [illegible] FAR [illegible] `teid` [illegible] `remoteip`[illegible]
3. [illegible] SGW [illegible] RedirectIndex [illegible] `DELETE /v1/walled_garden/:seid` [illegible] SMF [illegible]

[illegible] 304 [illegible]

[illegible]: [illegible]

[illegible]: [illegible] HTTP 304[illegible] Web [illegible]`/hotspot-detect.html`[illegible]`/generate_204` [illegible] `If-Modified-Since` [illegible] `If-None-Match` [illegible] 304[illegible] 304[illegible]

[illegible]:

1. UPF [illegible] HTTP [illegible] - [illegible] Web [illegible]
2. [illegible]200[illegible] 304[illegible]
3. [illegible] `Cache-Control: no-store`[illegible] `ETag`/`Last-Modified` [illegible]
4. [illegible]`curl -v -H "If-None-Match: foo" http://<portal_ip>/hotspot-detect.html` - [illegible] 200[illegible] 304[illegible]

[illegible]

[illegible]: [illegible] `GET /v1/walled_garden` [illegible] -- [illegible]CRM [illegible] -- [illegible]/[illegible]`curl` [illegible] `Host:` [illegible]

```
curl -s -H 'Host: portal.example'
http://<portal_ip>/   # -> [illegible]/[illegible]    [illegible]
curl -s -H 'Host: connectivitycheck.gstatic.com'
http://<portal_ip>/   # -> [illegible]���[illegible]
curl -s -H 'Host: <portal_ip>'
http://<portal_ip>/   # -> [illegible]
```

□□: □□ IP □ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ IP□□□□□□□□ UE □ HTTP □□ □□□□□□□ **`Host`** □□□□ `Host: connectivitycheck.gstatic.com`□□□□ Web □□□□□□□ `Host` □□□□□□□□□□□□□ □□□□□□ -- □□□□□UPF □□□□ `Host` □□□□□□□□□□□□□□□□□□ □□□□□□□□

□□□□:

1. □□□□□□□ □□□□□ **IP**□□□□ IP □□□□□ `Host:` □□□□□□□□
2. □□□□□□□□□□□□ □□□□□□□□□□□□□ `Host:` □□□□□□□□□
3. □□□□ `curl` □□□□□□□□□□□ IP □□□□□□□□□□□□□□□□□□□□□□

□□□□□

□□□□□□□□□□□□□□ IP □□□□□ □□□□□□`IPPROTO_RAW`□□□□ 255□□□□ Erlang □ `:socket` □□□□□□□□□□□□□□□□□□□□□□□□□□□ IP □□□□□��� eBPF □□□□□ `sendto` □□□□□□□□□□□

□□□□: □ GTP-U □□□□□□□□□□ IP □□□□□□□□□□ IP □□□□□ UE IP□□□□□□□□□ IP□□□□□ `IPPROTO_RAW` □□□□□□□□□□□□□□□□□□□ IP □□□□□□□□□□□□UPF □ N6 □□□□□□□□□/□□□□ □□□□□□□□□□□□

□□□□□

□□	□□□□	□□
□□□□□□	`EPERM` - □□□□□□□ root □ `CAP_NET_RAW`	□□ OmniUPF □ root □□□□□□ `CAP_NET_RAW` □□
□□□□□□□□□□□□ □ UE	N6 □□□□□□□	□ UPF □□□□□□□□□□□□□
□□□□□ `Walled garden: raw socket open failed`	□□□□□□□□□	□□ `systemd` □□ `AmbientCapabilities=CAP_NET_RAW`
□□□□□□ UE □□□ □□ IP □□□	N6 □□ NAT □□□	□□□□□ UE IP □□□□□ UPF □□□□

□□ UPF □□□□□ `Walled garden forward failed` □ `raw socket open failed` □□□ □□ `upf_walled_garden_packets_forwarded_total` □ `upf_walled_garden_bytes_forwarded_total` Prometheus □□□□□□□□□□□□□

Prometheus □□□□□□□

□□: □□□□□□□□ `dst_ip` □ `domain` □□ □□□□□□□

```
# □□□□□□□ /24 □□□□□□□□□□□ IP
sum by (dst_subnet) (
  label_replace(
    rate(upf_walled_garden_bytes_forwarded_total[5m]),
    "dst_subnet", "$1.0/24", "dst_ip", "(\d+\.\d+\.\d+)\.\d+"
  )
)
```

Web UI □□□□

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10. XDP □□□□
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OmniUPF Web UI □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ Phoenix LiveView □□□□□□

- □□□□□ PFCP □□□□□ PDU □□
- □□□□ PDR□FAR□QER □ URR □□□□□
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□□□□□□□ REST API □□□ OmniUPF □□□□□□□□□

- □□ PFCP □□□□□
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□□□□□□□□ HTTPS □ OmniUPF □□□□□□□□□

```
https://<upf-server>:443/
```

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□□□□□□□ `config/config.exs` □□□ OmniUPF □□□

□□□□□□□□□□□□ UPF □□□

`upf_hosts` □□□□□□ UI □□□□□□□□□□□□□□ OmniUPF □□□

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- □□ - `/sessions` - PFCP □□□□□
- □□ - `/rules` - PDR□FAR□QER□URR □□□□
- □□□ - `/buffers` - □□□□□□□□□□
- □□ - `/statistics` - □□□□□□□XDP □□□□□
- □□ - `/capacity` - eBPF □□□□□□□□□
- □□ - `/upf_config` - UPF □□□□□□□□□

- □□ - `/routes` - UE □□□□□□□□□□OSPF□BGP□
- **XDP** □□ - `/xdp_capabilities` - XDP □□□□□□□□□
- □□ - `/logs` - □□□□□

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URL□`/sessions`

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□□□□□□□□□□ OmniUPF □□□□□□□ PFCP □□□□□□

PFCP □□□□

□□□□□□ PFCP □□□□□ SMF/PGW-C □□□□□□□

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□□ **ID**	SMF □ PGW-C □□□□□□FQDN □ IP□
□□	SMF/PGW-C □□ PFCP □□□ IP □□
□□□□□ **ID**	□□□□□□□□□ PFCP □□ ID

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- □□ SMF □ UPF □□□□
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□□□□ PFCP □□□□□□□□ UE PDU □□□

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□□ SEID	UPF □□□□□□□□□□
□□ SEID	SMF □□□□□□□□□□
UE IP	□□□□□ IPv4 □ IPv6 □□
TEID	□□□□□ GTP-U □□□□□□□
PDRs	□□□□□□□□□□□□□
FARs	□□□□□□□□□□□□
QERs	□□□□ QoS □□□□□□
URRs	□□□□□□□□□□□□
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- □ **IP** □□□□□□□ UE IP □□□□□
- □ **TEID** □□□□□□□□ ID □□□□
- □□□□□□□□□□ PDR/FAR/QER/URR JSON □□□□
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- □□□□□□□ **(PDRs)**□□□ TEID□UE IP□FAR ID□QER ID□SDF □□□□□□ JSON
  - **PDR ID** □□□ - □□□□□□□□□□□□□□□□□ PDR □□□□
  - □□ PDR□TEID ≠ 0□□□□□□ PDR □□
  - □□ PDR□IPv4□□□□□□ PDR □□
  - □□ PDR□IPv6□□□□ IPv6 □□ PDR □□
- □□□□□□ **(FARs)**□□□□□□□□□□□□□□□

- **QoS □□□□ (QERs)**□MBR□GBR□QFI □□□ QoS □□
- **□□□□□□ (URRs)**□□□□□□□□□□□□□□□□□

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□□ UE □□□□

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

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- □□□ UPF □□□□□□□□
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- □□□□□ UE IP □ TEID
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URL□`/rules`

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PDR □□□ - □□□□□□□

□□□□□ UPF □□□□ PDR□□□ □□□□ □ □□□□□□

□□ **PDRs** (N3 → N6):

- □□□□□□ TEID □□□□□□□□□ PDR □□□□
- **TEID**□□□ gNB □ GTP-U □□□□ ID□□□□ - □□□□□□
- **FAR ID**□□□□□□□□□□□□□□ - □□□ FAR □□□□
- **QER ID**□□□□ QoS □□□□□□□□ - □□□ QER □□□□
- **URR IDs**□□□□□□□□□□□□□□ - □□□ URR □□□□
- □□□□□□GTP-U □□□□□
- **SDF** □□□□□□□□□□□□□

□□ **PDRs** (N6 → N3):

- □□□□□□ UE IPv4 □□□□□□□□□□□ PDR □□□□
- **UE IP**□□□□□□ IPv4 □□□□□□□□□□□□
- **FAR ID**□□□□□□□□□□□□□□ - □□□ FAR □□□□
- **QER ID**□□□□ QoS □□□□□□□□ - □□□ QER □□□□
- **URR IDs**□□□□□□□□□□□□□□ - □□□ URR □□□□
- **SDF** □□□□□□□□□□□□□□□□ sdf□sdf + □□□
- □□□□□□□□□□□ PDR□□□□□ 100□□□ 1000□

IPv6 □□ PDRs□

- API □□ IPv6 □□ PDR □□□
- □□□ IPv4 □□□□□ IPv6 □□□□
- □□□□□□□□□□□□ UI □□□

FAR □□□ - □□□□□□

□□□□ FAR □□□□□□□□□□

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- □□□□□□ FAR ID □□□□□□□ FAR □□□□
- □□□□□□ PDR □□□□□□□ FAR ID □□□□□□□
- □□□□□FAR □□□□□□□□□□

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FAR ID	□□□□□□□□□□
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□□	□□□□□□□□TEID□IP □□□

FAR □□□□□

- **FORWARD (1)**□□□□□□□□□□

- **DROP (2)**[illegible]
- **BUFFER (4)**[illegible]
- **NOTIFY (8)**[illegible]
- **DUPLICATE (16)**[illegible]

[illegible]

- [illegible]“[illegible]���[illegible]“[illegible]”[illegible]
- [illegible]
- [illegible] eBPF [illegible] FAR [illegible]

QER [illegible] - QoS [illegible]

[illegible] QoS [illegible]

[illegible]

- [illegible] PDR [illegible] QER ID [illegible] QER
- [illegible] PDR [illegible]QER [illegible]
- [illegible] QER[illegible] 100[illegible] 1000[illegible]

[illegible]	[illegible]
QER ID	[illegible] QoS [illegible] PDR [illegible]
MBR[illegible]	[illegible]kbps[illegible]
MBR[illegible]	[illegible]kbps[illegible]
GBR[illegible]	[illegible]kbps[illegible]
GBR[illegible]	[illegible]kbps[illegible]
QFI	QoS [illegible]5G [illegible]

QoS [illegible]

- **MBR = 0**[illegible]
- **GBR = 0**[illegible]
- **GBR > 0**[illegible]

URR [illegible] - [illegible]

[illegible]

[illegible]

- [illegible] URR ID [illegible] URR
- [illegible] PDR [illegible] URR ID [illegible] URR
- [illegible] PDR [illegible]URR [illegible]
- [illegible] URR[illegible] 100[illegible] 1000[illegible]

[illegible]	[illegible]
URR ID	[illegible] PDR [illegible]
[illegible]	[illegible] UE [illegible]
[illegible]	[illegible] UE [illegible]
[illegible]	[illegible]
[illegible]	[illegible] URR [illegible]

[illegible]

- [illegible]B[illegible]KB[illegible]MB[illegible]GB[illegible]TB[illegible]
- [illegible]
- [illegible]

[illegible]

- [illegible] URR
- [illegible] 0 [illegible] URR[illegible]

[illegible]

[illegible]

1. [illegible] → PDR [illegible]
2. [illegible] TEID [illegible] UE IP
3. [illegible] PDR [illegible] FAR [illegible] QER [illegible]

[illegible]

1. [illegible] → FAR [illegible]
2. [illegible] PDR [illegible] FAR ID
3. [illegible] FORWARD[illegible] DROP [illegible] BUFFER[illegible]
4. [illegible]

[illegible] **QoS** [illegible]

1. [illegible] → QER [illegible]
2. [illegible] MBR [illegible] GBR [illegible]
3. [illegible] 5G [illegible] QFI [illegible]

[illegible]

1. [illegible] → URR [illegible]
2. [illegible]��[illegible]
3. [illegible]
4. [illegible]

[illegible]

URL[illegible]`/buffers`

[illegible]

[illegible] UPF [illegible]

[illegible]

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- □□□ **TTL**□□□□□□□□□□□□□□

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- 会话级别的可靠性：所有 FAR 之间不会互相影响，不会串扰
- 简单：能够基于非常简单的底层原语实现复杂的流量处理逻辑

当前的挑战有哪些

- 缺少表达力的“转发动作”原语
- 缺少基于 FAR 的流水线
- 设计复杂

附录

挑战一的解决方案

1. 增加一组原生的、可组合的动作原语
2. 允许 FAR 之间的级联与动作组合
3. 清晰定义的执行与组合

挑战二方案

1. 使用一个统一抽象的“动作”来表达所有转发动作
2. 提供相应的配置与可选项
3. 支持“转发动作”组合与级联

挑战三的解决方案：

1. 明确定义一组可组合的 FAR，实现灵活的流量处理
2. 引入“动作”概念，实现复杂的逻辑
3. 通过对“转发动作”的组合实现复杂逻辑

挑战四的解决方案：

1. 提供一组简单的、可组合的动作原语
2. 允许组合、级联多个 FAR
3. 允许 SMF 使用简单的原语表达复杂的逻辑
4. 允许 SMF 根据需求灵活组合与级联

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URL□`/statistics`

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- **GTP-U** □□□□□□ GTP-U □□□□□□□□

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XDP □□

eXpress Data Path □□□□□

- **XDP** □□□□ XDP □□□□□□□□

- **XDP** □□□□□□□□□□□□□
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- □□ **N3**□□□□ gNB/eNodeB □□□□

N6 □□□□□□□□□□□

- □□ **N6**□□□□□□□□□□□/IMS□□□□□□□□
- □□ **N6**□□□□□□□□□□□□

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1. □□ XDP □□□□□□□□
2. □□ XDP □□□□□□□□
3. □□ N3/N6 □□□□□□

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1. □□□□□□□□□□□□□
2. □ UPF □□□□□□□□
3. □□□□□□□□□□□

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□□□□□ 5 □□□□□□

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URL□`/capacity`

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□□□□□□ UPF □□□□□□□□□□ eBPF □□□□□□□□□□

eBPF □□□□□

□□ eBPF □□□□□□□□□□□

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□□□□	eBPF □□□□□□□□`uplink_pdr_map`□`far_map`□
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- **□□□<50%**□□□□□□□□□□□
- **□□□50-70%**□□□□□□□□□
- **□□□□70-90%**□□□□□□□□□□□
- **□□□>90%**□□□□□□□□□□□□□

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uplink_pdr_map□

- □□□ TEID □□□□□ PDR
- □□□□□□□□□□□
- □□□□□□□□□□□□□□

downlink_pdr_map / **downlink_pdr_map_ip6**□

- □□□ UE IP □□□□□□□ PDR
- □□ UE IPv4/IPv6 □□□□□□
- □□□□□□□□□□□□□□

far_map[illegible]

- [illegible] FAR ID [illegible]
- [illegible] PDR [illegible]
- [illegible]

qer_map[illegible]

- [illegible] QER ID [illegible] QoS [illegible]
- [illegible] QoS[illegible]

urr_map[illegible]

- [illegible] URR ID [illegible]
- [illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]

[illegible]

1. [illegible] PDR [illegible]
2. [illegible]
3. [illegible]

[illegible]

1. [illegible]
2. [illegible] PDR [illegible]>90%[illegible]
3. [illegible]

[illegible]

1. [illegible]

2. □□□□□□□□□□□
3. □□□□□□□□□□□□□□

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eBPF □□□□□ UPF □□□□ UPF □□□□□□□□□□□□

- □□□□□□□□□ 10,000 - 100,000 □□
- □□□□□□□□□ 100,000 - 1,000,000 □□
- □□□□□□□□□ 1,000,000+ □□

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□□□□□□□ 100 □□□□ 64 □□□□ PDR □□□□□□ 64 MB □□□□□□

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URL□`/upf_config`

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UPF □□

□□□□ UPF □□□

- **PFCP** □□□SMF/PGW-C □□□ IP □□□□□
- **N3** □□□RAN□gNB/eNodeB□□□□ IP □□
- **N6** □□□□□□□□□□ IP □□

- **N9** □□□UPF □□□□□ IP □□□□□□
- **API** □□□REST API □□□□
- □□□OmniUPF □□□□

□□□□□eBPF□□□

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- □□ **N3** □□□□□□ N3 □□□□
- □□ **N9** □□□□□□ N9 □□□□□□□□□□

□□□□□□□□ eBPF □□□□□□□□□□□□□□□□□□□□□□□□□

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□□ UPF □□□□

1. □□ N3 □□ IP □□□ gNB □□□□
2. □□ N6 □□□□□□□□□□□□□
3. □□ PFCP □□□□□□ SMF □□

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

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1. □□ UPF □□□□□□□□
2. □□□□□□□□□□□□
3. □□□□□□

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URL□`/routes`

[illegible]

[illegible]UE[illegible]IP [illegible]OSPF [illegible] BGP[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]UE IP [illegible]
- [illegible]
- [illegible]

[illegible] UE IP [illegible]

[illegible] IP [illegible]

[illegible]	[illegible]
[illegible]	[illegible]
UE IP [illegible]	[illegible] UE [illegible] IPv4 [illegible] IPv6 [illegible]

[illegible]

- [illegible] UE IP [illegible]
- [illegible]
- [illegible]

OSPF [illegible]

OSPF[illegible]

[illegible]	[illegible]
[illegible] **ID**	OSPF [illegible]
[illegible]	OSPF [illegible] IP [illegible]
[illegible]	[illegible] OSPF [illegible]
[illegible]	OSPF [illegible]
[illegible]	OSPF [illegible]
[illegible]	[illegible]
[illegible]	[illegible]

OSPF [illegible]

- [illegible]
- [illegible]

BGP [illegible]

BGP[illegible]

[illegible]	[illegible]
[illegible] IP	BGP [illegible] IP [illegible]
ASN	[illegible]
[illegible]	BGP [illegible]
[illegible]/[illegible]	��[illegible]
[illegible]	[illegible]
[illegible]	[illegible] BGP [illegible]
[illegible]	[illegible] BGP [illegible]

BGP [illegible]

- [illegible] BGP [illegible]
- [illegible]

[illegible] BGP [illegible] ID [illegible] ASN[illegible] BGP [illegible]

OSPF [illegible]

[illegible] UE [illegible] OSPF [illegible] LSA[illegible]

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□□	□□□ OSPF □□□□
□□	LSA □□□□□□□□□
□□□	LSA □□□□□□

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- □□ UE □□□□□□□□□ OSPF
- □□□□□□□□□□□□□□□
- □□ LSA □□□□□□

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- □□□□□□□□□ FRR□□□□□□□□
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- □□□□□□□□□□
- □□ OSPF □□□BGP □□□□□□□

[illegible]

[illegible]

1. [illegible]
2. [illegible] OSPF [illegible]“[illegible]”[illegible]
3. [illegible] BGP [illegible]“[illegible]”
4. [illegible]/[illegible]

[illegible] **UE** [illegible]

1. [illegible] UE IP [illegible] UE
2. [illegible] OSPF [illegible]
3. [illegible] UE [illegible] LSA [illegible]
4. [illegible] UPF [illegible]

[illegible]

1. [illegible]
2. [illegible]“[illegible]”[illegible]
3. [illegible]
4. [illegible] OSPF/BGP [illegible]

[illegible] **UPF** [illegible]

1. [illegible] UPF [illegible]
2. [illegible]
3. [illegible] OSPF [illegible]
4. [illegible] BGP [illegible]

[illegible]

1. [illegible] UE [illegible]
2. [illegible]
3. [illegible] OSPF LSA [illegible]
4. [illegible] BGP [illegible]

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- **OSPF**□□□□□□□□□ 2 LSA □□□□
- **BGP**□□□□□□□□□□ BGP □□□
- □□□□□REST API □□□□ vtysh □□□□□ FRR

XDP □□□□

URL□`/xdp_capabilities`

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XDP □□□□□□ eXpress Data Path (XDP) □□□□□□□□□□ UPF □□□□□□□□□□□

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□□□□	□□□ XDP □□□DRV□SKB □ NONE□
□□□□□	□□□□□□□ NIC □□□□

XDP [illegible]

[illegible] XDP [illegible]

XDP_DRV[illegible]

- [illegible]~5-10 Mpps[illegible]
- [illegible] XDP [illegible]
- [illegible] XDP [illegible] NIC [illegible]i40e[illegible]ixgbe[illegible]mlx5 [illegible]
- [illegible] XDP [illegible]
- [illegible]✓[illegible] X[illegible]✗��

XDP_SKB[illegible]

- [illegible]~1-2 Mpps
- [illegible]
- [illegible]
- [illegible]
- [illegible]✓[illegible]

[illegible]

- [illegible] XDP [illegible]
- [illegible]

[illegible]

- [illegible]“[illegible]”[illegible]
- [illegible] XDP [illegible]

XDP [illegible] Mpps [illegible]

[illegible]

[illegible]

[illegible]

- "✓ [illegible] XDP_DRV [illegible]"
- [illegible]

[illegible]

- "⚠ [illegible] XDP_DRV [illegible]"
- [illegible]
- "⚠ [illegible] XDP_DRV"
- [illegible]

[illegible]

- [illegible] XDP [illegible]

Mpps [illegible]

[illegible]Mpps[illegible]Gbps[illegible]

[illegible]

[illegible]Mpps[illegible]

- [illegible]0.1 - 100 Mpps
- [illegible]��[illegible] XDP [illegible] Mpps
- [illegible]

[illegible]

- [illegible]64 - 9000 [illegible]
- [illegible]1200 [illegible] GTP [illegible]
- [illegible] GTP [illegible]

[illegible]

- **64B**[illegible]
- **128B**[illegible]
- **256B**[illegible]
- **512B**[illegible]
- **1024B**[illegible]
- **1518B**[illegible]

[illegible]

[illegible]Gbps[illegible]

- [illegible]
- [illegible]`Gbps = Mpps × Packet_Size × 8 / 1000`
- [illegible] GTP[illegible]UDP[illegible]IP [illegible]

[illegible]Gbps[illegible]

- [illegible]

- □□□ ~50 □□□ GTP □□□□
- □□□`Gbps = Mpps × (Packet_Size - 50) / 1000`

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- □□ Mpps □□□□□□□□□□□□□□
- □□□10 Mpps = 10,000,000 □□□□□

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- □□□□□□□□
- □□□`10 Mpps × 1200 □□ × 8 □/□□ ÷ 1000 = 96 Gbps`

□□ Mpps

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□□□ Mpps□

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- □□□□□□���□□□ Mpps = □□□ Gbps
- □□□□□□□□□□ Mpps = □□□ Gbps
- □□□□□□□□□□□□□□

GTP □□□□□

- □□□□□14 □□
- IP □□20 □□□IPv4□□ 40 □□□IPv6□
- UDP □□8 □□
- GTP □□8 □□□□□□
- □□□□□□□□□□□ ~50 □□

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□□ **XDP** □□□

1. □□□ XDP □□□□
2. □□□□ XDP □□□□□ DRV □□□□□□□□
3. □□ Mpps □□□□
4. □□□□□□

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1. □□□□□□□□□□□Mpps□
2. □□□□□□□□□□□□□□□□
3. □□□□□□□□□Gbps□
4. □□□□□□□□□□□□□□

□□ **XDP** □□□

1. □□□□□□□□□□ XDP_DRV □□
2. □□□□□□□□□□□□
3. □□□□□□□□□□□□□□□□□□□
4. □□□□□□□□□□ CPU □□□□

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1. □□□□□□□□□□□□□□□ Mpps
2. □□□ XDP □□□□□□□□
3. □□□□□□□□□□
4. □□□□□□□□□□□□□□□

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

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□□□□□**XDP_DRV**□□

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

□□□□□**XDP_SKB**□□

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- □□□□□□ CPU □□□□□□□□
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- □□ RSS□□□□□□□□□□□□□

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XDP □□□□□ 30 □□□□□□□□□□□□□□□□□□□

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URL□`/logs`

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□□□□ OmniUPF □□□□□□□

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- □□ Phoenix LiveView □□□□□□□
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OmniUPF □□□□□□ Elixir Logger □□□

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

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1. □□□□□□
2. □ SMF □□□□□□
3. □□ PFCP □□□□□□□□□

□□ **PFCP** □□□

1. □□ PFCP □□□□□□
2. □□□□□□/□□/□□
3. □□□□□□

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1. □□□□□□□□□
2. □□ eBPF □□□□□□
3. □□ FAR/PDR □□□□

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[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible] XDP [illegible]

[illegible]

- [illegible]
- [illegible] TTL[illegible]
- [illegible]
- [illegible]“[illegible]”[illegible]“[illegible]”[illegible]

[illegible]

- [illegible] UE [illegible]
- [illegible]
- [illegible] UPF [illegible]
- [illegible]

[illegible]

- [illegible]
- [illegible] UE [illegible]
- [illegible]
- [illegible]

[illegible]

- [illegible] 5-10 [illegible]
- [illegible]

- [illegible]URR [illegible]
- [illegible] UPF [illegible]

[illegible]

- [illegible] - PDR[illegible]FAR[illegible]QER[illegible]URR [illegible]
- [illegible] - [illegible]
- [illegible] - [illegible] Prometheus [illegible]
- **PFCP** [illegible] - PFCP [illegible]
- **API** [illegible] - REST API [illegible]
- [illegible] - UE [illegible] FRR [illegible]
- **XDP** [illegible] - [illegible] XDP [illegible] eBPF [illegible]
- [illegible] - [illegible]
- **UPF** [illegible] - [illegible] UPF [illegible]

OmniUPF [illegible] XDP [illegible]

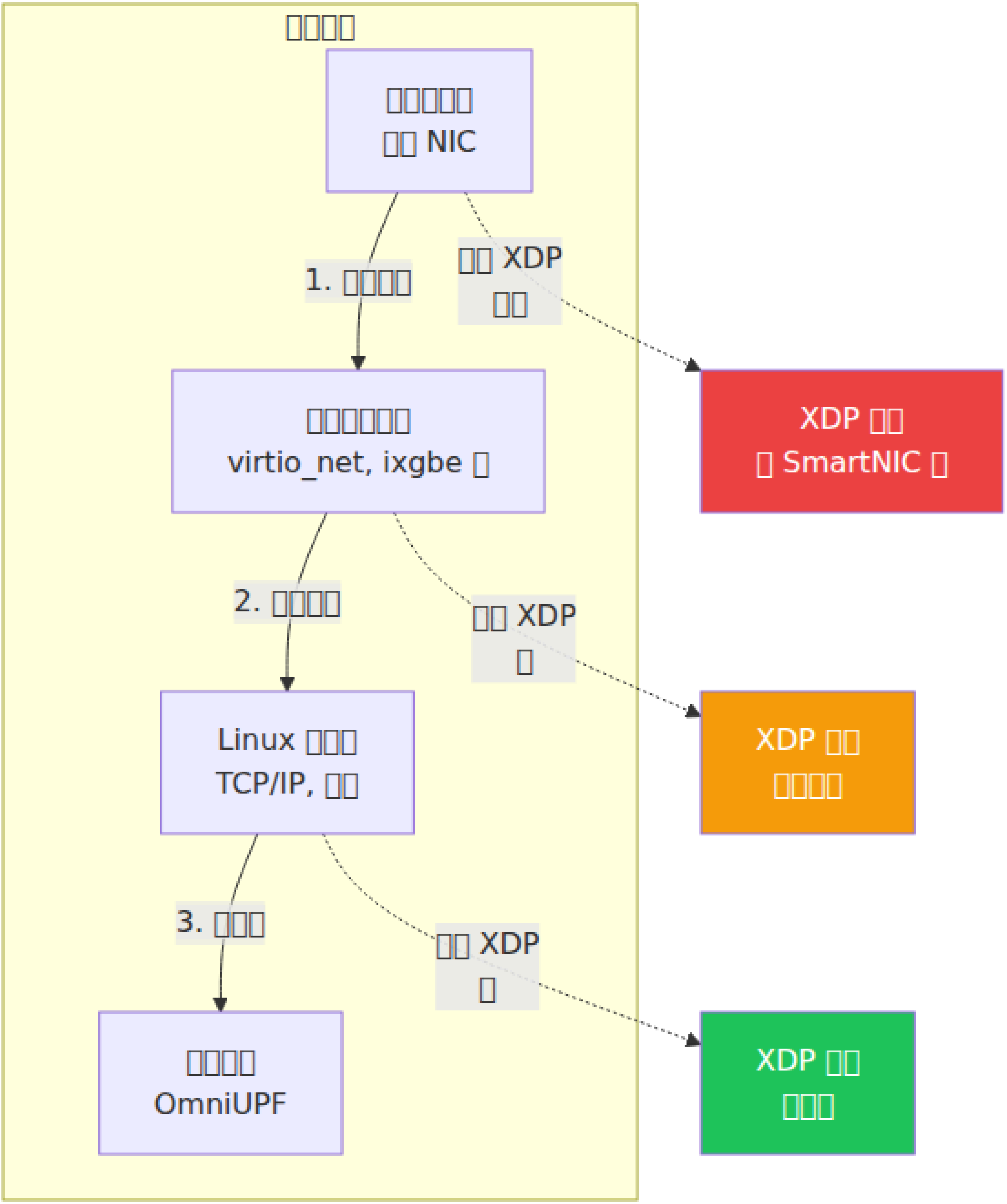
[illegible]

1. [illegible]
2. XDP [illegible]
3. [illegible]
4. [illegible]
5. [illegible]SmartNIC[illegible]
6. [illegible] Proxmox VE [illegible] XDP
7. [illegible] XDP
8. [illegible] XDP [illegible]
9. [illegible] XDP [illegible]

[illegible]

OmniUPF [illegible] **XDP (eXpress Data Path)** [illegible]XDP [illegible] Linux [illegible]eBPF[illegible]

XDP [illegible] **eBPF** [illegible]


□□□□
□□□□□
□□ NIC
1. □□□□
□□ XDP
□□
□□□□□□
virtio_net, ixgbe □
XDP □□
□ SmartNIC □
2. □□□□
□□ XDP
□
Linux □□□
TCP/IP, □□
XDP □□
□□□□
3. □□□
□□ XDP
□
□□□□
OmniUPF
XDP □□
□□□

□□□□□ XDP □□□ OmniUPF □□□□□□□□□□□□□□□□□□□□□□□□□□□□

XDP [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Linux [illegible]	[illegible]	NIC [illegible]
[illegible]	~1-2 Mpps	~5-10 Mpps	~10-40 Mpps
[illegible]	~100 µs	~10 µs	~1 µs
CPU [illegible]	[illegible]	[illegible]	[illegible]
NIC [illegible]	[illegible] NIC	[illegible] XDP [illegible]	[illegible] XDP [illegible] SmartNIC
[illegible]	[illegible]	[illegible]	[illegible]PCI [illegible]
[illegible]	[illegible]	[illegible]	[illegible]���[illegible]
[illegible]	`xdp_attach_mode: generic`	`xdp_attach_mode: native`	`xdp_attach_mode: offload`

[illegible] [illegible]

[illegible]

[illegible]

[illegible] XDP [illegible] [illegible] [illegible] Linux [illegible] eBPF [illegible] XDP [illegible]

□□□□

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

□□□□

- □□□□□□□□
- □□□□□□□□□□□□
- □□□□□□□□□□□□□□

□□

```
# /etc/omniupf/runtime.exs
xdp_interfaces = "eth0"
xdp_attach_mode = "generic"    # □□□□
```

□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□ CPU □□□

□□□□□□□□□□□□□□□□□□□□□□□□□□ `skb`□□□□□□ NIC □ TX □□□□□□□□□□□ □□□□□□ □□□□ □□□□□□□□□□ UE □□□□□□ IPv6 □□□□□□□□□□ `CHECKSUM_PARTIAL`□□□□□□□□□□□□□□□□□□ □ `csum_start`/`csum_offset` □□□ NIC □□□□□□ □□ □ UDP □□□□□□□□□□□□□□□□□□□□ XDP □□□□□□□□□`CHECKSUM_NONE`□□□□□□□□□□□□□□□□/□□□□□□□□□□□□ skb□□□□□□□□□□□ NIC□□□ virtio□□□□□□□□ NIC □ TX □□□□□□`ethtool -K <iface> tx off`□ — □□ TROUBLESHOOTING.md □“IPv6 SLAAC □□□ / UDP □□□□□”□□

□□□□□□□□□□

□□

□□ XDP □□□□□□□ □□ □□ eBPF □□□□□□□□□ Linux □□□□□□□□□□□□□□□□□□□□□□□□□□□ □□

□□□□

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

□□□□

- □□□□□□□□
- □□□□□□□□□□□□□
- □□□□□□□□□□□□□
- □□□□□□□□□□

NIC □□□□

□□ XDP □□□□ XDP □□□□□□□□□□□□□ NIC □□□□ XDP□

□□ **NIC��**□□□□□

- □□□□`ixgbe`□10G□□`i40e`□40G□□`ice`□100G□
- □□□`bnxt_en`
- □□□`mlx4_en`□`mlx5_core`
- Netronome□`nfp`□□□□□□□
- Marvell□`mvneta`□`mvpp2`

□□ **NIC**□□□□□□□□□□

- VirtIO□`virtio_net`□KVM□Proxmox□OpenStack□ ✓
- VMware□`vmxnet3` ✓
- □□□`hv_netvsc`□Hyper-V□ ✓
- □□□□`ena`□AWS□ ✓
- SR-IOV□`ixgbevf`□`i40evf`□PCI □□□ ✓

□□□VirtualBox □ □□□□ XDP□□□□□□□□□□

□□

```
# /etc/omniupf/runtime.exs
xdp_interfaces = "eth0"
xdp_attach_mode = "native"
```

□□□□□□□□□□□□□□□□□□□□ NIC □□□□□□□□□□□ Proxmox □□□□

□□□□□SmartNIC□

□□

□□ XDP □□□ NIC □□□SmartNIC□□□□ eBPF □□□□□□□ CPU □□□□□□□□□□□□□□□□□□□□□ □□□□□

□□□□

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

□□□□

- □□□□□ □□□□□ UPF □□ 10G □□□
- □□□□□□□□□□□
- □□□□□ □□□□□□ CPU □□□

□□□□

□□□□ Netronome Agilio SmartNIC □□ XDP □□□

- Netronome Agilio CX 10G/25G/40G/100G

□□□□□□□□□ □□□ □ **PCI** □□ - □□□□□□□□□□□□□

[illegible]

```
# /etc/omniupf/runtime.exs
xdp_interfaces = "eth0"
xdp_attach_mode = "offload"
```

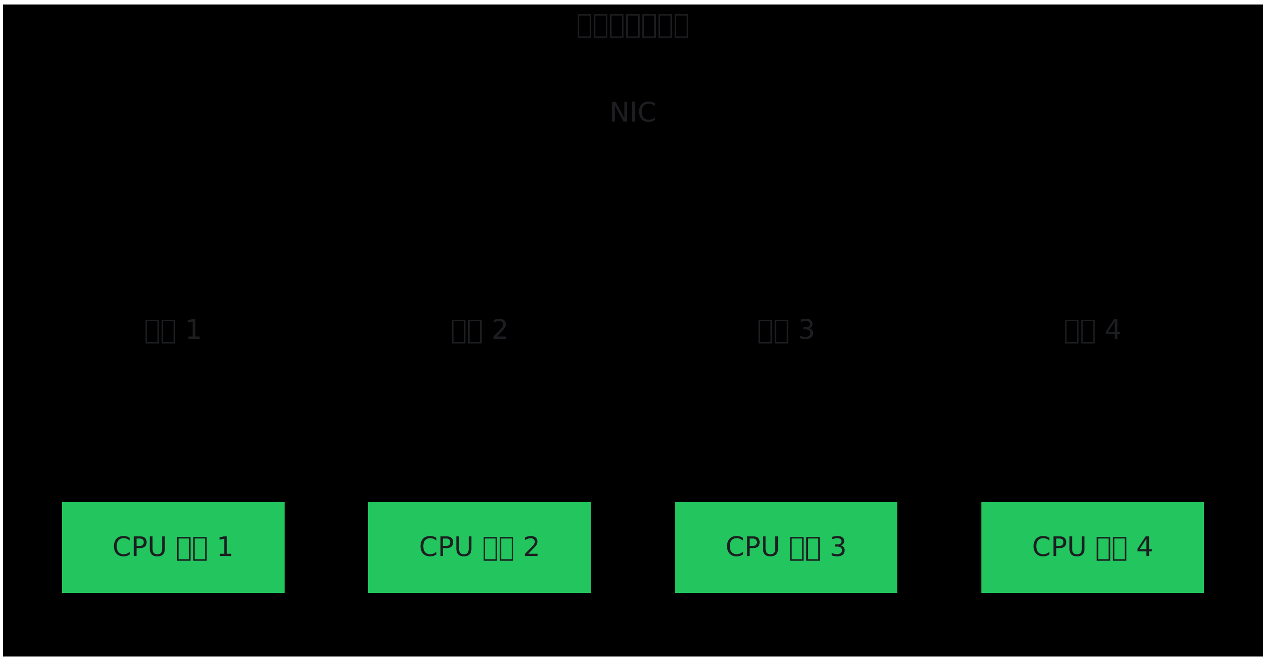
[illegible] Proxmox VE [illegible] XDP

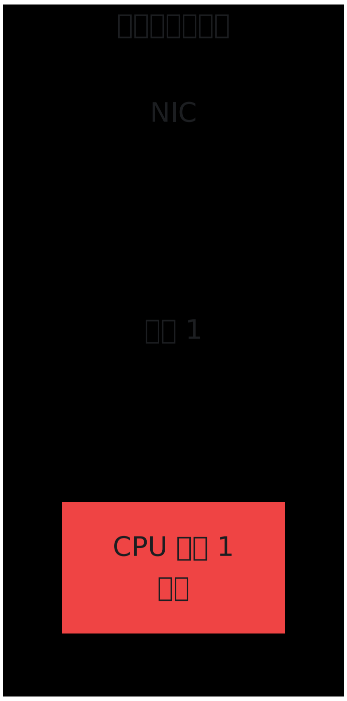
Proxmox VE [illegible] **VirtIO** [illegible] `virtio_net` [illegible] XDP[illegible] [illegible] [illegible] [illegible]

[illegible] 1 [illegible]

[illegible]

- [illegible] CPU [illegible] → [illegible]
- [illegible] CPU [illegible] → [illegible]


□□□□□□□
NIC
□□ 1
□□ 2
□□ 3
□□ 4
CPU □□ 1
CPU □□ 2
CPU □□ 3
CPU □□ 4



□ 2 □□□ Proxmox □□□□□□

□□ A□□□ Proxmox Web UI

1. □□□□□□□□□□□□□□□
    - □ Proxmox Web □□□□□□□□□□
    - □□ □□

2. □□□□□□
   - □□ □□ □□□
   - □□□□□□□□□□□□`net0`□
   - □□ □□
3. □□□□□
   - □□ **"□□□"** □□
   - □□□ **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=vmbr0,queues=8

# □□□□□□ 191□MAC BC:24:11:1D:BA:00
qm set 191 -net0 virtio=BC:24:11:1D:BA:00,bridge=vmbr0,queues=8

# □□□□□
qm shutdown XXX

# □□□□□□□□□
qm start XXX
```

□□□□□□□

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

□ 3 □□□□□□□□□□□□□

□□□□□□□SSH □□□□□□□□□

```
# □□□□□□
ethtool -l eth0

# □□□□□
# eth0 □□□□□□
# Combined:     8        <-- □□□□□□□□□

# □□□□□□
ls -1d /sys/class/net/eth0/queues/rx-* | wc -l
ls -1d /sys/class/net/eth0/queues/tx-* | wc -l

# □□□□□□ 8□□□□□□□□
```

□ 4 □□□ OmniUPF □□□□□ XDP

□□ OmniUPF □□□

```
# □□□□□□
sudo nano /etc/omniupf/runtime.exs
```

□□ XDP □□□

```
# □□
xdp_attach_mode = "generic"

# □□
xdp_attach_mode = "native"
```

□□ OmniUPF□

```
sudo systemctl restart omniupf
```

[illegible] 5 [illegible] XDP [illegible]

[illegible]

```
# [illegible]
journalctl -u omniupf --since "1 minute ago" | grep -i
"xdp\|attach"

# [illegible]
# xdp_attach_mode:native
# XDPAttachMode:native
# [illegible] XDP [illegible] "eth0"[illegible] 2[illegible]
```

[illegible] API [illegible]

```
# [illegible]
curl -s http://localhost:8080/api/v1/config | grep xdp_attach_mode

# [illegible]
# "xdp_attach_mode": "native",
```

[illegible] Proxmox [illegible]

[illegible]“[illegible] XDP [illegible]”

[illegible]

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

[illegible] 1 [illegible]

[illegible]

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

[illegible]

[illegible]

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

[illegible] XDP

VMware ESXi / vSphere

VMware [illegible] `vmxnet3` [illegible] XDP[illegible]

[illegible]

- ESXi 6.7 [illegible]
- [illegible] vmxnet3 [illegible] 1.4.16 [illegible]
- [illegible] 14 [illegible]

[illegible]

1. [illegible]

2. [illegible]

   - [illegible] → [illegible]
   - [illegible] → [illegible]
   - [illegible] [illegible] [illegible] [illegible]

3. [illegible] **.vmx** [illegible]

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

4. [illegible]

```
ethtool -l ens192  # □□□□□□
```

□□ **OmniUPF**□□ `runtime.exs` □□□

```
xdp_interfaces = "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
```

□□ Hyper-V

Hyper-V □□ `hv_netvsc` □□□□□□□□□ XDP□

□□□

- Windows Server 2016 □□□□□
- □□□□ Linux □□□□ 4.3 □□□

- □□ 2 □□□

□□□□□□

□ Hyper-V □□□□□ PowerShell□

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

□□ **OmniUPF**□□ `runtime.exs` □□□

```
xdp_interfaces = "eth0"
xdp_attach_mode = "native"
```

VirtualBox

□□□VirtualBox □ □□□□ XDP□

□□□VirtualBox □□□□□���□e1000□virtio-net□□□□ XDP □□□

□□□□□□□□□□□□□

```
xdp_attach_mode = "generic"    # VirtualBox □□□□
```

□□ XDP □□

□□□□□ XDP □□□□□□□□□□□□

1. □□ OmniUPF □□

```
# □□□□□□□
journalctl -u omniupf --since "5 minutes ago" | grep -i xdp

# □□□
# ✓ "xdp_attach_mode:native"
# ✓ "□□ XDP □□□□□"
# ✗ "□□□□" □ "□□□□□"
```

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. [illegible]

```
# [illegible] XDP
ethtool -i eth0 | grep driver

# [illegible] Proxmox/KVM[illegible] "virtio_net"
# [illegible] VMware[illegible] "vmxnet3"
# [illegible] Hyper-V[illegible] "hv_netvsc"
```

5. [illegible]

[illegible]

```
# [illegible]
watch -n 1 'curl -s http://localhost:8080/api/v1/packet_stats | jq .rx_packets'

# [illegible]~1-2 Mpps
# [illegible]~5-10 Mpps[illegible] 5-10 [illegible]
```

[illegible] XDP [illegible]

[illegible]“[illegible] XDP [illegible]”

[illegible]

```
[illegible] XDP [illegible] eth0
```

[illegible]

1. [illegible]

```
ethtool -i eth0 | grep driver

# □□□□□□ virtio_net/vmxnet3/hv_netvsc□□□ XDP □□□□□
```

2. □□□□□□□

   ```
   uname -r

   # □□ ≥ 5.15 □□□□□□ XDP
   ```

3. □□□□□□□□□ **XDP** □□□

   ```
   ip link show eth0 | grep xdp

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

□□□□□

- □□□□□□□□□□□ 5.15+
- □□□□□ virtio_net □□□□□`modprobe virtio_net`
- □□□□□□□□□ XDP□□□□□□□□□

□□□□□□□□□□□□

□□□

```
□□□□□□□□ XDP □□
```

□□□

□□ `dmesg` □□□□□□□

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

[illegible]

1. [illegible] **XDP**[illegible]
   - VirtualBox [illegible] XDP[illegible]
   - [illegible] NIC [illegible]
2. [illegible]
   - [illegible]`ethtool -l eth0`
   - [illegible] > 1 [illegible]
3. [illegible] **XDP** [illegible]

```
# [illegible] XDP
grep XDP /boot/config-$(uname -r)

# [illegible]
# CONFIG_XDP_SOCKETS=y
# CONFIG_BPF=y
```

[illegible]

- [illegible] Proxmox [illegible]
- [illegible]
- [illegible] XDP

[illegible]

[illegible]

[illegible]

1. [illegible]

```
# [illegible]
ethtool -S eth0 | grep rx_queue

# [illegible]
```

2. [illegible] **CPU** [illegible]

   ```
   # [illegible] CPU [illegible]
   mpstat -P ALL 1

   # [illegible] CPU [illegible]
   ```

3. [illegible] **XDP** [illegible]

   ```
   # [illegible] bpftool[illegible]
   sudo bpftool net list

   # [illegible] XDP [illegible]
   ```

[illegible]

- [illegible]8-16 [illegible]
- [illegible] CPU [illegible]��[illegible]
- [illegible] CPU [illegible]

[illegible]XDP [illegible]xdp_aborted > 0[illegible]

[illegible]

```
curl http://localhost:8080/api/v1/xdp_stats
{
  "xdp_aborted": 1234,  # [illegible]
  ...
}
```

[illegible]

XDP □□□□□ eBPF □□□□□□□□□□□□□

1. □□ **eBPF** □□□□□□

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

2. □□□□□□□□□

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

# □□□□□ 100% □□□
```

□□□□□

- □□□□□□ eBPF □□□□
- □□□□□□□□□□□□□ eBPF □□
- □□ Linux □□ eBPF □□□□□□

□□□Proxmox □□□□□□□□

□□□`ethtool -l eth0` □□□□ 1 □□□□□□□□□

□□□

1. □□ **Proxmox** □□□□□□

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

# □□□□queues=8
```

2. □□□□□□□□□□□□

```
# □ Proxmox □□□
qm status YOUR_VM_ID

# □□□□ "status: stopped" □□□□□□
```

□□□□□

```
# □ Proxmox □□□
# □□□□□���□
qm shutdown YOUR_VM_ID
sleep 10
qm start YOUR_VM_ID

# □□□□□□□□□□
ethtool -l eth0
```

□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□

□□□□□ XDP □□□□□□

□□□

```
□□□□□ XDP □□□□□□□□
```

□□□

XDP □□□□ `CAP_NET_ADMIN` □ `CAP_SYS_ADMIN` □□□

□□□□□

1. □ **root** □□□□ **OmniUPF**□□□□□□□□

   ```
   sudo systemctl restart omniupf
   ```

2. □□□□ **systemd**□□□□□□□□□□□□

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

3. □□□□ **Docker**□□ `--privileged` □□□

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

□□□□□□

OmniUPF □□□□□□□□□□□□□□

□□	□□□□	□□□□	□□
□□□□□	1.5 Mpps	8.2 Mpps	□□ **5.5** □
□□	95 µs	12 µs	□□ **8** □
CPU □□□□□1 Gbps□	85%□1 □□□	15%□□□□□	□□ **5** □□□
□□□□□	~1.2 Gbps	~10 Gbps	□□ **8** □

□□□□□□□□□□□□□□ □□□□ □ □□□□□□

XDP □□□□

⚠ **□□□□□□□□□□□□□□□□□□ Omnitouch □□□□□□□□□□□□□□□□□□□□ 100% □□□**

□□□□□□□ XDP □□□ NIC

□□ NIC □□□□□ OmniUPF □□□ XDP □□□

□□□ NIC□□□□□□□□□

□□	□□	□□□□	**XDP □□**	□□
□□□ X520	10GbE	ixgbe	□□ ✓	□□□□□□□□□□□□□□
□□□ X710	10/40GbE	i40e	□□ ✓	□□□□□□□□
□□□ E810	100GbE	ice	□□ ✓	□□□□□□□□□
□□□ i350	1GbE	igb	□□ ✓□□□ 5.10+□	□□□□□□□□

Mellanox/NVIDIA NICs (□□□)

□□	□□	□□□□	**XDP □□**	□□
ConnectX-4	25/50/100GbE	mlx5	□□ ✓	□□□□□□□□□□□
ConnectX-5	25/50/100GbE	mlx5	□□ ✓	□□□□□□□□□□
ConnectX-6	50/100/200GbE	mlx5	□□ ✓	□□□□□□□□□□□□
BlueField-2	100/200GbE	mlx5	□□ ✓	□□ DPU □□□ SmartNIC

Broadcom NICs

□□	□□	□□□□	**XDP □□**	□□
BCM57xxx □□	10/25/50GbE	bnxt_en	□□ ✓	□□□ Dell/HP □□□

□□ NICs (□□□□□)

□□	**NIC □□**	□□□□	**XDP □□**	□□□	□□
Proxmox/KVM	VirtIO	virtio_net	□□ ✓	□□□□□□	□□□□□□□
VMware ESXi	vmxnet3	vmxnet3	□□ ✓	□	□□ ESXi 6.7 □□□□□
Hyper-V	□□ NIC	hv_netvsc	□□ ✓	□	Windows Server 2016 □□□□□
AWS	ENA	ena	□□ ✓	□	EC2 □□□□
VirtualBox	□□	□□	□□□ □	□	□□□□□□□□□

□□□□□□□ NICs

□□□ **XDP** □□□□□eBPF □ NIC □□□□□

□□□	□□	□□	□□
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	□□□□

□□□□□□□ NICs □□□□□□□□□□□□□□□□□□□□□□□□□□□ XDP□

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□□□□□□□□□□□□ 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 □□□
VirtualBox	□□□ XDP □□	□□□ Proxmox/KVM
□□□ NICs	□□□□□□□□□□	□□□□ Intel/Mellanox
□□□□ NICs (<2014)	□ XDP □□□□□□	Intel X520 □□□

□□□□□□□

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1. □ □□□□□□: □□ Linux □□□□□□□□ XDP

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

2. □ □□□□: □□□□ ≥ 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=vmbr0,queues=8
qm shutdown <VM_ID> && sleep 10 && qm start <VM_ID>

# □□□□□□□
ethtool -l eth0  # □□ 8 □□□
sudo nano /etc/omniupf/runtime.exs  # □□: xdp_attach_mode =
"native"
sudo systemctl restart omniupf
journalctl -u omniupf --since "1 min ago" | grep xdp  # □□□□□□
```

[illegible] XDP [illegible]

```
# [illegible]
curl -s http://localhost:8080/api/v1/config | grep xdp_attach_mode

# [illegible]
curl -s http://localhost:8080/api/v1/xdp_stats | jq

# [illegible]
ethtool -l eth0
```

OmniUPF API □□

□□

OmniUPF API □□□□□□□□ RESTful □□□□□□□□□□□□ eBPF □□□□□□□□□ API □□□ UPF □□□ □□□□□□□□□□□□□□

API □□

□□□□□

- **PFCP** □□□□□□□□□□□□□□□□□□ UE IP □ TEID □□
- **PFCP** □□□□□□□□□□□□□□□□□

□□□□□

- □□□□□□□ **(PDR)**□□□□□□□□□□□□□ (IPv4/IPv6)
- □□□□□□ **(FAR)**□□□□□□□□□□□□□
- **QoS** □□□□ **(QER)**□□□□□□□□ QoS □□
- □□□□□□ **(URR)**□□□□□□□□□□□□□□

□□□□□□

- □□□□□□□□□ FAR □□□□□□ (`GET /buffer`, `GET /buffer/:far_id`)
- □□□□□□□□□□□□□□□ (`POST /buffer/:far_id/flush`, `DELETE /buffer/:far_id`, `DELETE /buffer`)
- □□□□□□□□□□□ (`POST /buffer/:far_id/notify`)
- □□□□□□□ DLDR □□□□ (`GET /buffer/notifications`)

□□□□□□

- □□□□□□□□□□□□□□□□□ (GTP, IP, TCP, UDP, ICMP, ARP)
- **XDP** □□□□□□□□□□□ (□□□□□□□□□□□□□)
- **N3/N6** □□□□□RAN □□□□□□□□□
- □□□□□FIB □□□□ (□□□□□□□□□□□)

[illegible]

- **UE** [illegible] UE IP [illegible] gNB [illegible] (`GET /routes`)
- **FRR** [illegible] (`POST /routes/sync`)
- [illegible] (`GET /routing/sessions`)
- **OSPF** [illegible] OSPF [illegible] (`GET /ospf/database/external`)

[illegible]

- **UPF** [illegible] (`GET /config`, `POST /config`)
- [illegible] (`GET /dataplane_config`)
- **XDP** [illegible] XDP [illegible] (`GET /xdp_capabilities`)
- **eBPF** [illegible] (`GET /map_info`)

Web UI [illegible]

OmniUPF Web UI [illegible] API [illegible] API [illegible] Web UI [illegible] [illegible]

Swagger API [illegible]

[illegible] API [illegible] **OpenAPI 3.0 (Swagger)** [illegible]���[illegible] Swagger UI [illegible]

- [illegible]/[illegible]
- [illegible] API [illegible]
- [illegible]
- HTTP [illegible]

[illegible] Swagger UI [illegible] OmniUPF API [illegible]

[illegible] Swagger UI

Swagger [illegible]

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

[illegible]`http://10.98.0.20:8080/swagger/index.html`

API [illegible]

[illegible] API [illegible]

```
/api/v1
```

API [illegible]

[illegible]

OmniUPF API [illegible]PDR [illegible] URR [illegible]

1. □□□□□□□□□□□□
   - `page`□□□□□ 1 □□□
   - `page_size`□□□□□□□□□□100□□□□1000□
2. □□□□□□□□□
   - `offset`□□□□□□□□
   - `limit`□□□□□□□□□□□□1000□

□□□□□

```
# □□□□□□□□□ 50 □□□□□
GET /api/v1/pfcp_sessions?page=2&page_size=50

# □□□□□□□□□ 100 □□□□□□□□ 50 □
GET /api/v1/pfcp_sessions?offset=100&limit=50

# □□□□□□□□□□□□□ 100 □
GET /api/v1/pfcp_sessions
```

□□□□□

```
{
  "data": [
    { /* session object */ },
    { /* session object */ },
    ...
  ],
  "pagination": {
    "total": 5432,
    "page": 2,
    "page_size": 50,
    "total_pages": 109
  }
}
```

□□□□□

- `/api/v1/pfcp_sessions` - PFCP □□□□

- `/api/v1/pfcp_associations` - PFCP □□□□
- `/api/v1/routes` - UE IP □□
- `/api/v1/uplink_pdr_map` - □□ PDR□□□□□□
- `/api/v1/uplink_pdr_map/full` - □□ PDR □□□ SDF □□□□□□
- `/api/v1/downlink_pdr_map` - □□ PDR IPv4□□□□□□
- `/api/v1/downlink_pdr_map/full` - □□ PDR IPv4 □□□ SDF □□□□□□
- `/api/v1/downlink_pdr_map_ip6` - □□ PDR IPv6□□□□□□
- `/api/v1/downlink_pdr_map_ip6/full` - □□ PDR IPv6 □□□ SDF □□□□□□
- `/api/v1/far_map` - □□□□□□
- `/api/v1/qer_map` - QoS □□□□
- `/api/v1/urr_map` - □□□□□□

□□□□□□□

- `GET /api/v1/buffer` - □□□□ FAR □□□□□□□□□
- `GET /api/v1/buffer/:far_id` - □□□□ FAR □□□□□
- `GET /api/v1/buffer/notifications` - □□ DLDR □□□□
- `DELETE /api/v1/buffer` - □□□□□���□□□
- `DELETE /api/v1/buffer/:far_id` - □□□□ FAR □□□
- `POST /api/v1/buffer/:far_id/flush` - □□□□□□□□□□□
- `POST /api/v1/buffer/:far_id/notify` - □□□□ DLDR □□

□□□□□

- `GET /api/v1/config` - □□□□ UPF □□
- `POST /api/v1/config` - □□ UPF □□□□□□□□□□□□□
- `GET /api/v1/dataplane_config` - □□□□□□□□□□

□□□□□□□

- `GET /api/v1/routes` - □□ UE □□
- `POST /api/v1/routes/sync` - □□□ FRR □□□□□
- `GET /api/v1/routing/sessions` - □□□□□□□□
- `GET /api/v1/ospf/database/external` - □□ OSPF □□ LSA □□□

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- □□ Web UI □□□□□ `page_size=100`
- □□□□□□□□□ `page_size=1000`□□□□□□
- □□ `pagination.total_pages` □□□□□□□
- □□ `page_size` □□□ API □□□□□□□□

CORS □□

□□□□□□ (CORS) □□□□□□ API □□□□□□□ Web UI □□□□□□□□□□□□□□□ API□

Prometheus □□

□□ REST API□OmniUPF □□ `/metrics` □□□□□□□ `:9090`□□□□ Prometheus □□□

□□□□□

- □□□□□□ PFCP □□□□□□□
- □□□□□□□□□□□
- XDP □□□��
- □□□□
- eBPF □□□□□□□
- URR □□□□

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- **Web UI □□** - □□□ API □□□□□□□□□
- □□□□ - Prometheus □□□□
- **PFCP □□□□** - PFCP □□□□□□□□□
- □□□□□□ - PDR□FAR□QER□URR □□
- □□□□□□ - FRR □□□ UE □□
- □□□□ - □□□□□□□□□
- □□□□ - UPF □□□□
- **Swagger UI** - □□□ API □□□□ `localhost` □□□□□ UPF □□□

UE [illegible]

> [illegible]
>
> - API [illegible] - [illegible] API [illegible]
> - [illegible] - Web UI [illegible]

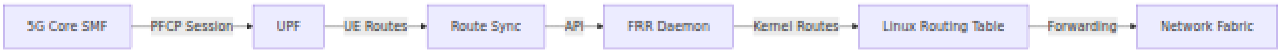
[illegible]

UPF[illegible] **FRR**[illegible] [illegible]UE[illegible]IP [illegible] UE [illegible]

[illegible] FRR[illegible]

FRR[illegible] [illegible] Linux [illegible] Unix [illegible] BGP[illegible] OSPF[illegible]RIP [illegible]FRR [illegible]

[illegible]


5G Core SMF
PFCP Session
UPF
UE Routes
Route Sync
API
FRR Daemon
Kernel Routes
Linux Routing Table
Forwarding
Network Fabric

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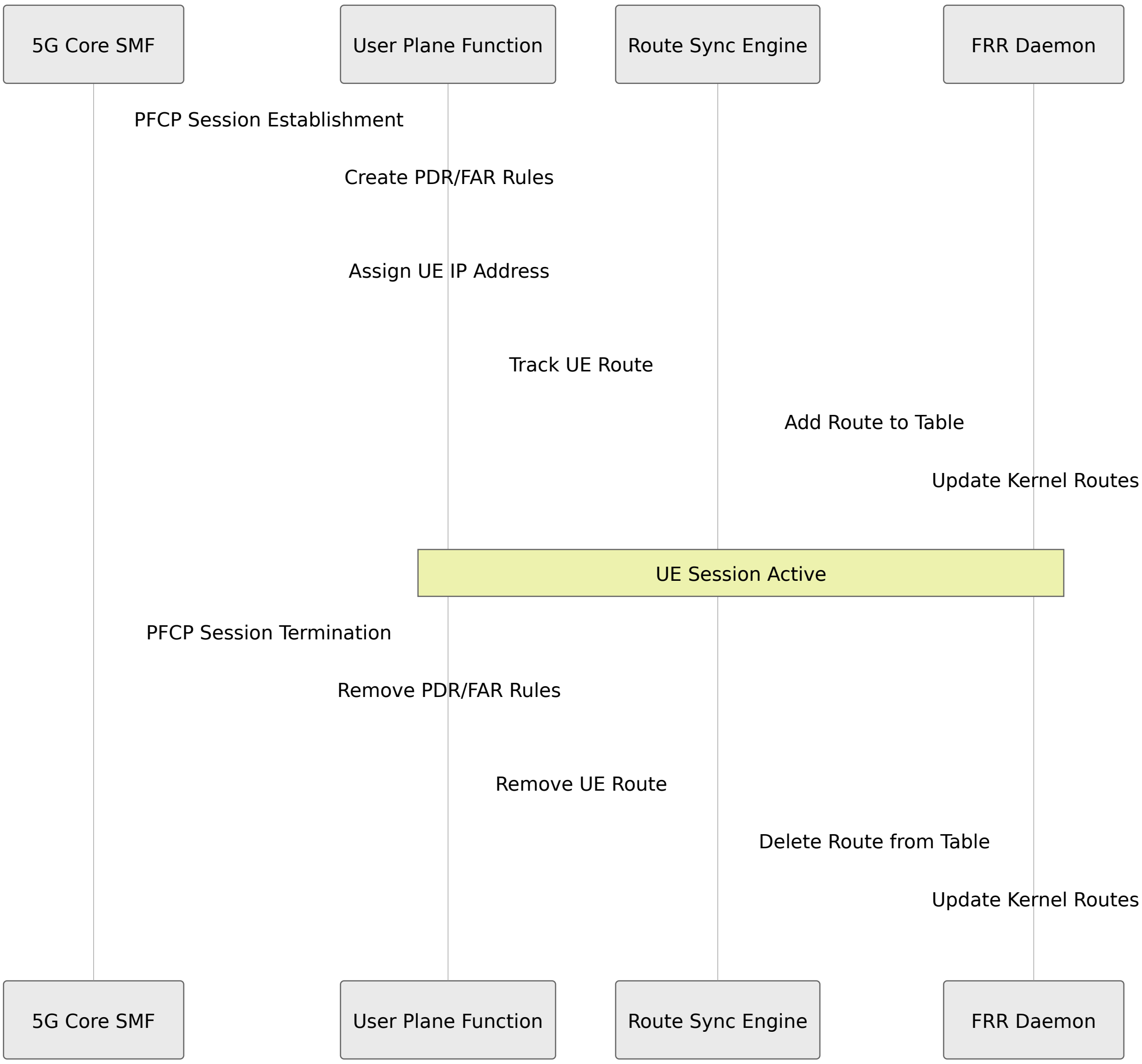
5G Core SMF
User Plane Function
Route Sync Engine
FRR Daemon
PFCP Session Establishment
Create PDR/FAR Rules
Assign UE IP Address
Track UE Route
Add Route to Table
Update Kernel Routes
UE Session Active
PFCP Session Termination
Remove PDR/FAR Rules
Remove UE Route
Delete Route from Table
Update Kernel Routes
5G Core SMF
User Plane Function
Route Sync Engine
FRR Daemon

□□□□

UPF □□□□□□ UE IP □□□□□□□□□□□□□□□□□□□□□

1. □□ **UE** □□□□□□□□□□ PFCP □□□□□□□ UE IP □□
2. □□□□□□□□□□□□□□□□□□□□□□□□
3. □□□ **FRR**□□□□ API □□□□□□□□□ FRR □□□□
4. □□□□□□□□□□□□□□□□□□□□/□□□□□□□□□□

FRR [illegible]

[illegible]

FRR [illegible] **Ansible** [illegible] [illegible] Ansible [illegible] FRR [illegible] **Jinja2** [illegible] Ansible [illegible] UPF [illegible]

[illegible] FRR Jinja2 [illegible]

```
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 static
 network {{ hostvars[inventory_hostname]['ansible_default_ipv4']['network'] }}/{{ mask_cidr }} area 0
 area 0 authentication message-digest
!
line vty
!
end
```

[illegible]

1. [illegible] Ansible [illegible] FRR Jinja2 [illegible] `roles/frr/templates/frr.conf.j2`[illegible]
2. [illegible] Ansible [illegible] UPF [illegible]
3. [illegible] Ansible [illegible] FRR [illegible] UPF [illegible]

4. □□□□□Ansible □□□□□□□□□□□IP □□□□□□ ID □□□□□□ UPF □ FRR □□

Jinja2 □□□□□□□□□□

- **OSPF** □□□□□□ ID□□□□□□□□□□□□□□□
- **BGP** □□□ASN□□□□□□□□□□□□□
- □□□□□□□□□□□□□□□□□□□`redistribute static` □□ UE □□□
- □□□□□□□□□□□□□□□□□��□
- □□□□□OSPF/BGP □□□□

UPF □□□□□□□ FRR □□□□□□□ UPF □□□UPF □□□□□□ PFCP □□□□□ FRR vtysh □□□□□□ UE IP □□□□ □□□□□IPv4 □ /32□IPv6 □ /128□□□□□□□□□

1. □□ **FRR** □□□□□□□□ UPF □□□□□□□□□ vtysh□
2. **□□ `redistribute static` □□□ FRR □□
3. □□□□ **FRR** □□□□□□□□□OSPF□BGP□□
4. □□□□□□□□ UE □□□□□□□□ UPF □□

> □□□UPF □□ FRR □ vtysh □□□□□□□□□□□ FRR □□□□□□□□□□□□□□□□□□ OSPF/BGP □□□□□ `redistribute static`□□□□ `redistribute kernel`□

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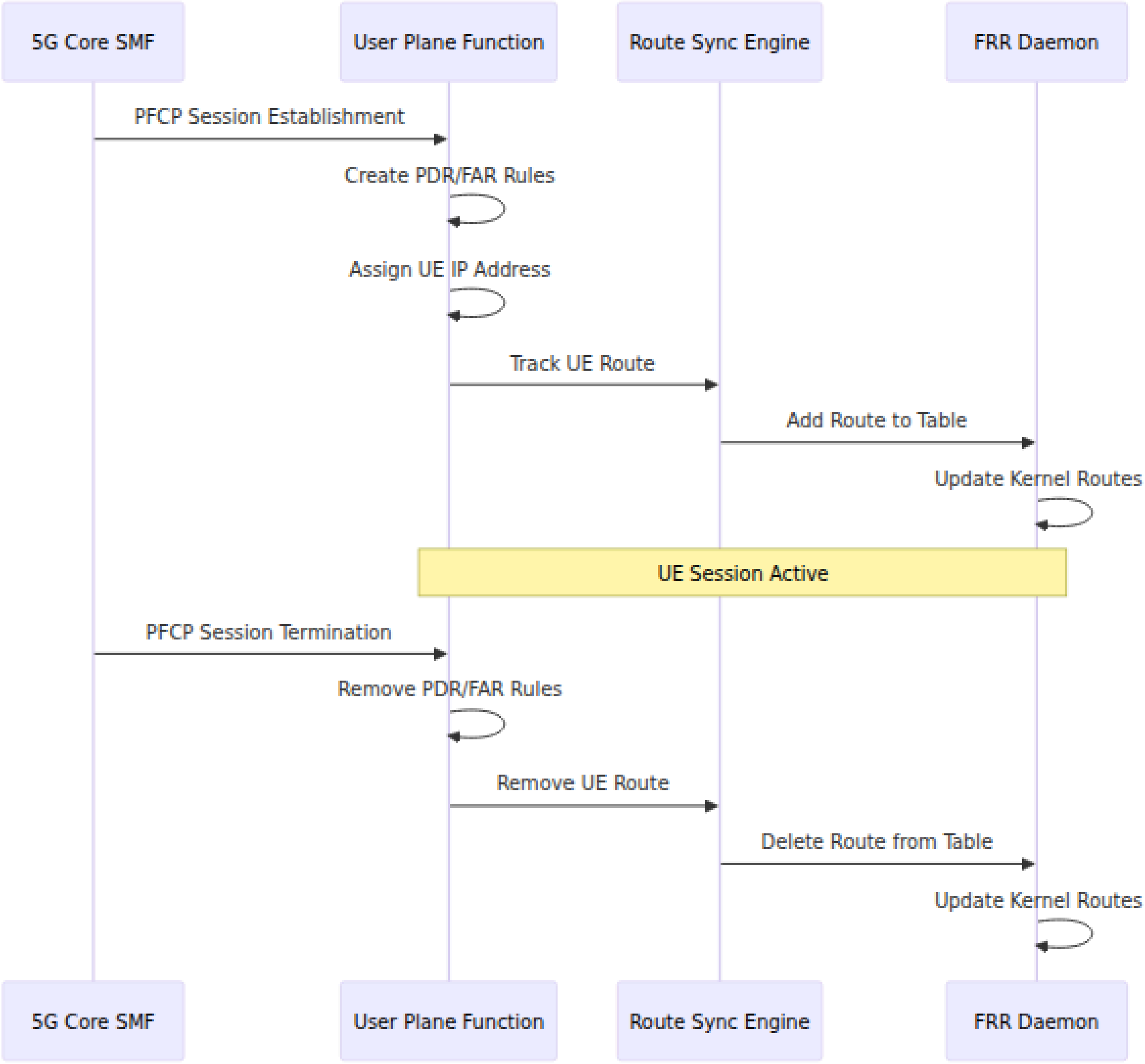
- □□□□□□□□□□□ Ansible □□□ FRR Jinja2 □□□□□□□□□□□□□□ UPF □□
- **Ansible** □□□□□□□Jinja2 □□□□□□□□□□□□□OSPF □□□BGP □□□□□□□□□□□□
- **UPF** □□□□□□□□□ UPF □□□□□□□□□ PFCP □□□□□□ UE IP /32 □□
- □□□□□□□□□ UPF □□ FRR □□□□□□□□□□□□□□□□ UE □□
- □□□□□□□ Ansible □□□□□□□□□□□□���□□□□□ UPF □□□□□

[illegible]


5G Core SMF
User Plane Function
Route Sync Engine
FRR Daemon
PFCP Session Establishment
Create PDR/FAR Rules
Assign UE IP Address
Track UE Route
Add Route to Table
Update Kernel Routes
UE Session Active
PFCP Session Termination
Remove PDR/FAR Rules
Remove UE Route
Delete Route from Table
Update Kernel Routes
5G Core SMF
User Plane Function
Route Sync Engine
FRR Daemon

[illegible]

Web UI [illegible]

UPF [illegible] [illegible] [illegible]

- [illegible]
- [illegible] UE IP [illegible]
- [illegible]
- [illegible] UE IP [illegible]
- **OSPF** [illegible] OSPF [illegible]

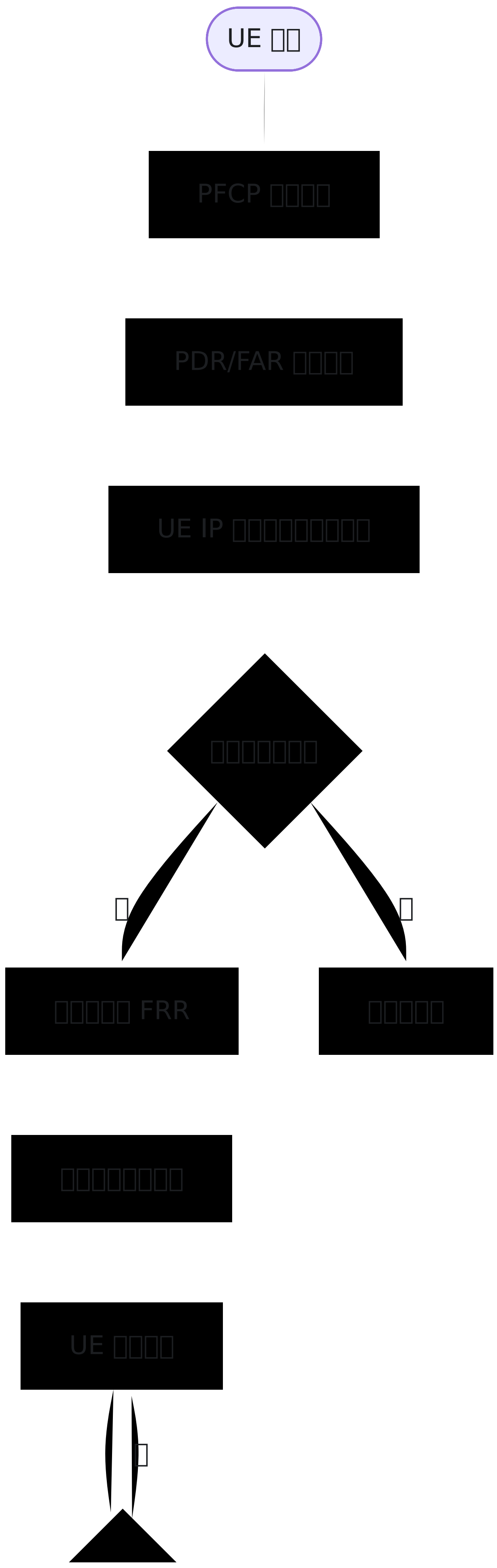
- **BGP** [illegible]BGP [illegible]
- **OSPF** [illegible] UE [illegible] LSA [illegible]

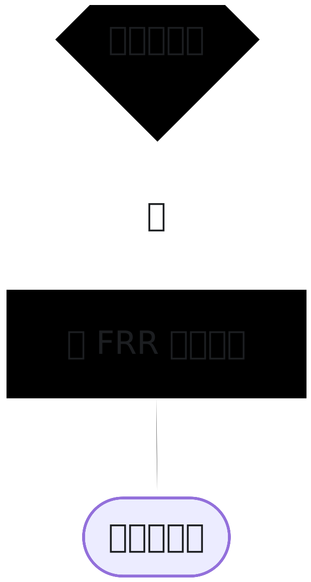
[illegible] UE [illegible]

[illegible]

[illegible] Web UI [illegible] [illegible] [illegible]

1. [illegible] UPF [illegible] UE [illegible]
2. [illegible] FRR [illegible]
3. [illegible]
4. [illegible]
5. [illegible]


UE
PFCP
PDR/FAR
UE IP
FRR
UE



[illegible]

- [illegible]
- [illegible] UE [illegible]
- [illegible] UE [illegible]
- [illegible]
- [illegible] Web UI [illegible]

[illegible]

API [illegible]

UPF [illegible]

- `GET /api/v1/routes` - [illegible] UE [illegible]
- `POST /api/v1/routes/sync` - [illegible] FRR [illegible]
- `GET /api/v1/route_stats` - [illegible]
- `GET /api/v1/routing/sessions` - [illegible]OSPF [illegible]BGP [illegible]
- `GET /api/v1/ospf/database/external` - [illegible] OSPF AS-External LSA [illegible]

> [illegible]API [illegible] - [illegible] [illegible]

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□□□□□□□ IP □□□□□□`100.64.18.5`□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

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- □□□□□□□

IPv6 □□

□□□□□□□ IPv4 □ IPv6 UE □□□

□□□□	□□□□	□□
IPv4	/32	`100.64.18.5/32`
IPv6	/128	`2001:db8::1/128`

□□ IPv6□□□□□□ FRR □□□□□□□ OSPFv3 □ BGP IPv6 □□□□□

```
router ospf6
 redistribute static
```

□□□ BGP□

```
router bgp <asn>
 address-family ipv6 unicast
  redistribute static
```

FRR □□

OSPF □□ LSA □□□

□□□□□□□ FRR OSPF □□□□□□□□□□ UE □□□□□□□□□□□□ OSPF□□□ LSA□□□ 5□□□□□□□□□ □□ OSPF □□□□

FRR OSPF □□□□□□□ LSA□□□ UE □□ 100.64.18.5/32 □□□□ E2□□□□□ 2□□□□

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- □□ **LSA (10.98.0.20)**□UPF □□□□□□□
- □□□ **LSA (192.168.1.1)**□OSPF □□□□□
- □□ **LSA**□□□ UE □□ `100.64.18.5` □ E2□□□□□ 2□□□□□□□□□□ OSPF

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