Virtual Mobile Core Placement for Metro Area

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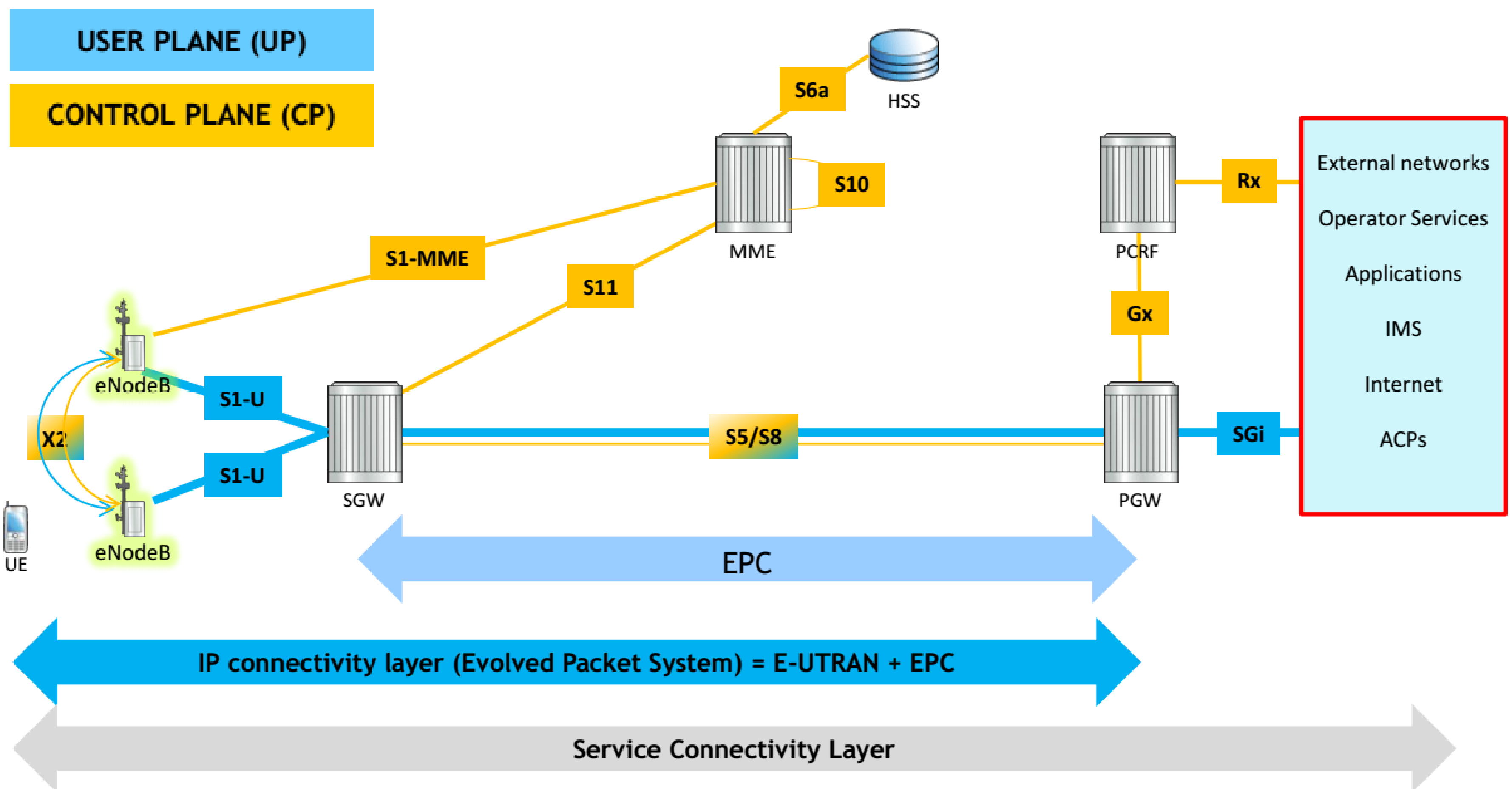
Motivation

- Volume of data to be transported in across a mobile network keeps increasing
- Proprietary hardware is difficult to upgrade and replace
- Further, the Average Revenue Per User (ARPU) is not rapidly increasing
- Network Function Virtualization (NFV) tries to resolve the above challenges by virtualizing the mobile core

Difference from previous work

- Mobile core is critical for connecting User Equipment (UE) to Internet and vice-versa
- Mobile core is also critical for functioning of the Radio Access Network (RAN)
- Here, Service Chain (SCs) result from looking at interaction of various mobile core elements whereas earlier SCs were actual value-added services

Mobile Core Architecture (Evolved Packet Core (EPC))



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[1] Introduction to Evolved Packet Core (EPC) – EPC elements, protocols and procedures – Alcatel Lucent

Control and Data Plane Elements of EPC

- Exclusively Control Plane Elements
  - Mobility Management Element (MME)
  - Policy and Charging Rules Function (PCRF)
  - Home Subscriber Server (HSS)

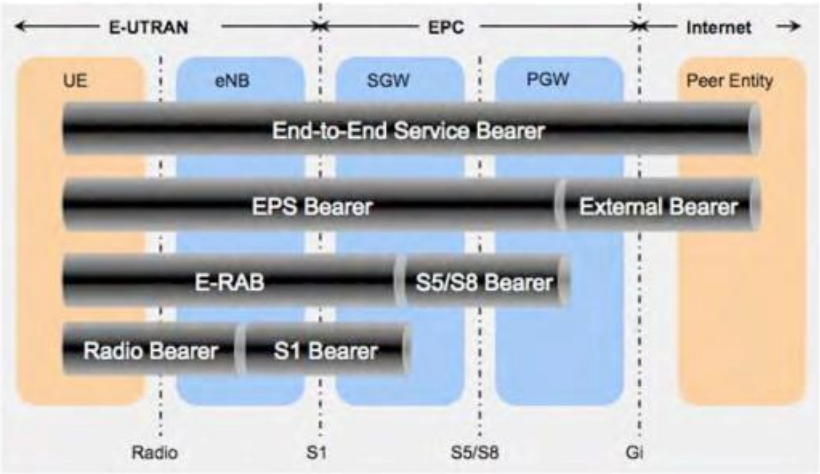
- Data Plane Elements
  - Serving Gateway (SGW)
  - Packet Data Network Gateway (PGW)

Data Path Setup

- Traffic passes from UE to PGW (upload) or from PGW to UE (download) over a GTP (GPRS Tunneling Protocol)
- Setup of a GTP tunnel requires control signaling which depends on the type of Non-Access Stratum (NAS) procedure
- Type of NAS procedure used to setup GTP tunnel depends on UE state (EMM-Registered, EMM-Deregistered, ECM-Idle, ECM-Connected)
- Control signaling is a set of chained requests which we realize as the control service chain
- Data path also requires the SGW->PGW traversal for download and PGW->SGW traversal for upload

Evolved Packet System (EPS) Bearer

- Each EPS bearer context represents a GTP tunnel between UE and PGW
- Can be a default bearer context or a dedicated bearer context
- Default EPS bearer context is activated when UE requests a connection to PGW during EPS attach procedure
- Additionally, the network can activate one or several dedicated EPS bearer contexts in parallel



[2] Protocol Signaling Procedures in LTE - Radisys

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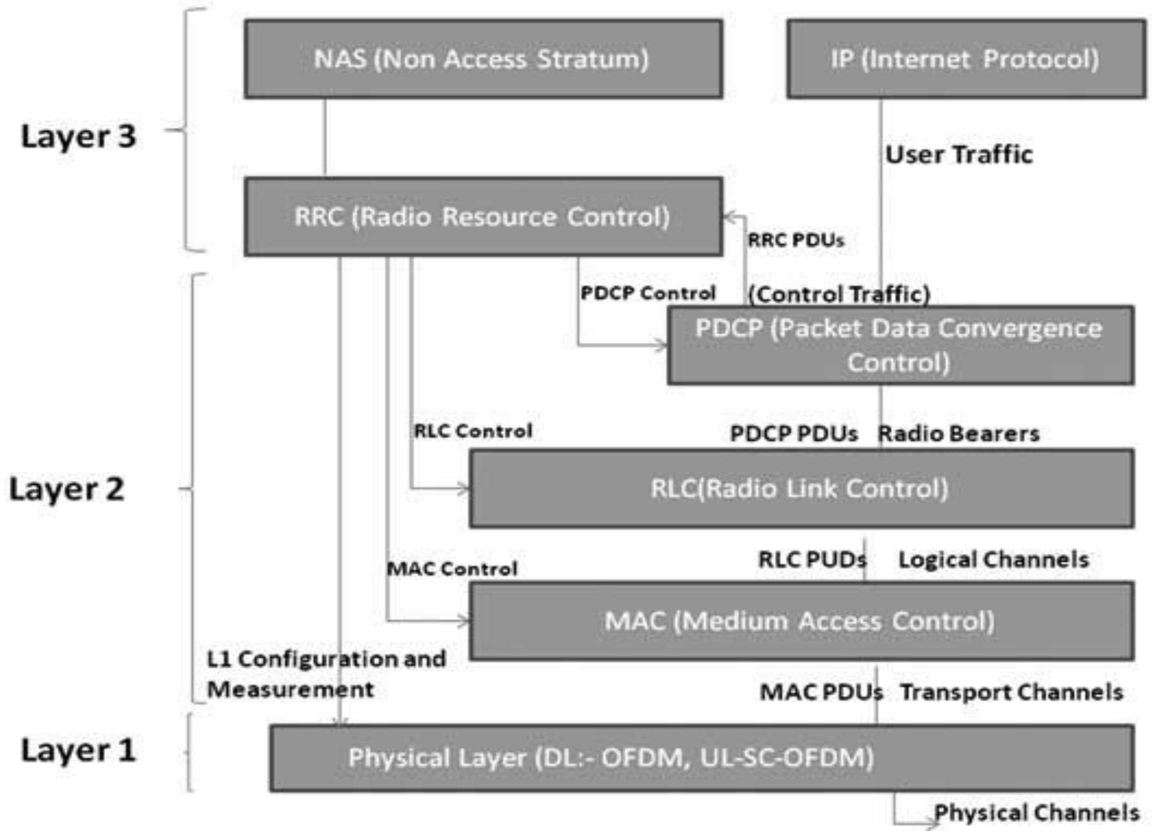
LTE Protocol Stack



NAS (Non-Access Stratum)

- NAS protocols control EPC procedures
- Non-Access Stratum (NAS) resides between the UE and the MME in the control plane
- NAS is responsible for call processing and session management functions of creation, deletion, modification and management of default and dedicated radio bearers
- NAS procedures are grouped in 2
  - EPS Mobility Management (EMM), and
  - EPS Session Management (ESM)

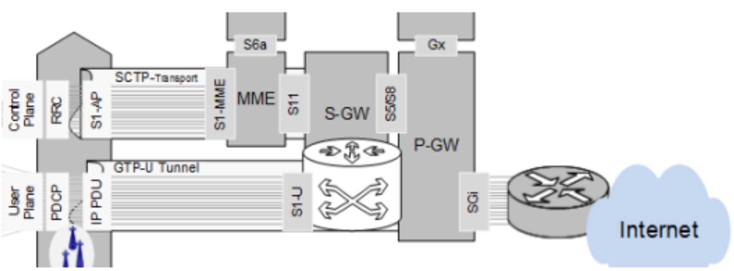


Fig. 1. Traditional cellular EPC with logical interfaces

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EPC Procedures Summary

Event Type	MME	HSS	S-GW	P-GW	PCRF
Attaches	10	2	3	2	1
Additional Default Bearer Setups	4	0	3	2	1
Dedicated Bearer Setups	2	0	2	2	1
Idle-to-Connected Transitions	3	0	1	0	0
Conntected-to-Idle	3	0	1	0	0
X2-based Handovers	2	0	1	0	0
S1-based Handovers	8	0	3	0	0
Tracking Area Updates	2	0	0	0	0
Total	34	2	14	6	3

TABLE I. TRANSACTION PER NAS EVENT BY EPC ELEMENT

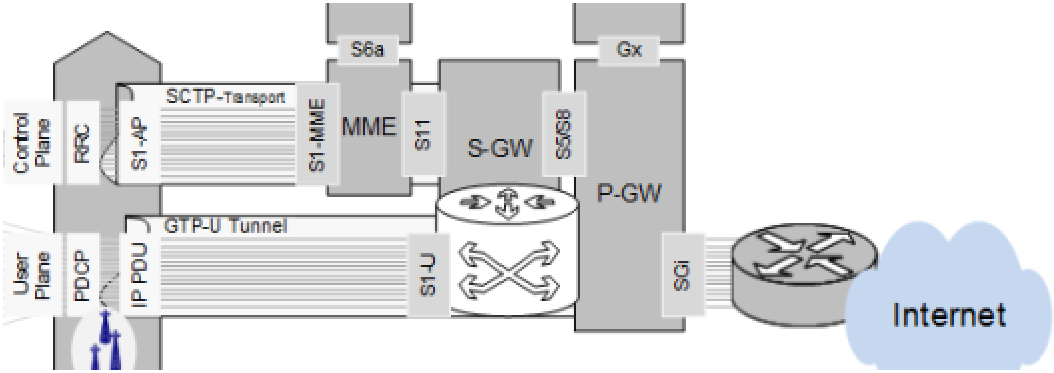

Fig. 1. Traditional cellular EPC with logical interfaces

[3] Understanding the bottlenecks in Virtualizing Cellular Core Network Functions - Intel Labs, Connectem, AT&T Labs

Network Attach Procedure

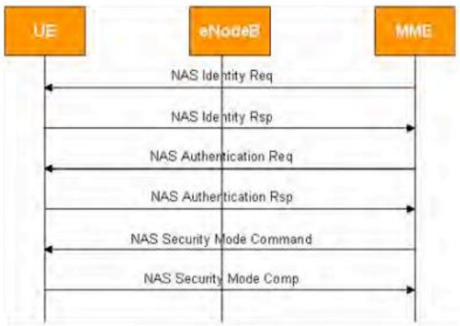

Figure 10. *NAS Common Procedures*

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[2] Protocol Signaling Procedures in LTE - Radisys

Chained Requests (Control Plane)

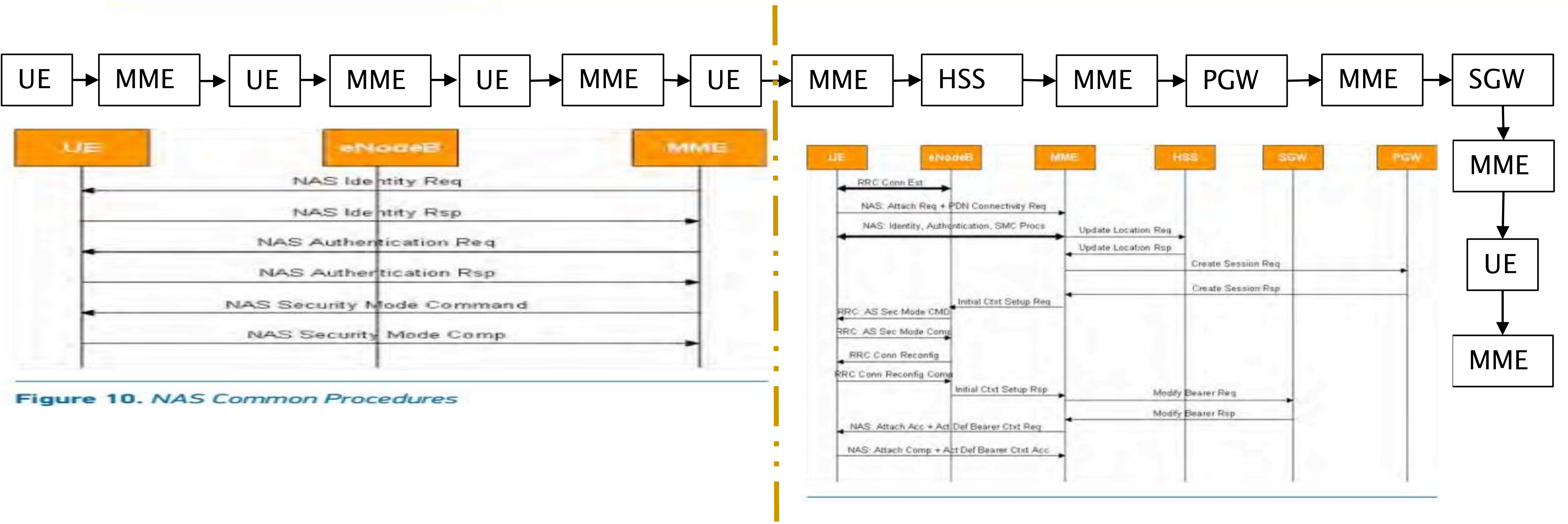

Figure 10. *NAS Common Procedures*

Control Plane Service Chain with EPC elements only

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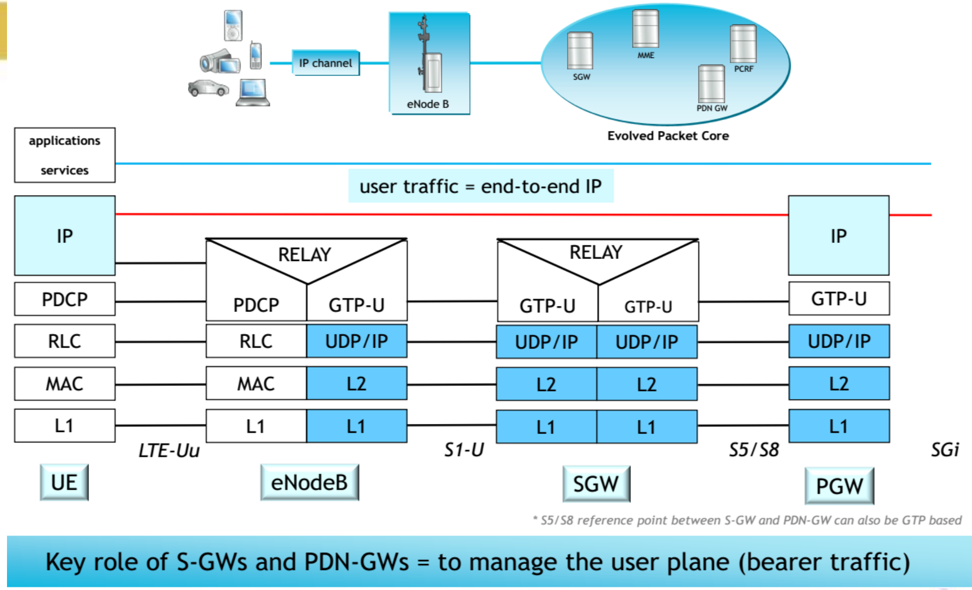
[2] Protocol Signaling Procedures in LTE - Radisys

Chained Requests (Control Plane + Data Plane)



Downlink Chain

MME → HSS → MME → PGW → MME → SGW → MME → PGW → SGW

Uplink Chain

MME → HSS → MME → PGW → MME → SGW → MME → SGW → PGW

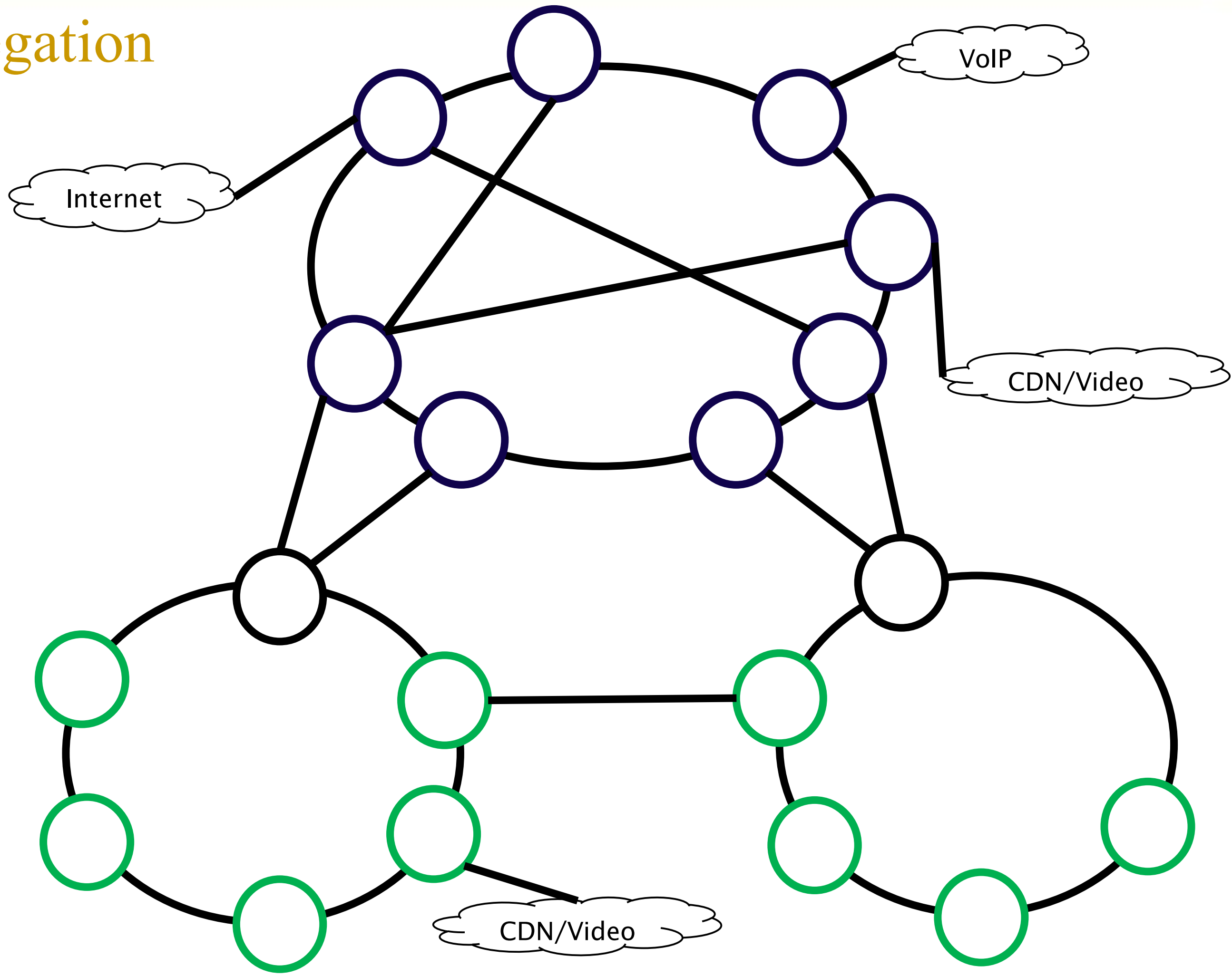
1] Introduction to Evolved Packet Core (EPC) – EPC elements, protocols and procedures –

Problem Statement

- To determine the placement of mobile core element VNFs and traffic routing to minimize the network-resource (bandwidth) consumption, given:
  - Network topology, capacity of links
  - Set of NFV nodes
  - Number of NFV nodes that can be used
  - Aggregated traffic flows
    - Using a Non-Access Stratum (NAS) procedure (attach, handover)
    - Requesting a service (voice, video, data)
  - Number of Replicas of each VNF
  - Latency requirement of services
  - Latency requirement of control signaling
  - Processing delay of VNFs
  - Propagation delay

Modeling

Traffic Aggregation Point (TAP)



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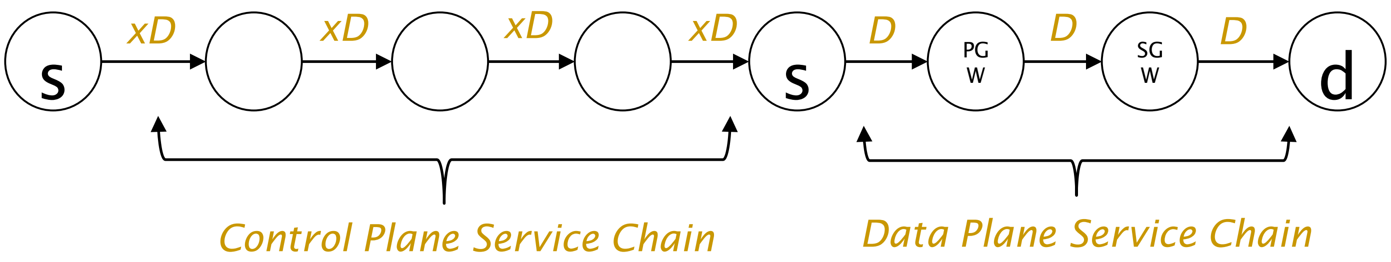
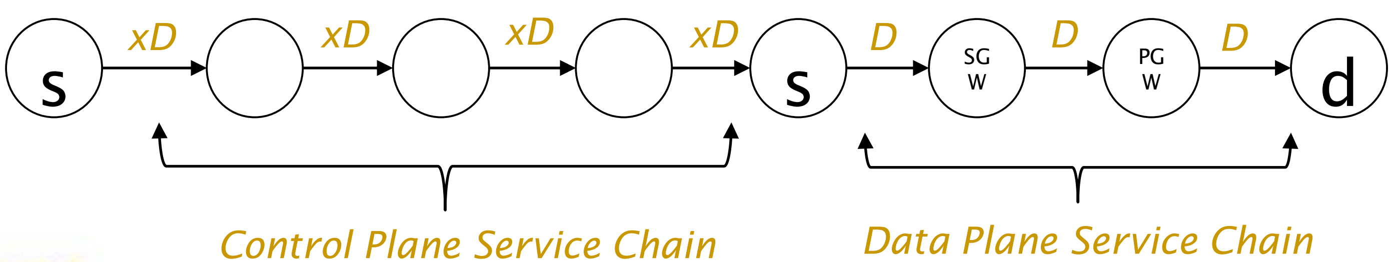
- Aggregated traffic flows from and to Traffic Aggregation Points (TAPs) with data plane traffic (*D*) and control plane traffic being a fraction of it (*x*D*)

  - Download with NAS procedure (DNAS)



  - Upload with NAS procedure (UNAS)



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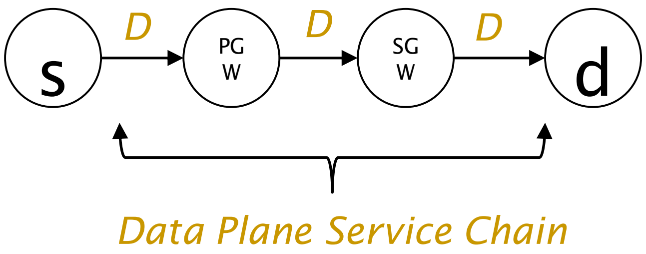
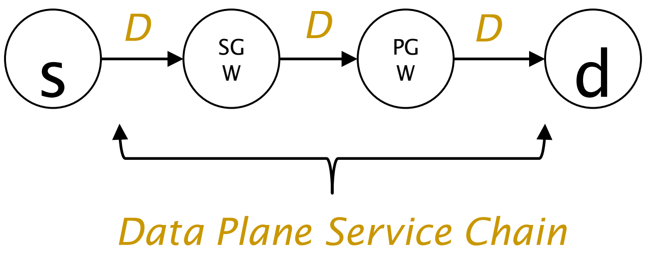
- Download (DL)



- Upload (UL)



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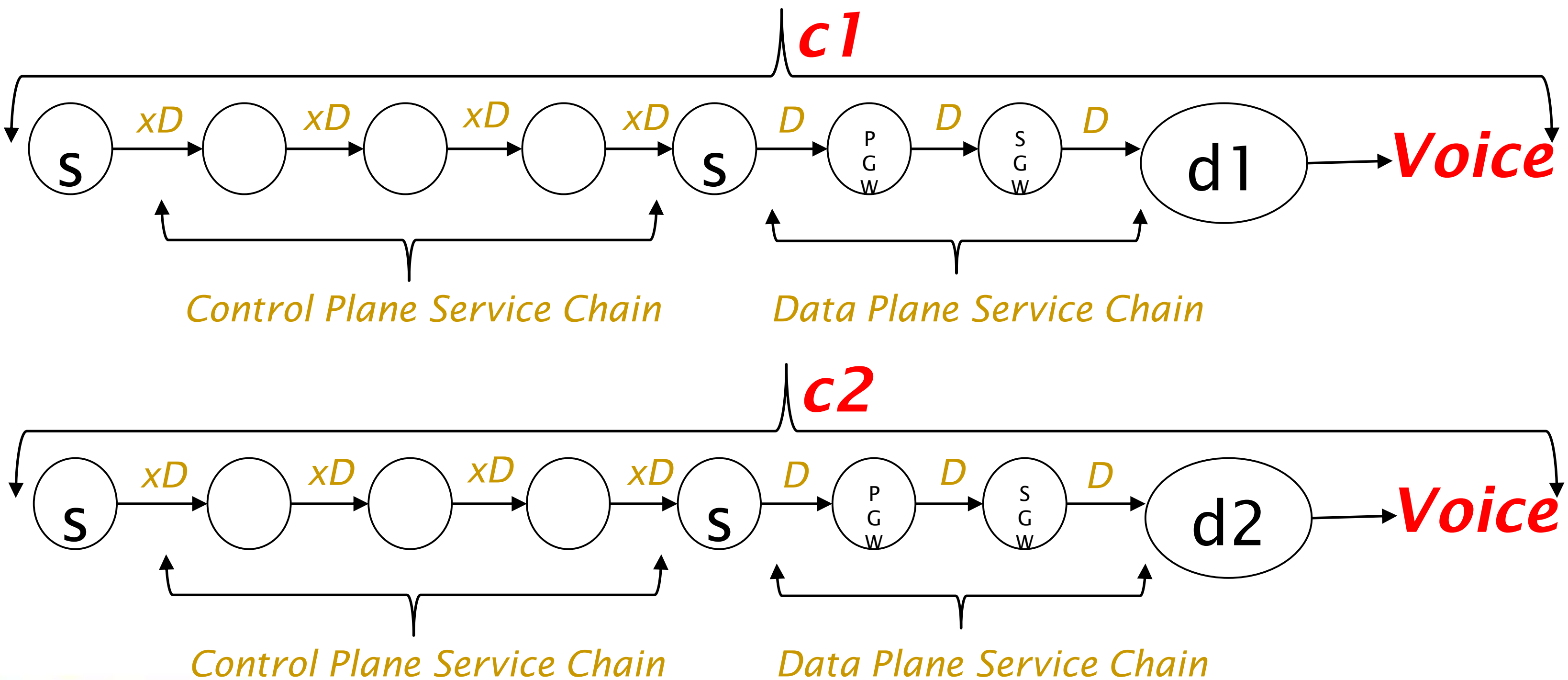
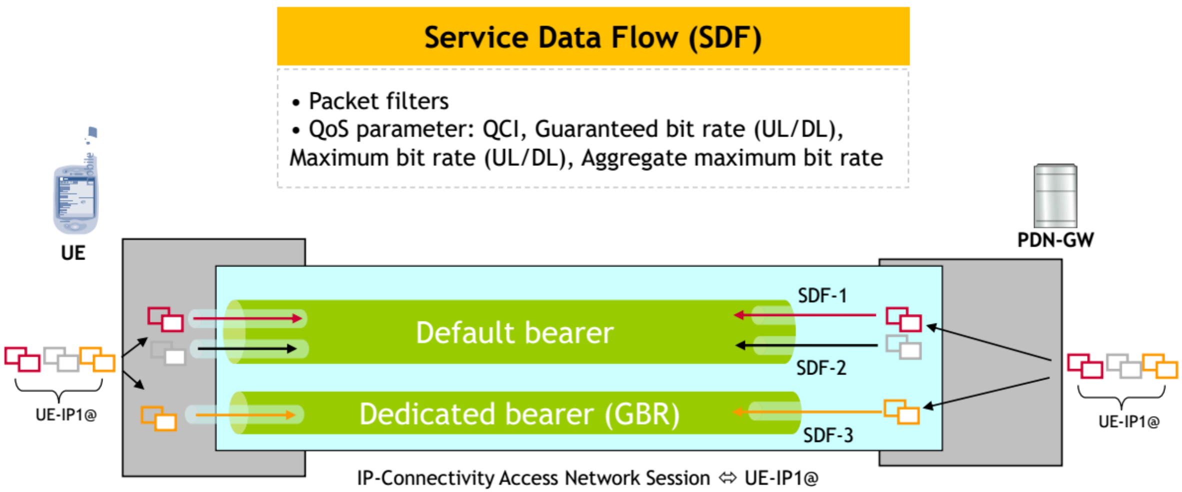
- To simplify modeling, each aggregated traffic flow, NAS procedure, uplink/downlink, application request is considered a distinct service chain, where source (s) and destination (d) are also VNFs with location constraints



Latency

- Control Plane Latency
  - Bearer Setup Latency
    - Default Bearer (Attach NAS Procedure) – 500ms
    - Dedicated Bearer (Service Request NAS Procedure) – 250 ms



- The PGW needs to support fine-granularity of QoS and charging enforcement functions beyond transport / bearer level
  - Multiple Service Data Flow (SDF) can be aggregated onto a single EPS bearer
  - Uplink and downlink packet filters are defined for each bearer, and QoS enforcements are applied

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- Data Plane Latency
  - Propagation delay
  - Processing delay

Table 1: Mean packet processing delay

no. of Tunnels	10	100	1 K	10 K
bits/sec	1 M	10 M	100 M	1 G
packets/sec	83	830	8.3 K	83 K
Virtualized GW T_{proc}	62 μs	83 μs	109 μs	132 μs
Decomposed GW T_{proc}	15 μs	15 μs	15 μs	15 μs

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[2] Applying NFV and SDN to LTE Mobile Core Gateways; The Functions Placement Problem – A. Basta, W. Keller, M. Hoffmann, H. J. Morper, K. Hoffmann

Delay Budget for Applications

Delay Budget for Applications-3GPP TR23.401 V8.1.0

QCI Value	Resource Type	Priority	Delay Budget (1)	Error Loss Rate (2)	Example Services
1 (3)	GBR	2	100 ms	10^{-2}	Conversational Voice
2 (3)		4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3 (3)		3	50 ms	10^{-3}	Real Time Gaming
4 (3)		5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5 (3)	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6 (4)		6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (3)		7	100 ms	10^{-3}	Voice, Video (Live Streaming), Interactive Gaming
8 (5)		8	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p sharing, progressive download, etc.)
9 (6)		9			

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[3] LTE Design and Deployment Strategies – Z. Savic, Cisco

vEPC Data Details - 1

Table 2 summarizes the general requirements of vEPC. Some deployments could be smaller while others larger. While some KPIs such as session count, total bandwidth requirement could vary based on size of the deployment, others stay constant. Important KPIs to pay attention to are packet loss, jitter and latency.

Critical Parameters	Values
Number of sessions	~ 1 to 10 Milions
Gateway total bandwidth	~ 10 to 100 Gbps
Bandwidth/users	10-50 Mbps
Packet loss	~ 1%
Jitter	10 – 30 ms
Data Plane Latency for critical Apps	~50 ms
Initial session attach	~500 ms

Critical Parameters	Values
Encryption support	Desired in hardware
Control plane events/ sec	~ 5000/sec
User plane packet/ sec	~5 Million Packet/sec
Packet size	Varies (typically 64 to 1500)
QoS classes to support different traffic types	>5 (3GPP defines 9 classes)

Table 2: vEPC Traffic Profile (Source: OPNFV Summit 2016)

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[4] NFV reference architecture for deployment of mobile networks – Red Hat Linux, Jan 2017

vEPC Data Details - 2

Market design parameters		
	Operational network values	Empirical values emulated
Number of subscribers in market	50,000	50,000
Busy hour tonnage (GB)	224	119
Default bearers (APNs) per subscriber	2.5	1.0
Total number of default bearers	125,000	50,000
Number of eNodeBs in market	400	4
Number of eNodeBs per TA	30	4

Subscriber busy hour control plane signaling model			
Control plane event type	Number of busy hour events	Operational network rate (event/s)	Empirical rate emulated (event/s)
Attach	10,000	3	1000
Bearer setups	225,000	63	1000
Connected-to-idle transitions (inactivity)	225,000	63	1000
X2-based handovers	200,000	56	1000
S1-based handovers	5000	1	1000
Tracking area updates (mobility)	10,000	3	1000
Detach	10,000	3	1000

Table 1. Market design and signaling model.

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[5] High-Performance Evolved Packet Core Signaling and Bearer Processing on General-Purpose Processors – Sprint, Intel, Connectem, NG4T - 2015

vEPC Data Details - 3

NG40 load profile packet rate calculations						
Downlink						
Packet rate/ 1000sec	Number of user/ traffic group	Packet size (Bytes)	Overhead S1u + mac + eth Bytes	Packet rate Pkts/sec	L3 (IP) throughput Mb/s	L2 (eth) throughput Mb/s
26,963	10,000	64	74	269,630	138.051	297.672
56,800	10,000	1426	74	568,000	6,479.744	6,816.000
3638	10,000	1426	74	36,380	415.023	436.560
15,285	10,000	1000	74	152,850	1,222.800	1,313.287
10,854	10,000	1000	74	108,540	868.320	932.576
	Average	1004		1,135,400	9,123.938	9,796.094
					Overhead %	7.37%
Uplink						
13,482	10,000	64	74	134,820	69.028	148.841
28,400	10,000	1426	74	284,000	3,239.87	3,408.000
1819	10,000	1426	74	18,190	207.512	218.280
7643	10,000	1000	74	76,430	611.44	656.687
5427	10,000	1000	74	54,270	434.16	466.288
	Average	1004		567,710	4,562.01	4,898.10
					Overhead %	7.37%

Subscriber busy hour user plane traffic model	
User plane traffic type	**Share of tonnage %**
Progressive video	71.19%
Video conferencing	4.56%
VOIP	1.50%
Media downloads	13.30%
Non-real-time applications (web, email)	9.45%
Total	**100.00%**

Table 2. NG40 D/L, U/L packet rate calculations and user plane traffic model.

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[5]High-Performance Evolved Packet Core Signaling and Bearer Processing on General-Purpose Processors – Sprint, Intel, Connectem, NG4T - 2015

CPU-to-throughput Relationship

Table 1: Examples of Brocade vEPC performance with different numbers of physical cores.

		21 cores[1]	36 cores[1]	54 cores[1]
Control Plane Performance	Simultaneous Attached Users (SAUs)	1 million	2 million	3 million
	Number of bearers	1.2 million	2.4 million	3.6 million
	Attaches per second	3,500	7,000	10,500
Data Plane Performance	Throughput[2] (Gbps)	10	20	30

Notes:
[1] Physical cores.
[2] Throughput measured with IMIX traffic.

[6] Data Sheet Brocade vEPC

Mobile Backhaul Bandwidth

Mobile Backhaul Bandwidth – Last Mile

Considerations

- Use <u>quiet time peak</u> for each cell
- Not all cells will peak at same time- Factor this for 3/6 sector eNB
- Microwave – Number of hops, total bandwidth
- Access ring will have dual homing to pre-agg

All values in Mbps — Scenario, from TUDR study		Single Cell: Mean (as load-> infinity)	Single Cell: Peak (lowest load)	Single base station Tri-cell Tput: busy time mean	Single base station Tri-cell Tput: peak	X2 Overhead (overhead 4%): busy time mean	X2 Overhead (overhead 4%): peak	Total U-plane + Transport overhead — No IPsec (overhead 10%): busy time mean	No IPsec (overhead 10%): peak	IPsec (overhead 25%): busy time mean	IPsec (overhead 25%): peak
DL	1: 2x2, 10 MHz, cat2 (50 Mbps)	10.5	37.8	31.5	37.8	1.3	0	36.0	41.6	41.0	47.3
DL	2: 2x2, 10 MHz, cat3 (100 Mbps)	11.0	58.5	33.0	58.5	1.3	0	37.8	64.4	42.9	73.2
DL	3: 2x2, 20 MHz, cat3 (100 Mbps)	20.5	95.7	61.5	95.7	2.5	0	70.4	105.3	80.0	119.6
DL	4: 2x2, 20 MHz, cat4 (150 Mbps)	21.0	117.7	63.0	117.7	2.5	0	72.1	129.5	81.9	147.1
DL	5: 4x2, 20 MHz, cat4 (150 Mbps)	25.0	123.1	75.0	123.1	3.0	0	85.8	135.4	97.5	153.9
UL	1: 1x2, 10 MHz, cat3 (50 Mbps)	8.0	20.8	24.0	20.8	1.0	0	27.5	22.8	31.2	26.0
UL	2: 1x2, 20 MHz, cat3 (50 Mbps)	15.0	38.2	45.0	38.2	1.8	0	51.5	42.0	58.5	47.7
UL	3: 1x2, 20 MHz, cat5 (75 Mbps)	16.0	47.8	48.0	47.8	1.9	0	54.9	52.5	62.4	59.7
UL	4: 1x2, 20 MHz, cat3 (50 Mbps)*	14.0	46.9	42.0	46.9	1.7	0	48.0	51.6	54.6	58.6
UL	5: 1x4, 20 MHz, cat3 (50 Mbps)	26.0	46.2	78.0	46.2	3.1	0	89.2	50.8	101.4	57.8

Total BW = DL + UL (20MHz, 2X2 DL MIMO, 1X2 UL MIMO) 105.3+42 ~ 145 Mbps

[3] LTE Design and Deployment Strategies - Z. Savic, Cisco

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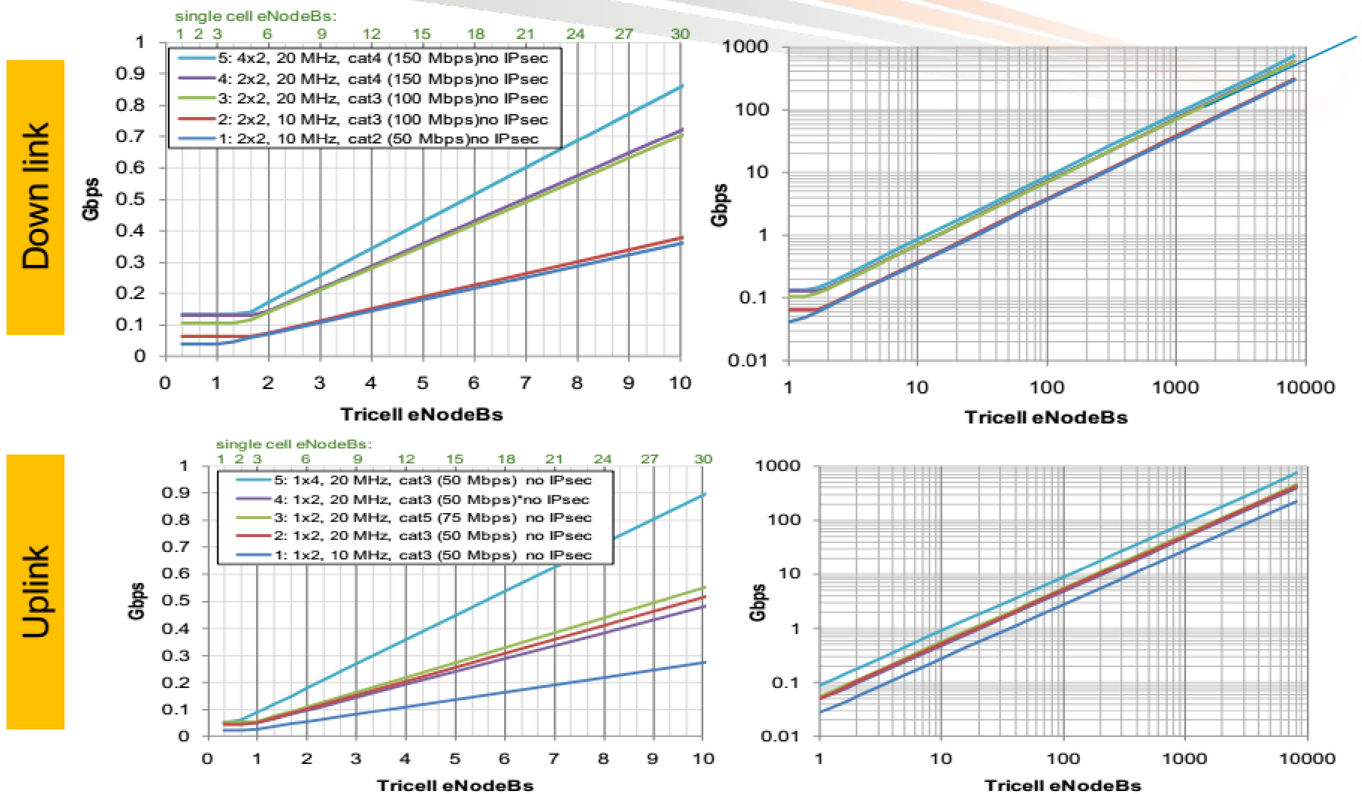
Mobile Backhaul Bandwidth – Agg & Core



Total BW = DL + UL ; For 10,000 eNB (Tricell) = 700+500 = 1200 Gbps

Per eNB in Core ~ 1200/10,000 ~ 120 Mbps

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Results

- Reduction in bandwidth consumption as
  - Number of NFV Nodes increase
    - Where are these nodes?
    - How much compute capacity needs to be installed?
    - How many nodes provide a trade-off point
  - Number of VNF Replicas increase
    - Which VNFs are most distributed and centralized?

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