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Flexible Ethernet Fronthaul

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intelligent Converged Network consolidating Radio and optical access aRoundUSer equipment

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- Nathan Gomes

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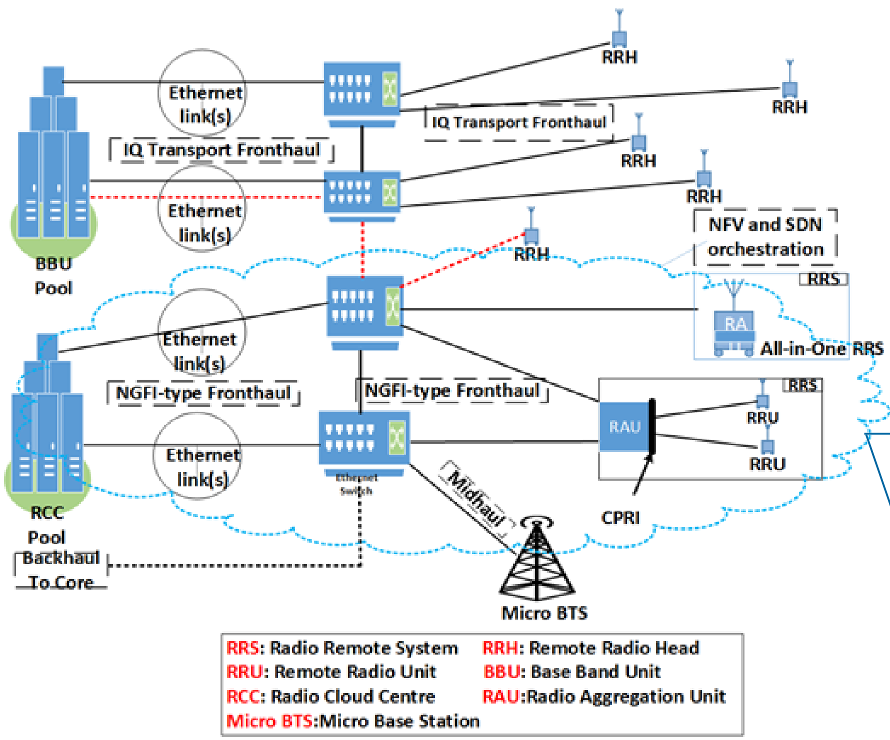
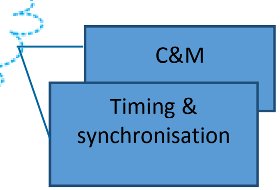
Introduction: Fronthaul Architecture





*Definitions from China Mobile *et al (see* White Paper of Next Generation Fronthaul Interface*)*

Advantages of Ethernet:

- Ubiquitous, potentially low cost technology.
- Can aid structural and operation convergence (x-haul)
- Fully standardised (including OAM)
- Agnostic

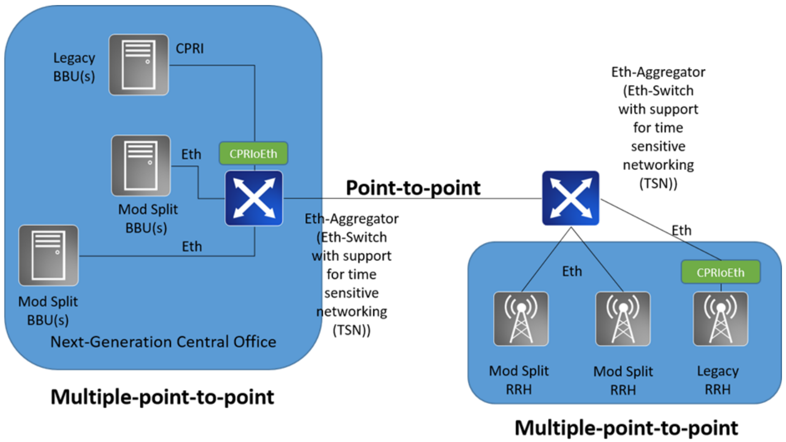
Disadvantages of Ethernet:

- Lack of sync in native form
- Latency and latency variation

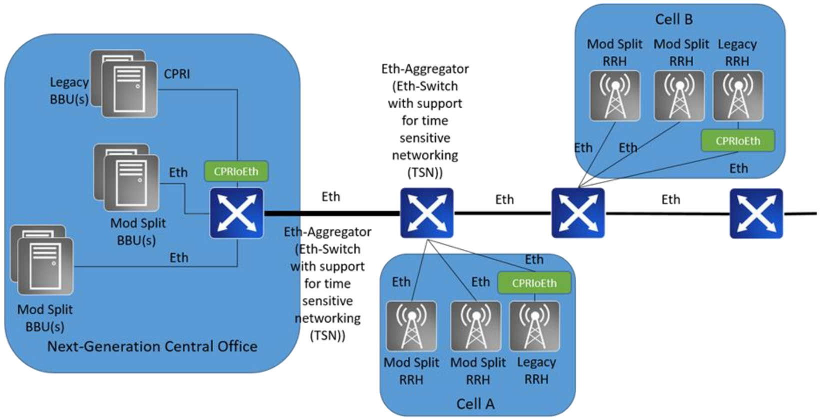
BBU ➔ RRH
Centralised processing, CPRI or generic I/Q transport

RRC (DU) ➔ RAU, all-in-one RRS (RU)
Variable functional split

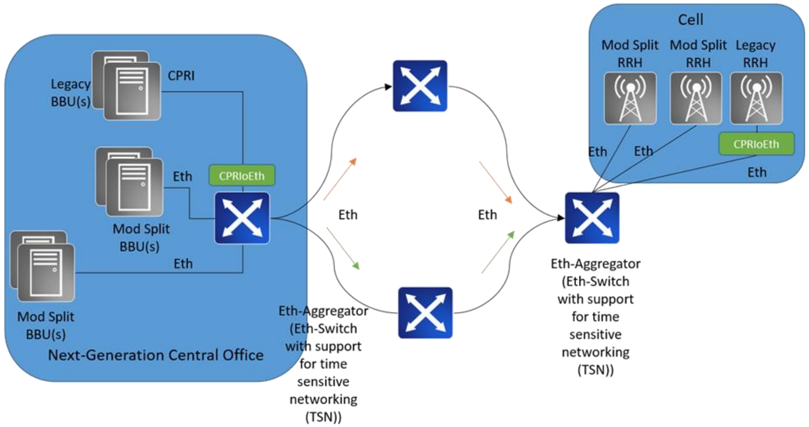
Mixed Traffic/ Multiple Topologies



Point-to-point and multiple point-to-point (star) topology (aggregator)

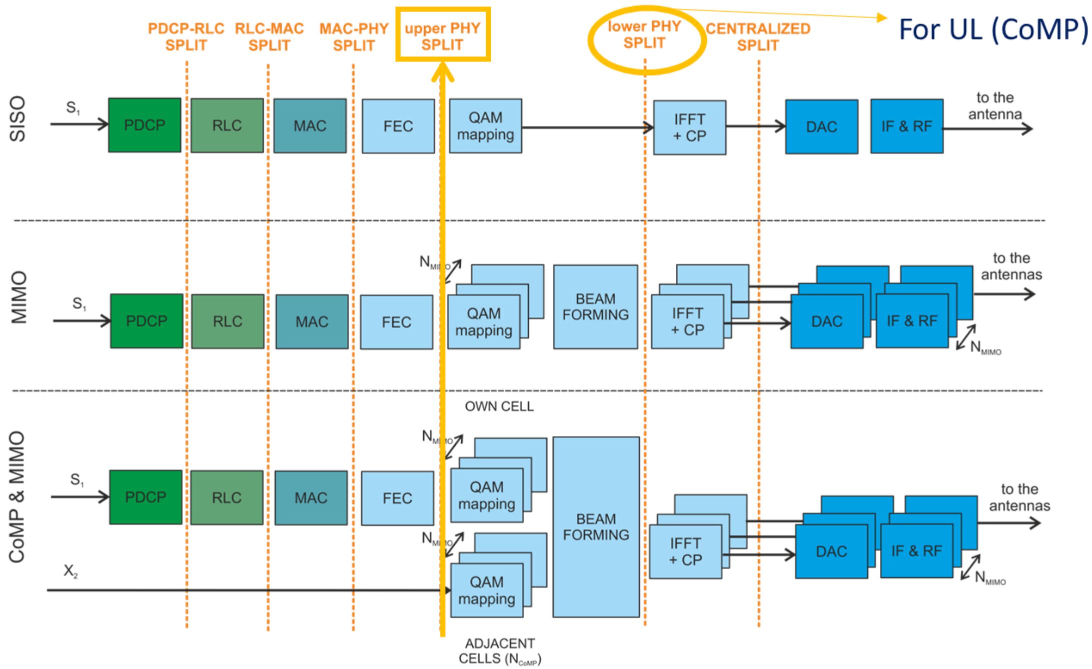


Tree topology (add and drop)



Ring topology (redundancy)

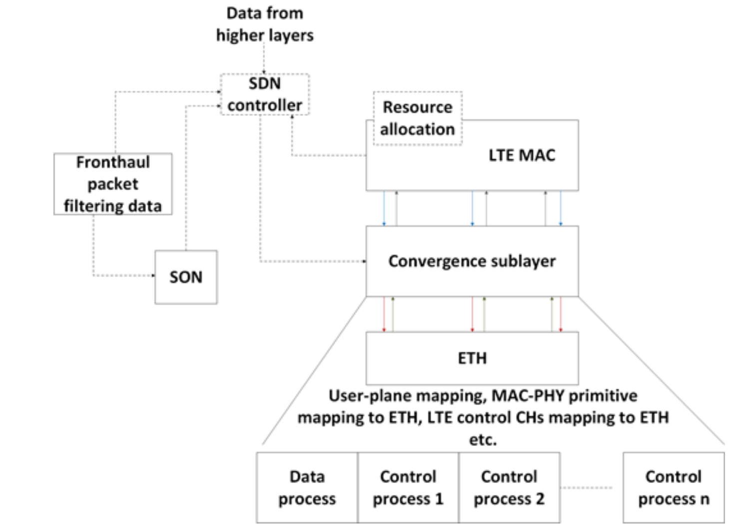
Why Flexible Split?



Fundamentally, different use-cases:

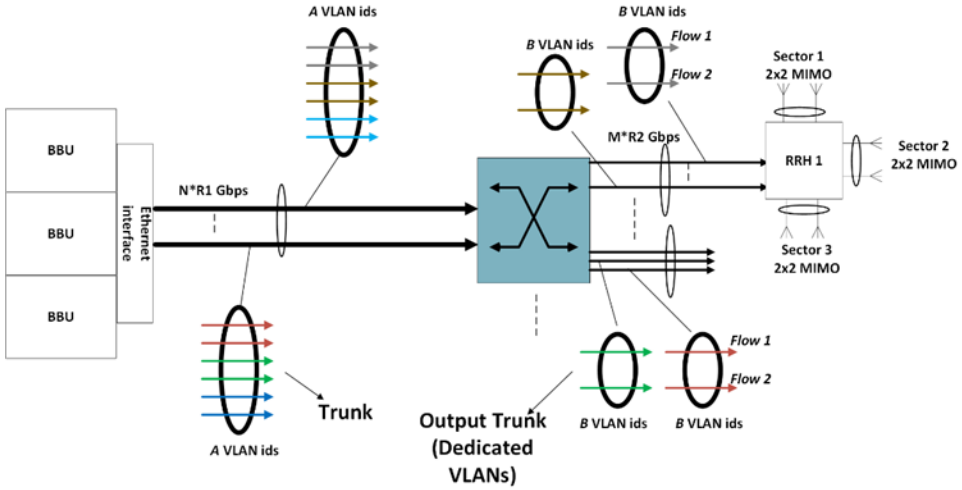
- ✓ *Coordinated techniques*
- ✓ *Mixed traffic KPI performance*
- ✓ *Multi-operator shared infrastructure*
- ✓ *Can exploit traffic temporal characteristics*
- ➢ *Statistical mux gains*

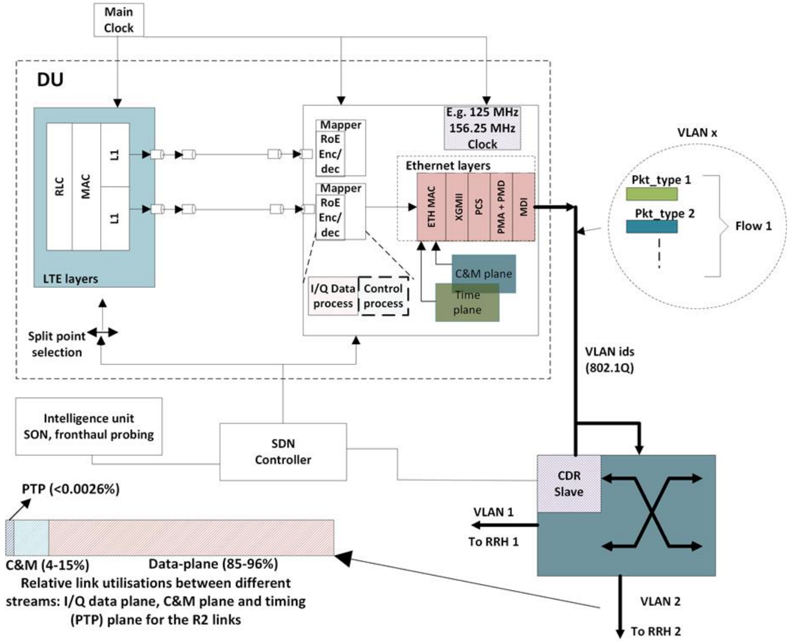
Example Architecture



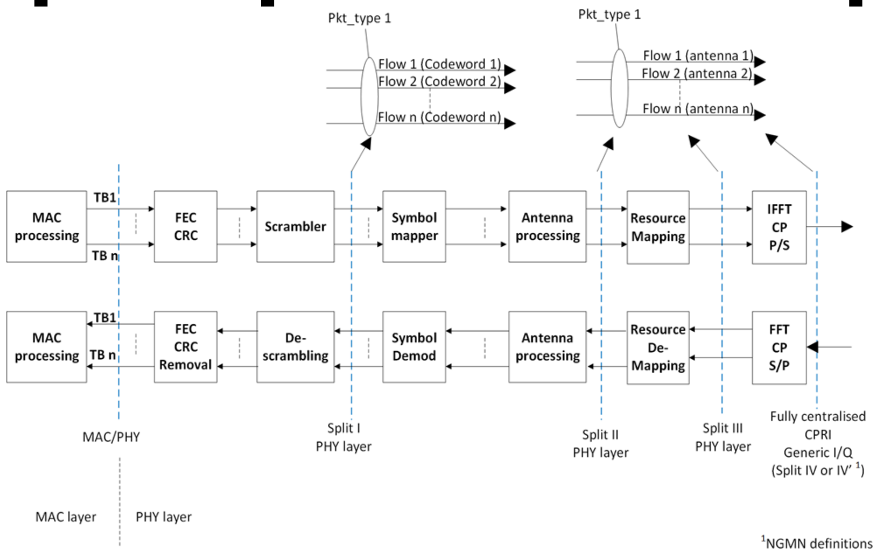
Design aspects:

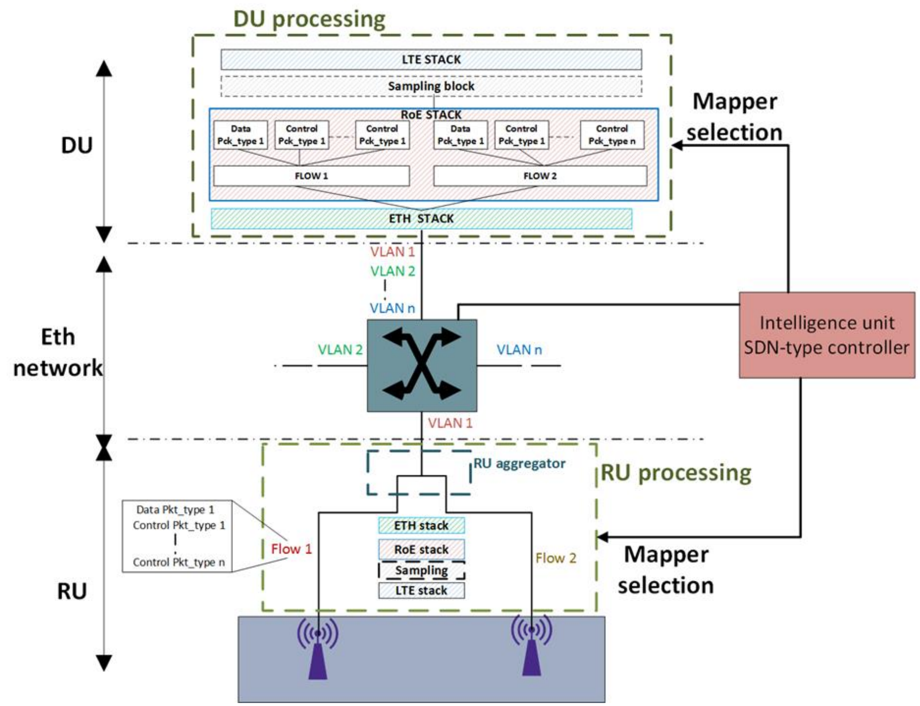
- Use concept of *VLAN Trunking*.
- Pure L2 architecture, with PTP (and assumed SyncE) and C&M planes.
- RoE-based mapping
- VLAN ID addressing of RRHs and flow IDs for antennas.
- SDN-type intelligent unit/SON/Ethernet packet probing





Split Options and Mappers





Num_IQ_samples_per_Container = N_{RB} x N_{RE} // Total number of REs used for data per PDSCH queue.

IQ_sample_length=2 x S_j //two times sample length for I and Q

Max_RoE_payload_size $\geq 2\sum_{1}^{k}\left(\sum_{j=1}^{Num\_IQ\_samples\_per\_Container} k\, S_j\right)$

RoE.numContainers= Num_MIMO

RoE.container[0….Num_MIMO-1].lenContainer= $2\sum_{j=1}^{Num\_IQ\_samples\_per\_Container} S_j$

RoE.numSegments=k where k|Num_users //Defines the number of PDSCH queues inserted into the payload section of each packet. For K>1 more than one queue worth of samples is inserted in a packet. K divides Num_users.

RoE.container[0…. Num_MIMO -1].flow_id=1,…., Num_MIMO

RoE.segment.flow_ids=1… Num_MIMO

seqNumMin=1

seqNumMax= Num_user // will depend on number of allocations per TTI and will be different every TTI i.e. sequence wraps around every TTI. The sequencing is used to synchronise the equivalent queues at the RU i.e. packet for first queue will have the lowest SN while packet for the last queue will have the highest SN.

seqNumIncrement= k

← Mapper Example for Split II, PDSCH based on RoE

Data Rate Requirements Per RU/Sector

Uplink data rates assuming 8 antennas and 100 MHz BW. For Splits I & II the sample resolution is 8 bits

Split selection	Sector load		
	20%	50%	100%
	Data rate /Gbps		
Split III	12.2	12.2	12.2
Split II	2.5	6.1	12.2
Split MAC/PHY[1]	0.2	0.5	1

[1]Two layers

Assumptions:

- ETH encapsulation overhead
- RoE overhead=10 octets
- 64B/66B encoding
- 6% C&M overhead
- PTPv2.

Preliminary Fronthaul Requirements for 5G

Fronthaul Requirements	Different kind of traffics supported by the evolved fronthaul			
	Legacy traffic (CPRI)	upper-PHY split in down and uplink (no CoMP)	upper-PHY split in downlink lower-PHY split in uplink (CoMP)	PDCP-RLC split
Data rate[1]	100 to 400 Gbps			
Max. latency (round-trip-delay)	150 µs (CoMP) 440 µs (no CoMP)	440 µs	150 µs	60 ms
Min. frequency accuracy	+/- 2 ppb (per hop)	+/- 2 ppb (per hop)	+/- 2 ppb (per hop)	+/- 2 ppb (per hop)
Min. phase and timing accuracy	+/- 10 ns (MIMO & TX diversity) +/-1.36 µs (LTE TDD)	+/- 30 ns	+/- 30 ns	not already defined
Max. latency imbalance	+/- 16 ns	+/- 163 ns	+/- 163 ns	not already defined
Max. error	10^{-12} BER			10^{-6} FLR

[1]Assuming 5G type signals and based on estimation of future small-cell deployment scenario (Trunk data rate).

Latency important for proper HARQ operation and CSI aging.

Frequency accuracy important for CFO and SFO performance at radio side.

Phase/time important for MIMO and TX diversity

Latency imbalance Important for PTP performance (timestamp accuracy)

Error performance important for different packet types. Normal operation in Ethernet is to drop erroneous packets. Can use cut-through switching (end stations ?)

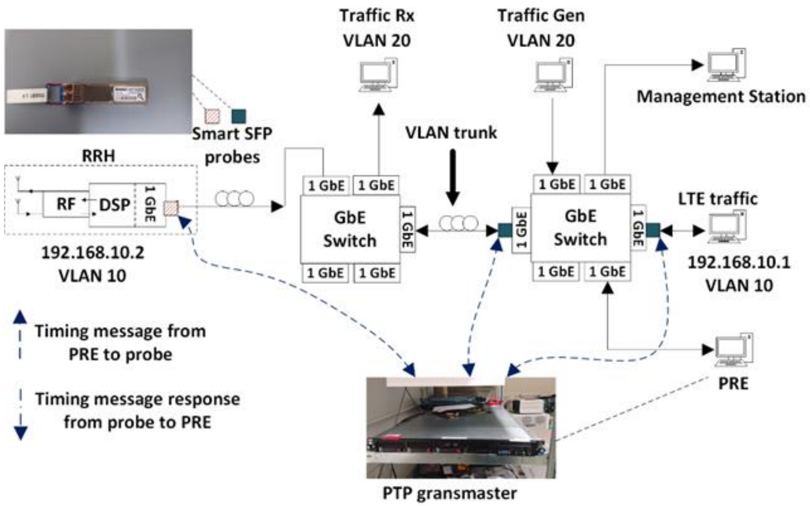
- *SyncE*
- *PTPv2 (new telecom profiles)/ 802.1AS*
- *TSN*

Dealing with Different Traffic Streams

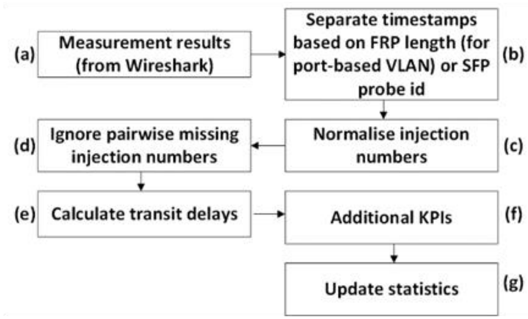
	Centralised (e.g. CPRI)	Split I	Split II	Split III/MAC-PHY
PDSCH	x	x	Low/Medium[5]	x
MAC control primitives	x	x	High	High
Transport blocks, DL (UL)	x	x	x	Low/Medium
PBCH	x	x	High[1]	x
PRACH	x	High[2]	High	High
Radio "slice" -time domain	High[3]	x	x	x
Data subcarriers-frequency domain	x	High[3]	x	x
PUCCH	x	x	Low/Medium	x
PUSCH	x	x	Low/Medium	x
DMRS	x	x	Low/Medium[4]	x

[1]When there is a master information block change (every 40 ms). Also dependent on implementation whether this channel is transported or whether it is generated at the RU through control primitives.
[2]Dropping PRACH frames will increase the delays in user access (for a number of users) and uplink resource grants.
[3]A frame drop will result in a whole radio slice being dropped as a worst case (potentially smaller effect as the slice may be divided amongst a number of frames based on frame size considerations).
[4]Implementation dependent. If transported as a block per TTI (encapsulated in a single Ethernet frame) it will have implications for all user allocations in that TTI.
[5]Implementation dependent. If a number of user queues are encapsulated in a single Ethernet frame, implications can be more severe.

Testbeds and KPIs

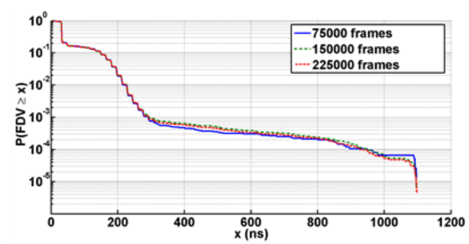


Algorithm for KPI extraction:



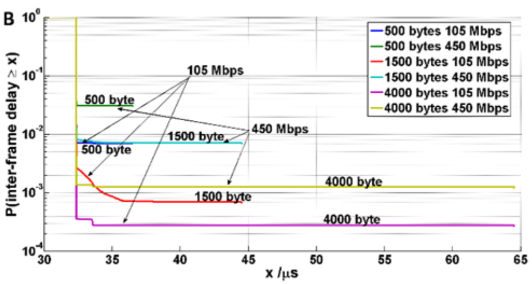
- PRE is a server that collects traffic information and extracts KPIs for performance monitoring.
- Different Switch schedulers

Frame delay variation:

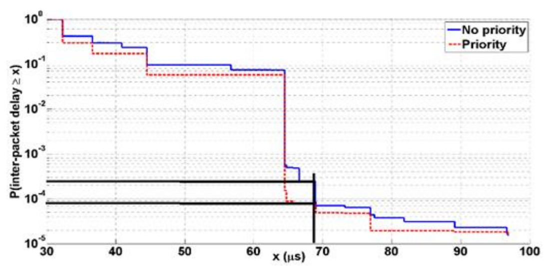


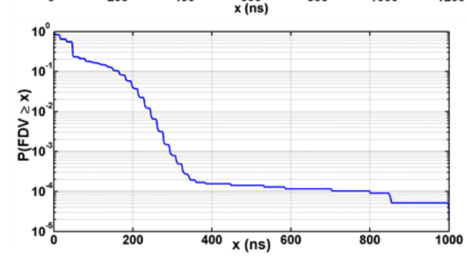
Single Switch:
m=52.9 ns
σ =53 ns

Inter-arrival delays:



Statistics for
buffer management:



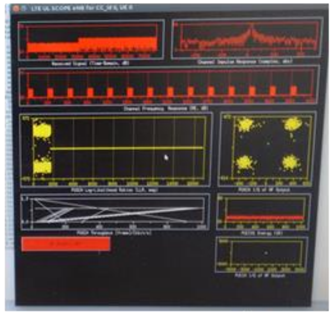


End-to-end:
m=55.7 ns
σ=60.1 ns

Testbeds and KPIs

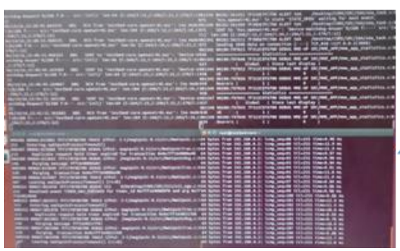
RU (PHY LTE, packetisation)

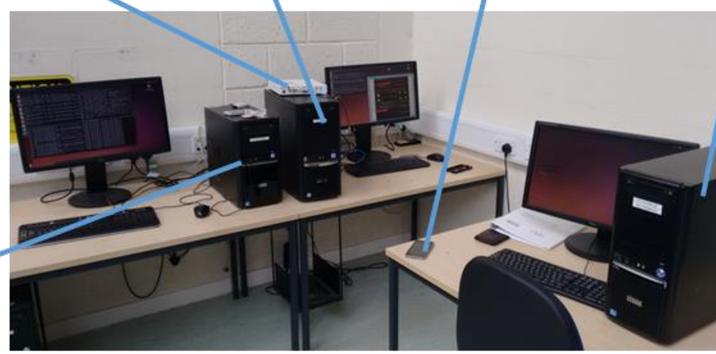
USRP (DSP, RF)



DU (>PHY LTE, packetisation)

EPC/eNodeB





- The ***Open Air Interface (OAI) software alliance*** is already in process of re-factoring code and implementing Split I.
- In-house development of MAC/PHY split and Split II in UL using OAI software.
- KPI extraction and performance monitoring
- Mixed traffic scenarios

Conclusion/Discussion

- Ethernet offers a number of advantages but also challenges regarding synchronisation, latency/latency variation and error propagation
  - Frequency & time/phase sync requirements become very stringent for 4G advanced features and 5G

- Multiple topologies are possible each with its own advantages/disadvantages
  - P2P/Star, Tree, ring

- A flexible functional split can be used for different use-cases
  - But more complicated design

- Dynamic KPI monitoring for performance evaluation with dynamic adaptation will be an important aspect for the NGFI
  - SON (longer time scales) and dynamic KPI extraction (shorter time scales) using pluggable "smart SFP" probes
  - Traffic steering/load balancing in fronthaul links, mapper selection

- TSN and new switch schedulers will need to be used. Current standardisation efforts include:
  - 802.1Qav Credit-based shaping
  - P802.1Qbv Time-aware shaping
  - P802.1 Qch Cyclic forwarding and queing
  - P802.1Qbu Frame preemption

Thank you
Any Questions?

iCIRRUS: D2.1 *iCIRRUS intelligent C-RAN architecture*, Jul. 2015
iCIRRUS: D3.1 *Verification of Ethernet as transport protocol for fronthaul/midhaul*, Jan. 2016
iCIRRUS: D3.2 *Preliminary Fronthaul Architecture Proposal*, Jul. 2016
(Available: www.icirrus-5gnet.eu/category/deliverables)

Also acknowledge:

http://www.intelligent-nirvana.net/

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