An SD-WAN Controller for Delay Jitter Minimization in Coded Multi-access Systems

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SD-WAN

“The software-defined wide-area network (SD-WAN or SDWAN) is a specific application of software-defined networking (SDN) technology applied to WAN connections to build higher-performance WANs using lower-cost and commercially available Internet access like broadband internet, 3G, LTE, enabling businesses to partially or wholly replace more expensive private WAN connection technologies.”

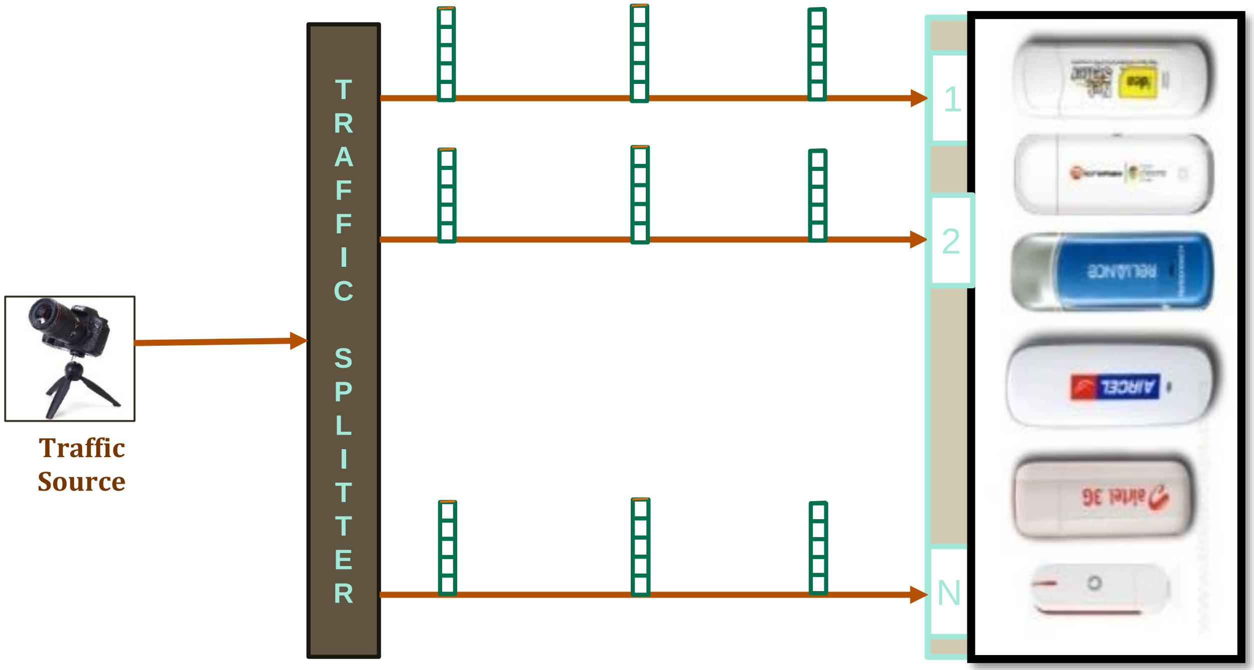
Fig: General representation of an SD-WAN

From: https://www.computertechreviews.com/definition/software-defined-wan-sd-wan/

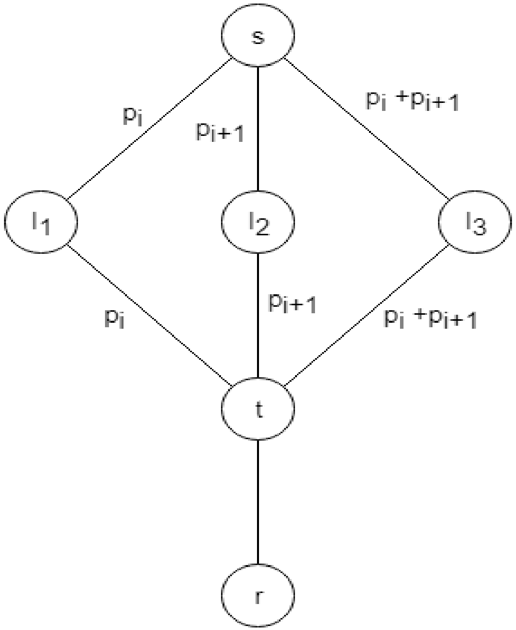
Our implementation

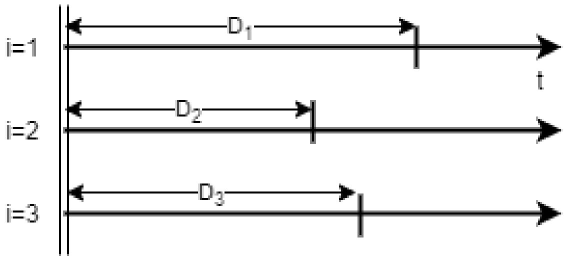
- APP layer agnostic
- Any UDP packet
- Not just LTE – any link
- **Auto adapts to links - RL**

Multiaccess



Interstream coding in Multiaccess





Effective Delay

$$D = \min(m, \{D_1, D_2, \cdots, D_{n+m}\})$$

m – original packets

n – extra (redundant) packets

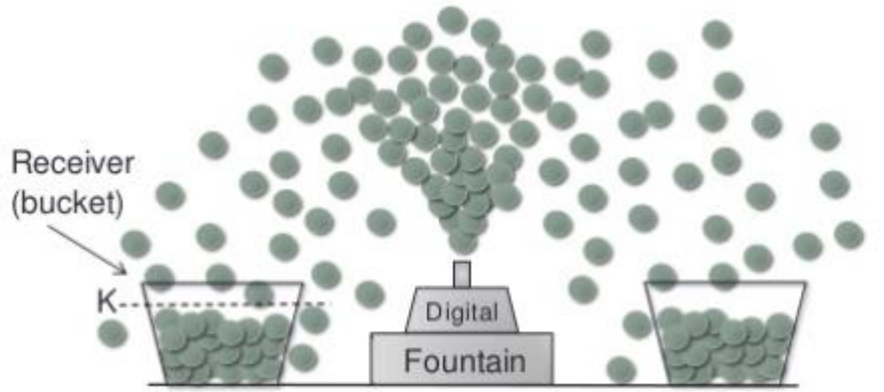
Interstream coding (cont'd) – Fountain codes

- From a given set of source packets, fountain codes can generate potentially limitless number of encoded packets.

- Original source symbols can ideally be recovered, from any subset encoded packets of size equal to the number of source packets.

Examples

- LT Codes – chances of recovery ~ 99%
  (Luby Transform)
- Linear Code – chances of recovery = 100%



From: https://www.slideshare.net/zemasa/fountain-codes

Interstream coding (cont'd) – Linear Codes

$$AX = B$$

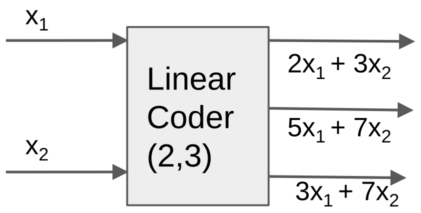
$$\begin{bmatrix} a_{11} & a_{21} & \cdots & a_{m1} \\ a_{12} & a_{22} & \cdots & a_{m2} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1n} & a_{2n} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix}$$

$$X = A^{-1}B$$

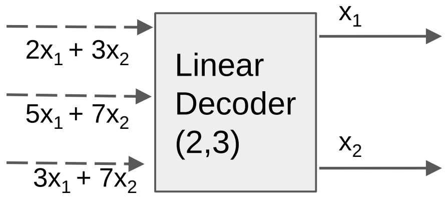
A = coefficient matrix

X = Vector of original packets

B = Vector of encoded packets

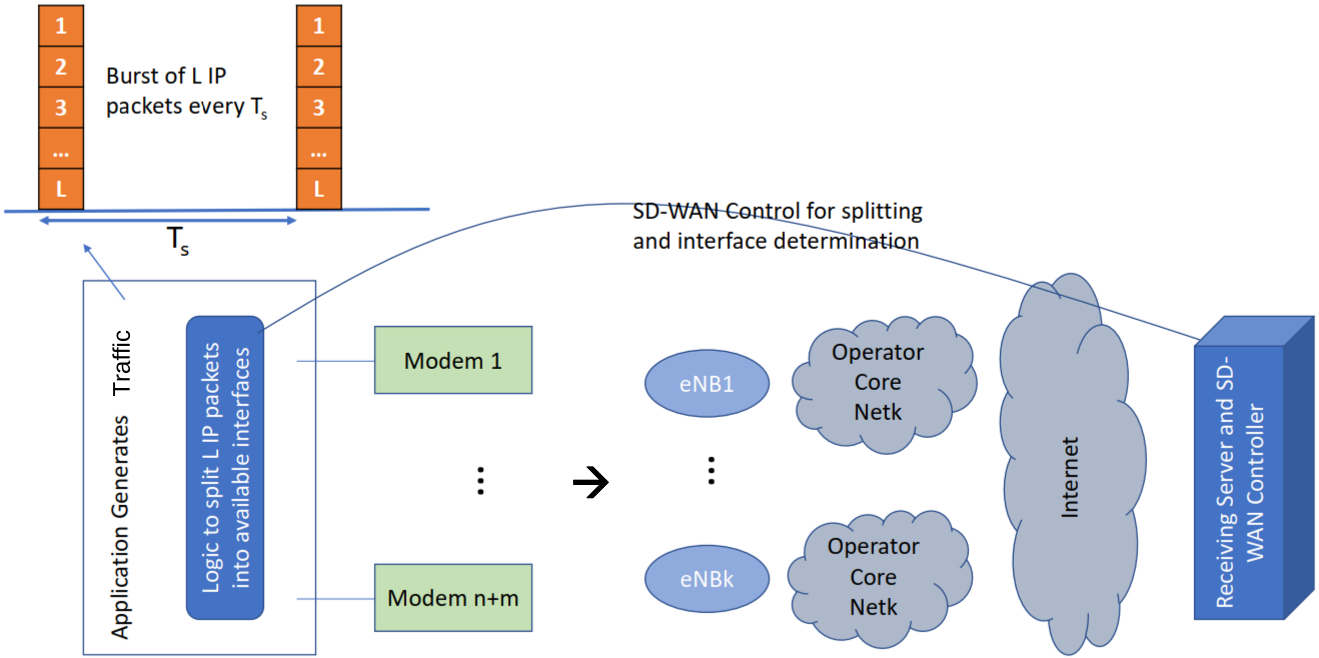


Interstream Coder



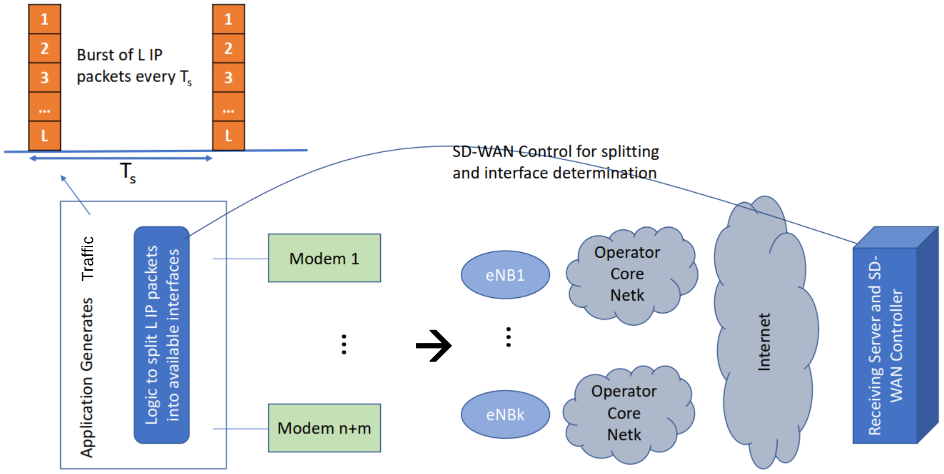
Interstream Decoder

Overview



1
2
3
...
L
Burst of L IP packets every T_s
1
2
3
...
L
T_s
SD-WAN Control for splitting and interface determination
Application Generates Traffic
Logic to split L IP packets into available interfaces
Modem 1
Modem n+m
eNB1
eNBk
Operator Core Netk
Operator Core Netk
Internet
Receiving Server and SD-WAN Controller

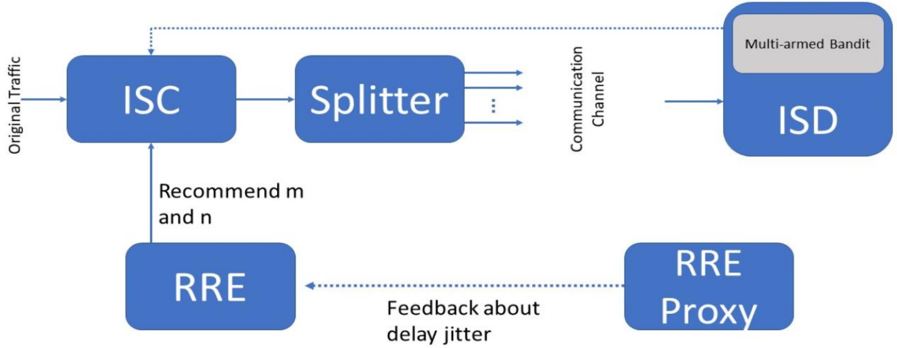
Adaptation



Three new challenges:

- Controlling the split of traffic into the available interfaces
- Controlling the redundancy level to achieve a target delay jitter performance
- Controlling the number of interfaces to be used for a given stream

Implementation – blocks



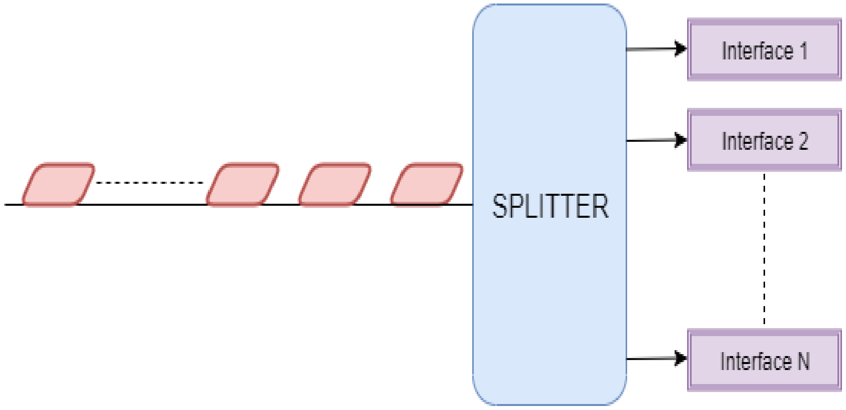
ISC – Interstream Coder

ISD – Interstream Decoder

RRE – Redundancy Recommendation Engine

Controlling the split of traffic into the available interfaces

- Probabilistic split
- Splitter selects each interface for the incoming packet with probabilities p $=\{p_1, p_2, \ldots, p_N\}$.
- $$\mathbf{p}(k+1) = \mathbf{p}(k) + \epsilon \frac{(\mathbf{p}(k) - softMax(k))}{||(\mathbf{p}(k) - softMax(k))||}$$
- k – update instant - 100 packets
- ||.|| is L_2 norm
- $softMax(k)$ is calculated on vector $\left(\frac{1}{j_1}, \frac{1}{j_2}, \cdots, \frac{1}{j_N}\right)$
- j_i is avg jitter of 100 packets of i^{th} interface

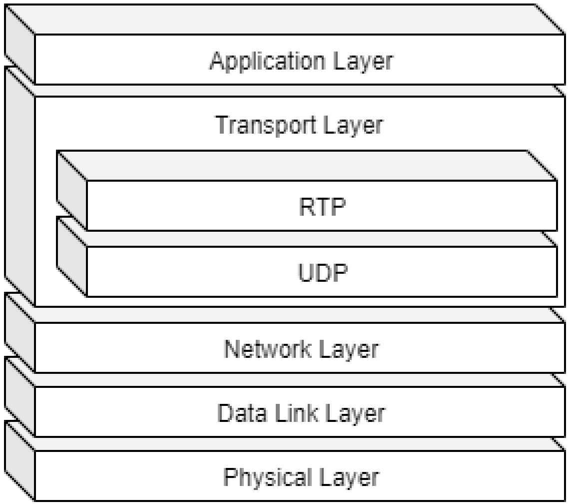


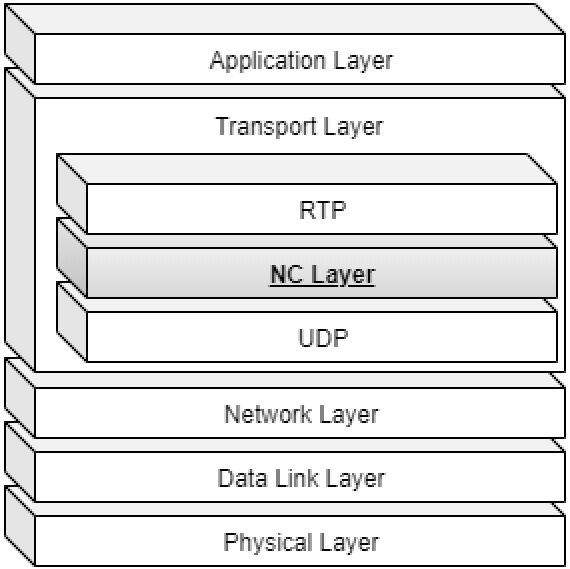
Controlling the redundancy level

- $m(t+1) = m(t) + \delta(t)$
- θ is a tolerance to avoid ping-pong effect.

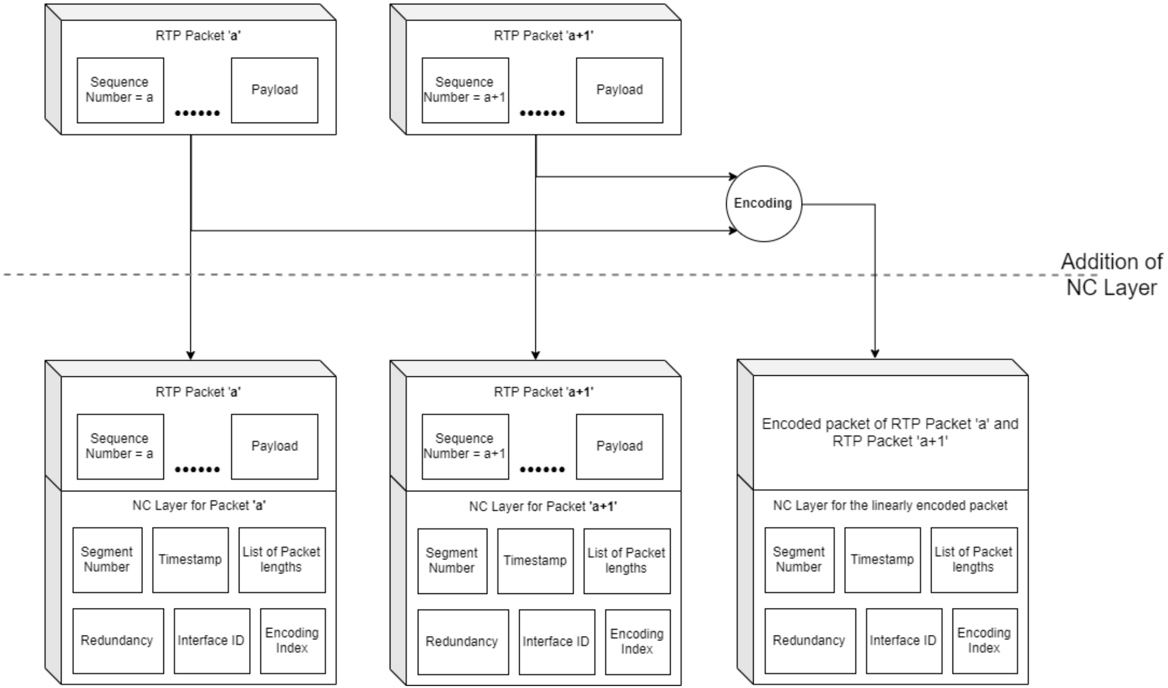
$m(t) - m(t-1)$	$J(t) - J(t-1)$	$\delta(t)$
>0	$<-\theta$	1
>0	$>\theta$	-1
<0	$<-\theta$	-1
<0	$>\theta$	1

Implementation - layer

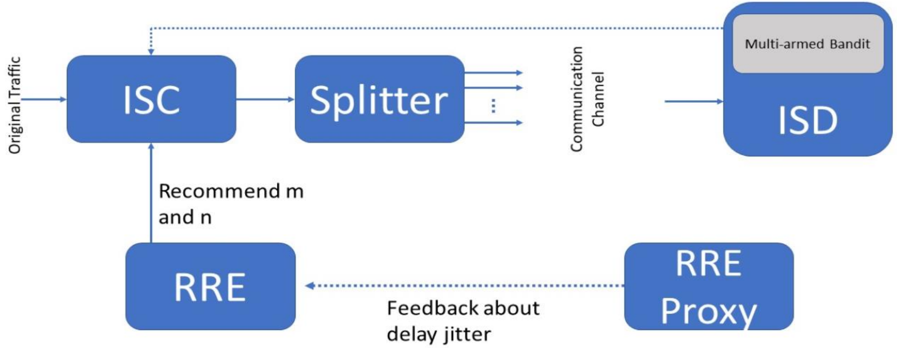




Implementation – header fields



Implementation – blocks



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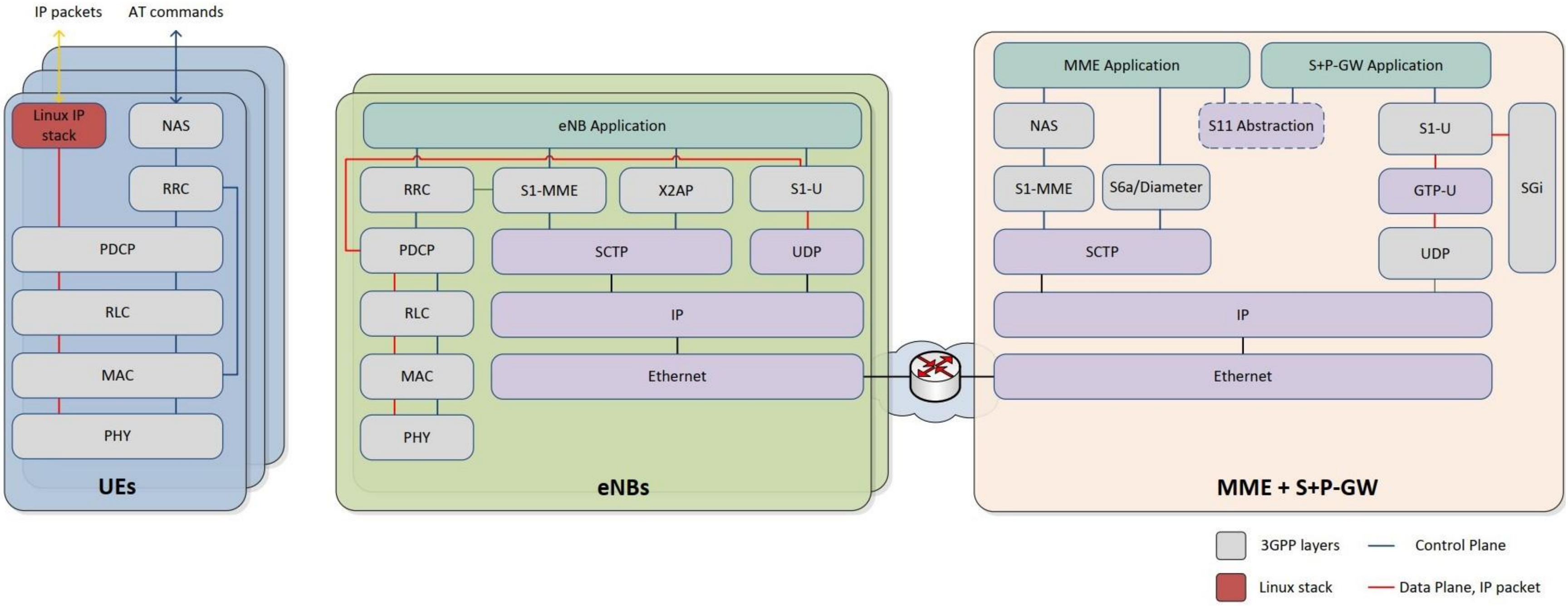
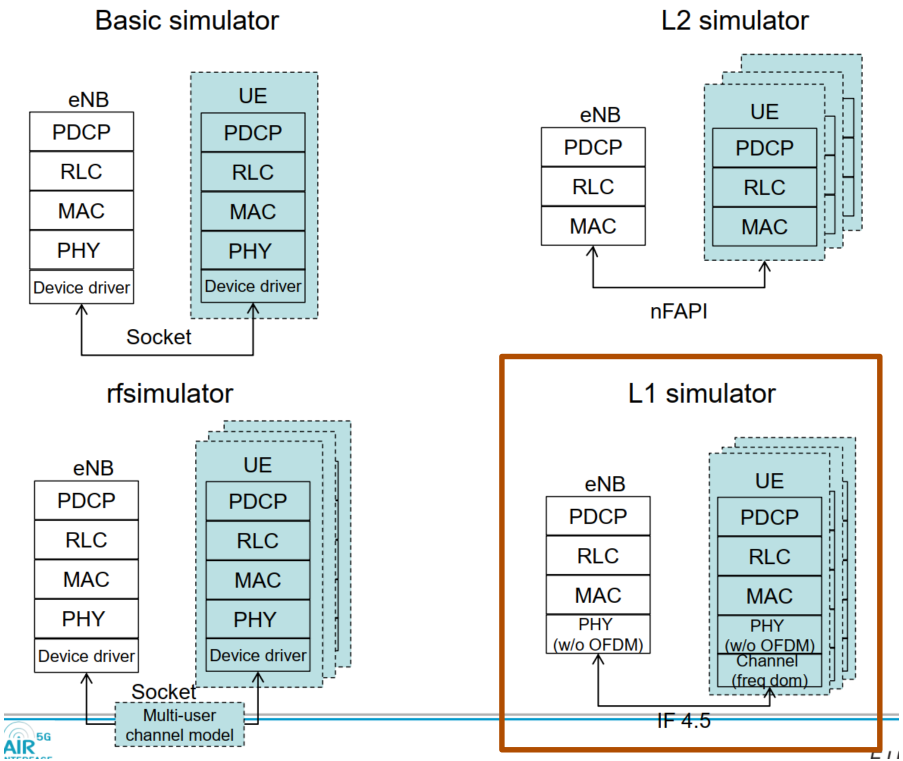
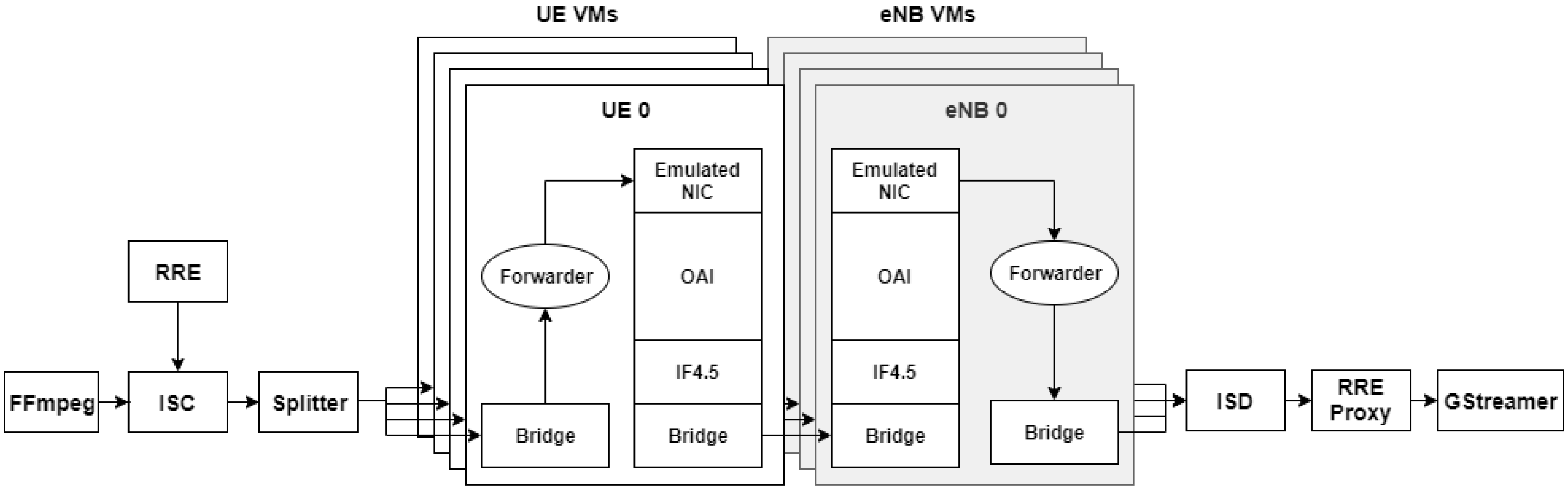
OpenAirInterface (OAI) by EURECOM



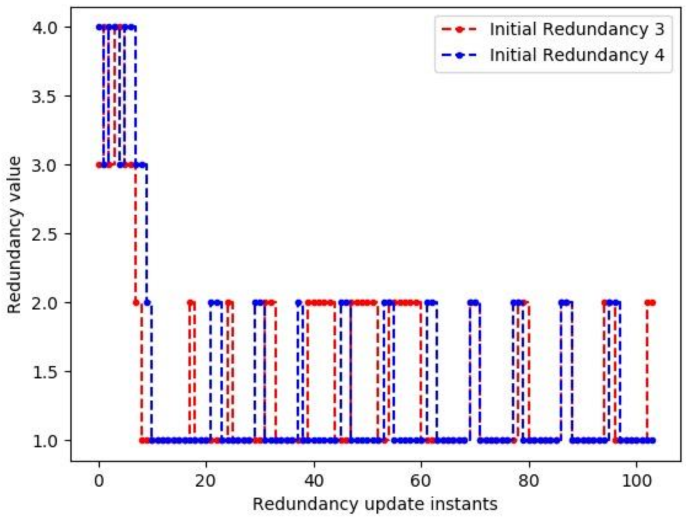
OAI Simulators

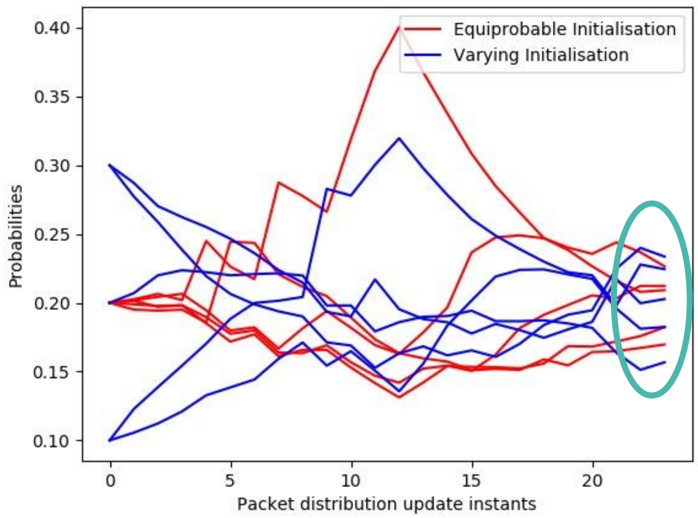


OAI Simulator testbed on five VMs

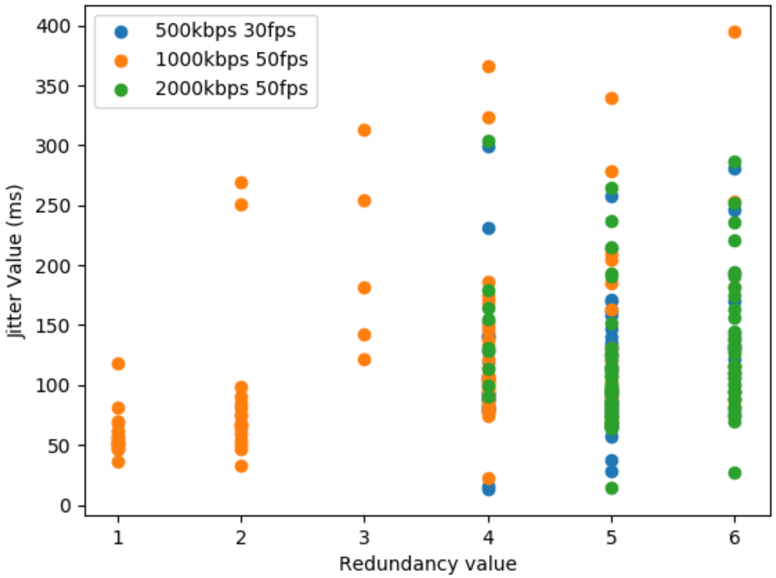


Results on OAI - Convergence





Results on 8 real interfaces



THANK YOU

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