Experimental Evaluation of Functional Splits for 5G Cloud-RANs

Nikos Makris, Pavlos Basaras, Thanasis Korakis, Navid Nikaein and Leandros Tassiulas

University of Thessaly, Greece
Informatics & Telematics Institute (CERTH), Greece
Eurecom, France
Yale Institute for Network Science, USA

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NITLAB NETWORK IMPLEMENTATION TESTBED LABORATORY

Outline

- ✓ Introduction - Motivation
- ✓ Background Information
- ✓ Functional Split Architecture
- ✓ Testbed Deployment
- ✓ Experimental Evaluation
- ✓ Conclusions –Future Work

Introduction

- Cloud-RAN: disaggregation of the base station functions from a single unit to a Baseband Unit (BBU) and a Remote Radio Unit (RRU)
- The RRU can be considered as:
  - passive with sole purpose to transmit low level data over the air – RRH
  - more intelligent with part of the processes taking place over it (e.g. the entire PHY)
- High bandwidth for front/back-hauling such connections
  - Introduction of protocols such as CPRI, RoE, etc.
  - High cost for deployment of such solutions
  - Traditional Ethernet connections are also good candidates if the amount to transfer the data is reduced

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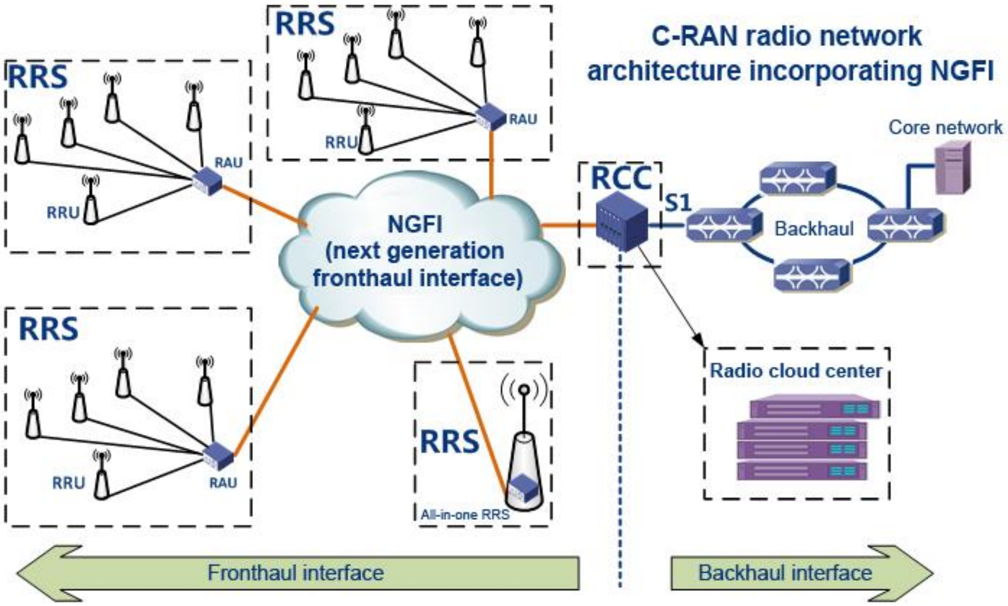
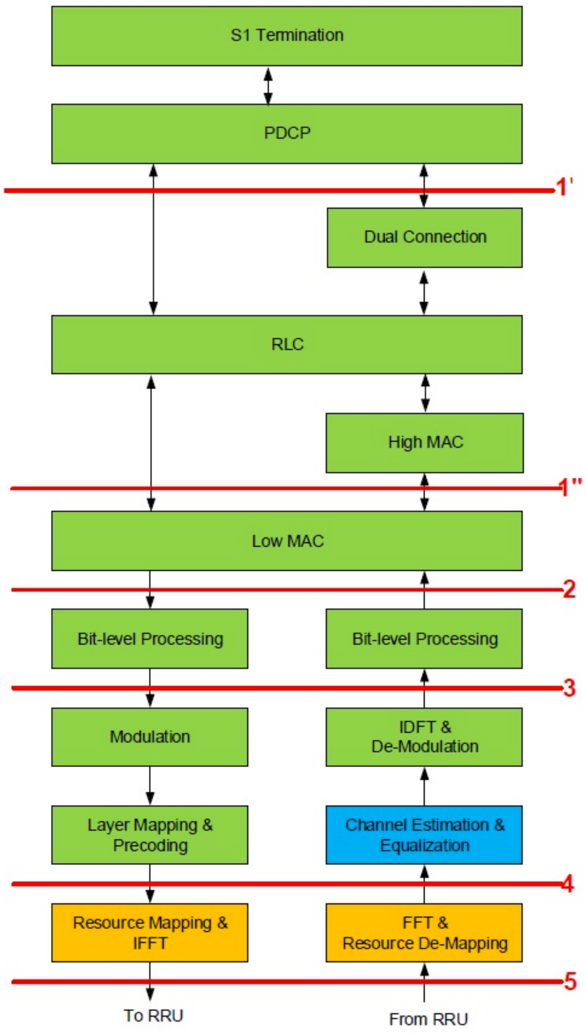
NGFI Splits – China Mobile

- ✓ NGFI is an open interface that redefines the functions of baseband remote radio units (RRUs).
- ✓ Some baseband processing functions are shifted to the RRU, which leads to a change in BBU and RRU architecture.
- ✓ BBU is redefined as the Radio Cloud Center (RCC), and the RRU becomes the Radio Remote System (RRS).
- ✓ Fronthaul is based on packet switch protocols rather than point-to-point connections.





Paper Contributions

- ✓ Given the OSI Layer2 related split points, we extract the real-time transfer requirements for a 5G Cloud-RAN.
  - ✓ We focus on the IF1′ (PDCP/RLC) and IF1″ (MAC/PHY) splits
- ✓ We implement and evaluate different functional splits over the LTE networking stack, complying with NGFI.
- ✓ We experimentally evaluate different transport protocols that bear the traffic of the identified splits (UDP/TCP/SCTP).
  - ✓ We use two approaches:
    1) based on stateless protocols (UDP), for the PHY layer splits (delay sensitive for scheduling transmissions)
    2) state-ful protocols (TCP/SCTP) for higher layer splits (slack delay requirements, buffering of the data is required).

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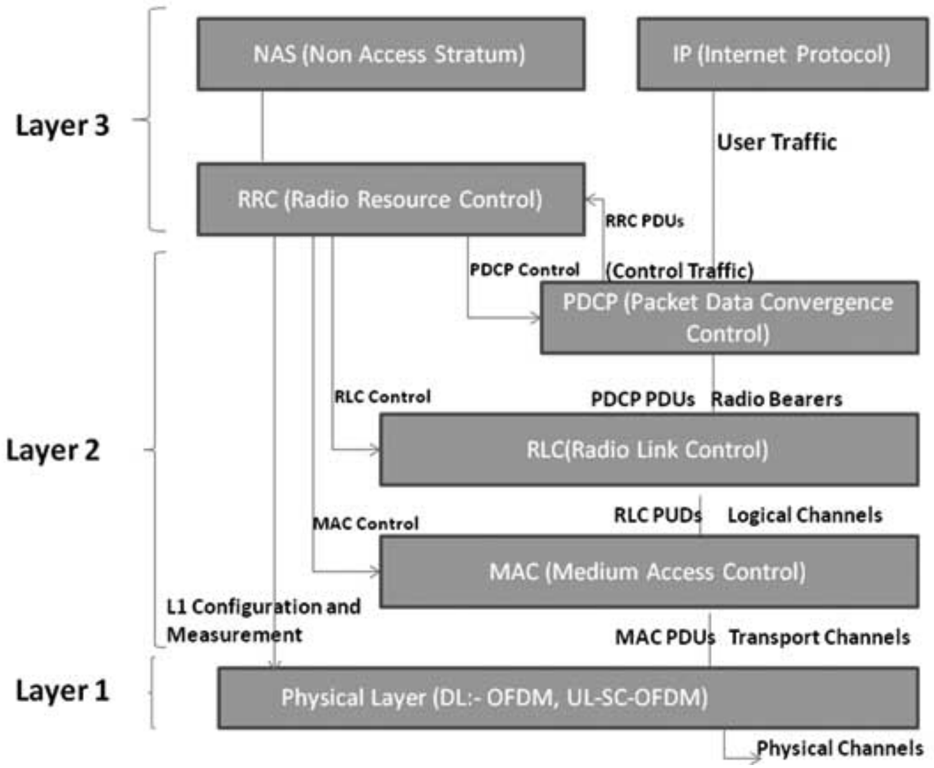
LTE Architecture

- ✓ We use as a reference design the LTE protocol architecture
- ✓ PDCP main functions: interfaces IP based networks, packet compression
- ✓ RLC main functions: transforming PDCP PDUs to MAC SDUs, concatenating/ segmenting and reassembling them.
- ✓ MAC functions: scheduling allocating resources for UEs
- ✓ PHY functions: FEC, encoding/decoding, equalization, FFT and finally the D/A or A/D conversion.



PDCP/RLC split Architecture

- Splits over the MAC layer seem to be yielding small performance benefits, as they need more transmissions in order to send the same amount of data to the RRU.
- Data sent are actual IP packets after the PDCP processing
  - Data has not gone through the concatenation process of RLC
  - For such splits, data sent to the RRU might need significantly more transmissions over the network (lower size than the data outputted by RLC)
  - As most of the contemporary networks can transfer packets of up to a specific size (e.g. MTU equal to 1500 bytes), the usage of technologies like Ethernet can be advantageous for such splits.
- Several benefits of implementing a PDCP/RLC split:
  - PDCP can be deployed as a convergence layer among different technologies
  - Multiple technologies can be coordinated from a single PDCP/IP instance at the base station (seamless mobility experience across several technologies with a very little overhead for the network operator, aggregation of interfaces and higher network capacity)

MAC/PHY split architecture

- ✓ The MAC/PHY split that we examine has been identified as one of the potential splits in current bibliography
- ✓ For this split, RRU and BBU are synced and operate in a subframe basis.
- ✓ BBU can instruct, based on the output of the MAC scheduling policy, the subframe allocation for each UE.
- ✓ The actual data that needs to be transferred from the BBU to the RRU is equal to the Transport Block Size (TBS), depending on the modulation and the physical resource blocks which are allocated to each specific UE.
- ✓ This split can be beneficial for the application of novel algorithms and technologies
  - ✓ e.g. dynamic scheduling of multiple RRUs, spectrum coordination algorithms, beamforming coordination etc.

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OpenAirInterface (OAI)

- ✓ We employ the OpenAirInterface platform for implementing the functional splits.
- ✓ Provides a completely open source implementation of the 3GPP E-UTRAN.
- ✓ We override the existing functions that are used for the communication of the layers and implement a client-server approach.
- ✓ This is applied only for the DL and UL channels (no control information yet).

PDCP/RLC split implementation

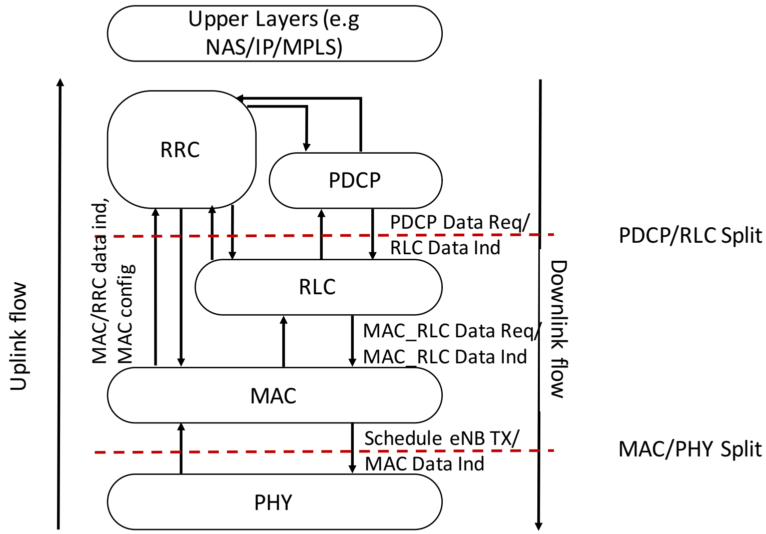
- ✓ Split architecture is based on locating the RLC and below layers on the RRU.
- ✓ When PDCP receives a packet, it goes through the normal layer procedures.
- ✓ When the data is sent to the RRU, RLC processes it and places it in a buffer waiting for the MAC protocol to request it.
- ✓ The buffer for handling this type of data in OpenAirInterface needed to be extended for carrying out our experiments.

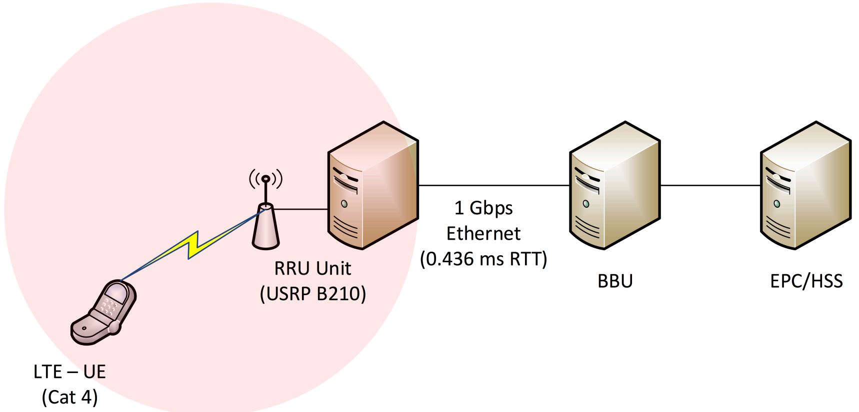
MAC/PHY split implementation

- ✓ For the MAC/PHY split, we override the part where the two layers communicate with each other.
- ✓ Upon the end of the MAC scheduling algorithm, the BBU instructs the RRU at which subframe the data will be transmitted over the air.
- ✓ This means that no buffering of the packets takes place on the RRU, but are solely handled by the above layers (BBU).
- ✓ Whenever data needs to be sent over the air, data streams are sent to the RRU along with all the signaling needed to orchestrate the PHY layer, including the subframe scheduled for transmitting, the number of physical resource blocks, the modulation and coding scheme (MCS), the antennas, etc.

Experiment Topology

- ✓ We employ the NITOS testbed for our experiments (http://nitos.inf.uth.gr) which provides us with the key experimental components for evaluating our approach.
- ✓ We evaluate our approach both on the simulator provided by OAI, and the real time operation by using a testbed node with an OAI compatible RF Front-end.





Network Parameters	Values
LTE mode	FDD Band 7
LTE Frequency	2680 MHz (DL)
No RBs	25, 50
UE	Cat. 4 LTE, Huawei E3272
OAISIM channel emulation	Rayleigh
OAISIM mobility	STATIC
Backhaul RTT	$\sim$ 436 msec
Backhaul connection	1Gbps Ethernet
Ethernet MTU size	1400 bytes

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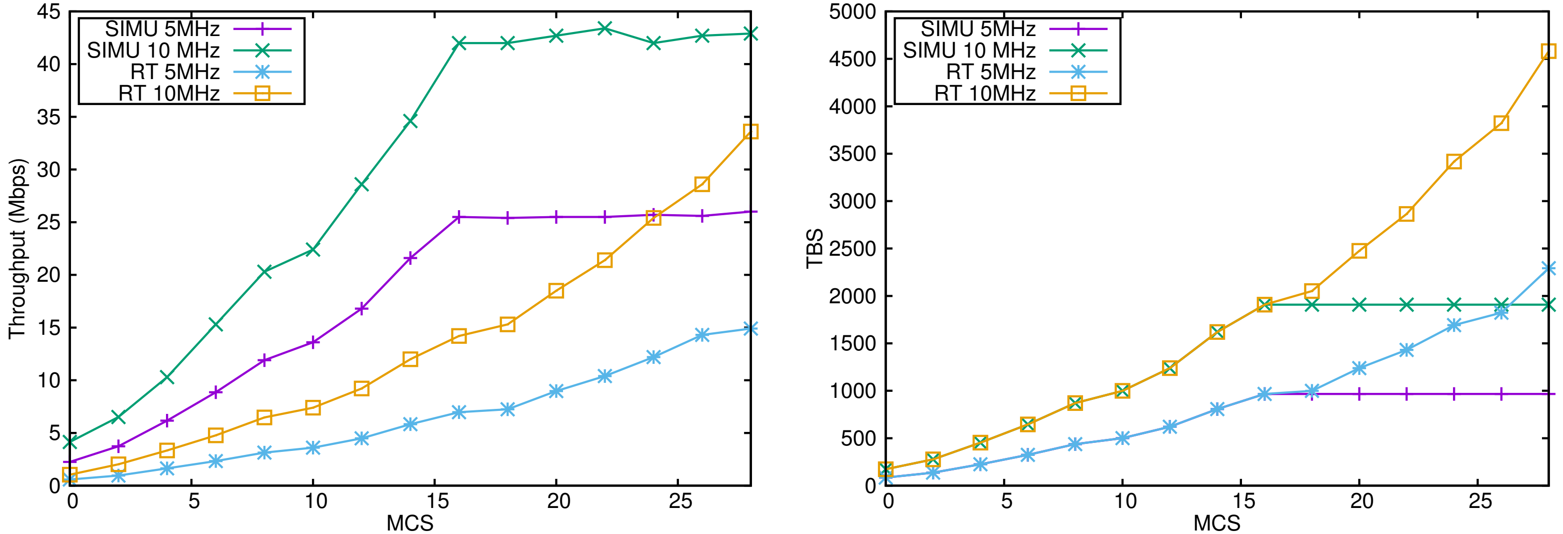
Experiment Methodology

- ✓ We conduct experiments with a resolution of 10 times per each measurement.
- ✓ For the SCTP results, we use 5 parallel streams for each association, and do not use the multi-homing features.
- ✓ For generating traffic for our measurements, we use the *iperf* traffic generator, set to saturate the wireless link with UDP traffic.
- ✓ Initially, we present some benchmarking results of the platform that we use for our experiments as reference measurements.
- ✓ The *vanilla* OpenAirInterface is used, configured as either the LTE emulation platform (OAISIM) or set to operate in real time (RT), running the whole LTE stack in one base station binary application.

Reference Results

- We measure throughput performance achieved per each MCS profile allocated by the eNodeB scheduler, and the mean TBS used.
- TBS is important for the MAC/PHY split, as the output of the MAC processing mandates the transferring of equal sized data to the RRU within the time scheduled for transmission.
- We observe that the OAISIM platform yields the same results for MCS indexes over 16 (due to the PHY abstraction flags used to run the platform).

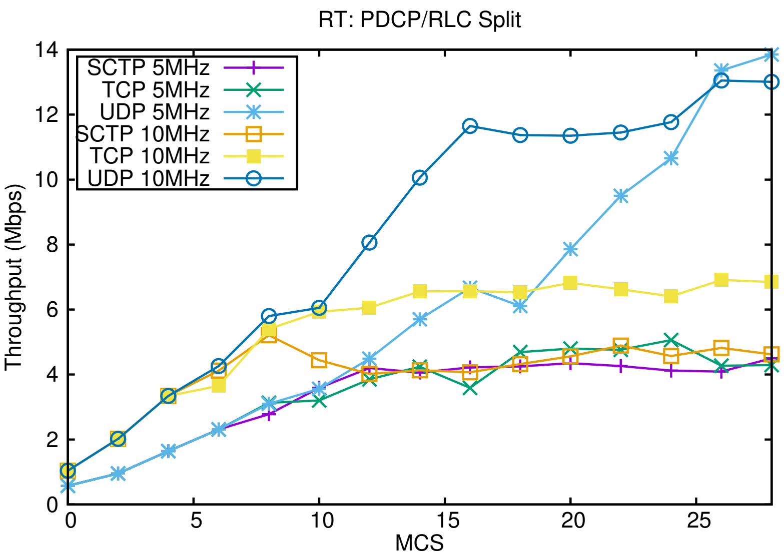


(a) Throughput achieved per MCS profile

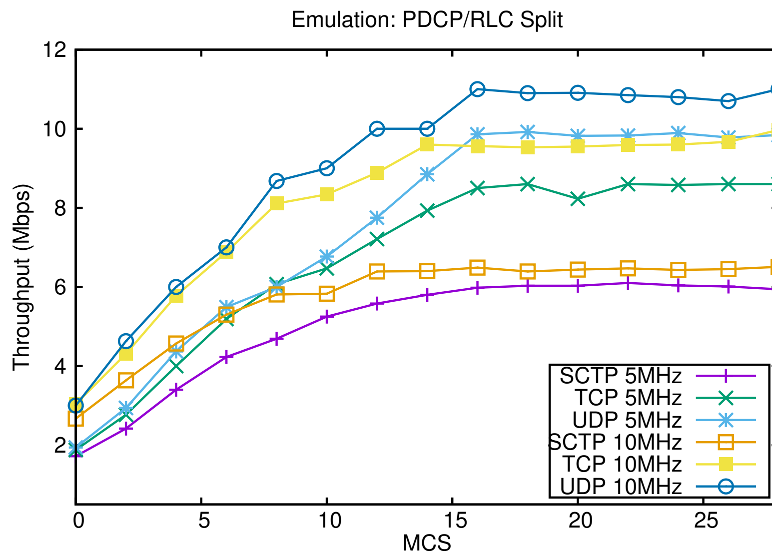
(b) TBS used per MCS profile

PDCP/RLC split evaluation

- ✓ Since the PDCP functions happen at a higher layer, the real time operation can be maintained with proper buffering at RLC.
- ✓ Whenever MAC layer is finished with the scheduling of its buffered packets, it requests the RLC buffered packets. (larger memory allocation is needed for enabling such a split)
- ✓ For the real time operation the worst performing protocol is SCTP.
- ✓ UDP outperforms both SCTP and TCP as due to its stateless nature, the overhead that is posed on the backhaul only regards the transmission of IP packets, after the PDCP handling and compression to the remote RRU with the RLC layer.



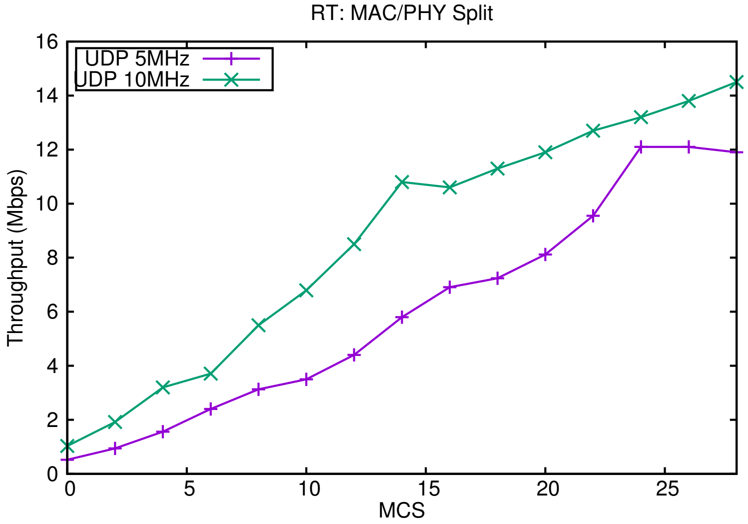
(a) Split results for real time



(b) Split results for OAISIM

MAC/PHY split evaluation

- ✓ We present results only for the UDP based data flow, as our first set of experiments denoted that it is the protocol that achieves better performance in such splits.
- ✓ The RRU employs a minimal queueing mechanism, so whenever the data is sent over the backhaul to the RRU, they are scheduled for transmission.
- ✓ If they are not sent during the scheduled subframe, they need to be discarded by the RRU.
- ✓ The split is taking place upon the decision of the scheduler on which subframe the data will be sent (with the subframe duration being 1 msec), the modulation and coding scheme which will be used and the physical resource blocks that will be allocated for each UE.



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Conclusions and Future Work

- ✓ For high layer splits (i.e. PDCP/RLC), the transport protocols can pose performance limitations
  - ✓ The RT operation of the base stations is not broken whatsoever
  - ✓ Stateless solutions (e.g. UDP) are found out to be more applicable
- ✓ For lower layer splits, like the MAC/PHY split, where the RRU transmissions are solely scheduled in the Cloud, real time operation mandates the use of high bandwidth solutions, with the least possible overhead.
- ✓ The proposed PDCP/RLC split can be used as a convergence sublayer among RRUs and BBUs that incorporate more than one heterogeneous wireless technologies.
- ✓ In the future, we foresee to investigate under real-world settings the impact of different functional splits in the low PHY layer and the definition of a detailed protocol for the intercommunication between BBU and RRUs.

Thank you!

Nikos Makris
University of Thessaly and CERTH
nimakris@uth.gr

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CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS