"Evolved User Equipment for Collaborative Wireless Backhauling in Next Generation Cellular Networks"

Apostolos Apostolaras
apaposto@uth.gr

University of Thessaly, Electrical & Computer Engineering Dept.
The Centre for Research & Technology Hellas, CERTH

Outline

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4) **Contribution**
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6) **Use Cases – Scenarios**
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Motivation

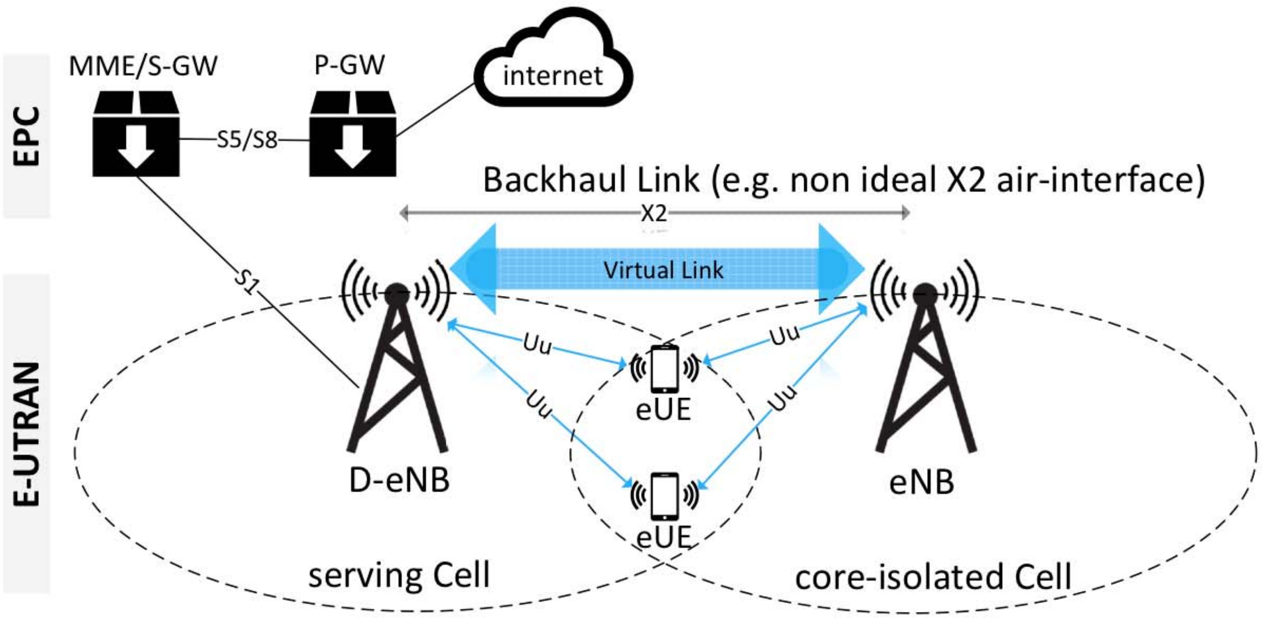
- Road to 5G
  - Improved Capacity
  - Extended Coverage
  - Energy Efficiency
- Currently…
  - Mobile Data Offloading
  - Cellular – WiFi interworking
  - Interference Coordination Techniques
  - Coordinated Multipoint Transmission
  - Small Cells
  - Device to Device

Future Cellular Networks

- Exploit UEs as active network elements
- Collaborative Communication
- Are users willing to convey traffic for the network?
  - Monetary incentives
  - Beneficiary data plans
  - Reduction on the subscription costs

- Evolve UEs to extend physical point-to-point links between eNBs
- Propose a new paradigm for link virtualization and new virtual air-interface
- Enable cooperative packet forwarding at L2/MAC

Collaborative Wireless Backhauling Architecture



Contribution

- **Dual Benefit**
  - Operators benefit from exploiting eUEs
    - improve network coverage
    - low-latency communication performance through MAC-packet level forwarding
  - Users benefit from their participation (at an expense on their battery consumption)
    - bargain for beneficiary data plans
    - improve their throughput performance
- **Use cases**
  - moving cell scenarios
    - eUEs act voluntarily as relays and packet forwarders
  - small/densified scenarios
    - eNBs provide multiple data pipes to eUEs through different radio bearers
- **Novelty**
  - dual CoMP is realized in uplink
    - eUEs form a virtual MIMO for transmitting to the eNB
    - eUEs **voluntarily** and **independently** contribute to the communication over the virtual-air interface
  - MAC scheduler
    - to handle collaborative transmissions
    - Low latency communication

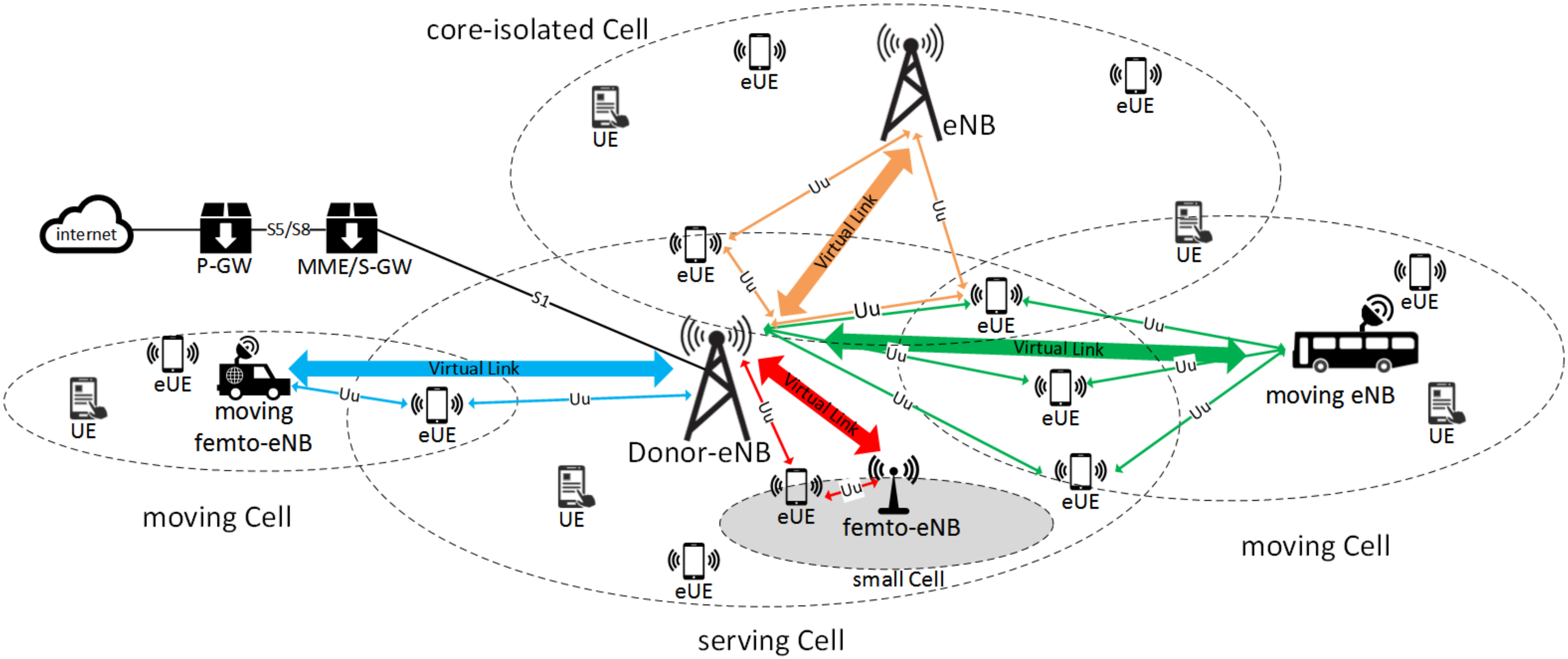
LTE Mesh Network Topology

- eNBs: legacy 3GPP base stations
  - Meshing
  - Coordination of user traffic
  - Management and scheduling of radio resources
  - Routing for intra and inter-cell communication

- Ues: legacy 3GPP user equipment

- eUEs: evolved UEs
  - Able to associate and connect with multiple eNBs
  - Interpret scheduling messages coming from eNBs on signaling channels to further enable traffic routing and packet forwarding

Use Cases


core-isolated Cell
eUE
eNB
eUE
UE
Uu
Virtual Link
Uu
internet
S5/S8
P-GW
MME/S-GW
eUE
Uu
UE
S1
Uu
eUE
eUE
Uu
Uu
Virtual Link
eUE
Uu
Uu
Virtual Link
moving eNB
UE
Uu
eUE
moving
femto-eNB
Uu
eUE
Uu
Donor-eNB
Uu
Virtual Link
Uu
eUE
eUE
UE
eUE
Uu
femto-eNB
moving Cell
UE
eUE
small Cell
moving Cell
serving Cell

Scenarios

- **Enable wireless backhauling to core-isolated eNBs**
  - eUEs convey voluntarily traffic between eNBs
  - eUEs are evolved into *on-demand* intermediate data forwarders
  - and form a virtual MIMO antenna
  - eUEs are enabled as a service by the eNBs to relay traffic
  - and offer low latency communication
- **Moving Cells**
  - Public Safety and Private Mobile Radio
  - Intelligent Transport Systems (ITS) applications
- **Small Cells**
  - eUEs help home-eNBs to re-establish X2-interface

LTE Mesh Network

- Virtual Overlay – Enable Mesh Networking
  - Signal-level Cooperation
    - Bit error probability is minimized with respect to QoS constraints
    - Presents an abstraction to higher layers: a Virtual Link with given probability of packet erasure
    - Implicates all eUEs (either in RX or TX) regardless of their perceived link quality with eNBs
    - Alamouti coding allows for independent coordination among UEs and over-the-air signal combination towards the destination eNB
  - **Packet-level Cooperation**
    - MAC performs scheduling and packet forwarding
    - MAC identifies the Physical links to be activated → minimize the frame error rate
    - DL → collaborative broadcast, UL→ dual CoMP
    - Low latency communication as identified packets belonging on collaborative transmission are being forwarded to the destination eNB without the need of traversing the eUEs' whole protocol stack
  - Network-level Cooperation
    - Local traffic routing and relay selection (over a virtual link) → network or higher layers
    - Packet forwarding → MAC

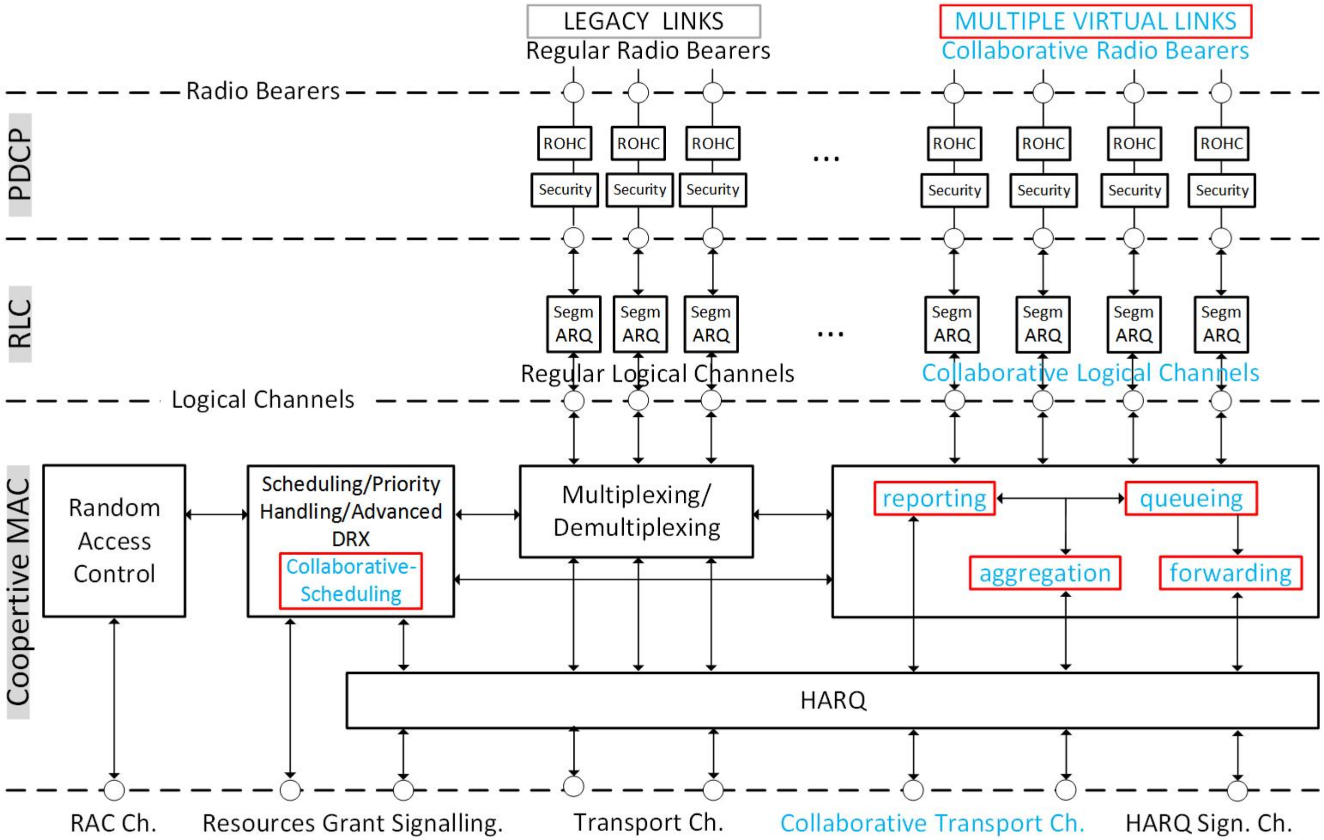
Physical Layer Design

- **Cell Search**
  - Standard LTE synchronization procedures to detect PSS and SSS
  - Non-Primary eNBs are allowed to re-initiate 3GPP RRC connection reconfiguration procedures
- **Synchronization**
  - Donor eNBs provide a time reference synchronization to the core-isolated eNBs
    - Over-the-air decentralized network synchronization
    - Utilize a common synchronization channel
    - No coordination is required, scalable
- **Coding**
  - OFDMA, single frequency
  - eUEs and UEs share the same resources
  - DL (eNB-to-eUEs) → Decode and Forward (**BROADCAST**)
  - UL(eUEs-to-eNB) → distributed Alamouti (**VIRTUAL MIMO- *dual* CoMP**)
  - Destination eNB performs framing allocation to the collaborative eUEs by sending a scheduling grant request with info related to the PDUs sequence number, size and HARQ id
  - Having correctly decoded the requested PDU during broadcast, each eUE performs Alamouti coding independently
    - Autonomous antenna element
  - Robust to the number of collborting eUEs: → at least one eUE is required to have correctly decoded the PDU during the broadcast phase

MAC Layer Design (1/3)

- **Queuing:**
  - Packet storage using buffers maintained at the MAC layer
  - Sophisticating indexing of packets inside the buffers based on their sequence number and their size to support multiple TBS formats.
- **Reporting:**
  - MAC buffer status report (BSR) is sent periodically from eUEs to dest eNB to update storage info.
- **Aggregation:**
  - It is used to concatenate the MAC PDUs and bundle them when this is instructed by the eNB (multiple TBS)
- **Forwarding:**
  - It identifies whether an incoming PDU is related to a certain virtual link in which the eUE participates.
  - If so, it stores the incoming PDU in the respective eUE's buffer for the specific VL at the MAC
- **Collaborative Scheduling:**
  - It schedules transmission for the outgoing PDU on the corresponding virtual link
  - Schedulin is instructed by the destination eNB on the intermediate eUEs

Collaborative Protocol Stack



MAC layer Design (2/3)

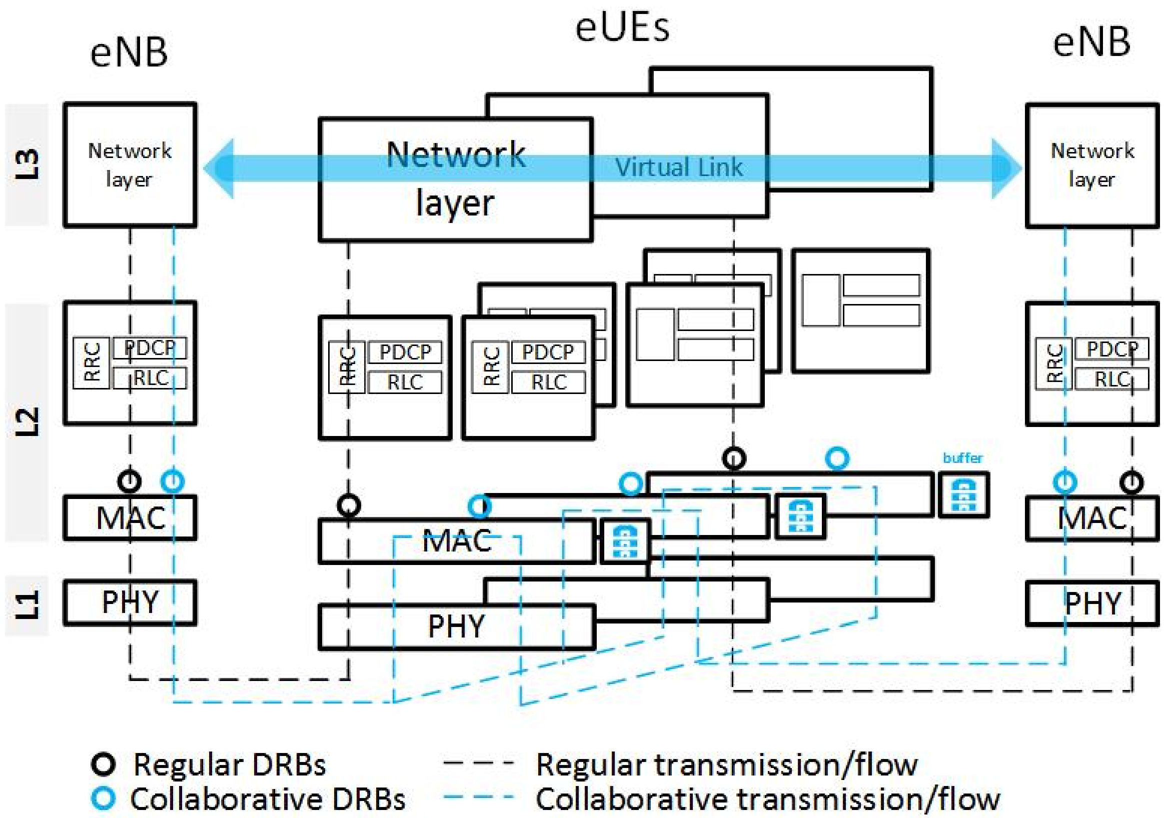
- **eUE Cell Association and Initialization**
  - As a legacy UE performing “attach” to its serving eNB (primary eNB)
  - Access to core is provided by S-GW and P-GW functionalities
  - A second “attach” is triggered on the eNBs that is allowed to connect (information taken from primary eNB)
  - eNBs initiate virtual data radio bearer interfaces and trigger the buffer initiation on the corresponding PDU buffer queues on the eUEs

- **Virtual Link Setup**
  - Virtual Link := Collaborative Radio Bearer (CO-RB)
    - Hides the transportation info to the higher layers as it can be composed of several point-to-point physical links
  - Collaborative RNTI → differentiates a regular from a collaborative transmission and helps to identify packets on the collaborative Virtual Link
  - Part of the MAC header
  - Two CO-RNTIs (an ingress and engress) can be used for setting up a Virtual Link

MAC layer Design (3/3)

- Virtual Link H-ARQ
  - To reduce latency,
  - eUEs correctly send a BSR to the destination eNB as soon they decode a MAC PDU.
  - If the destination eNB decides to schedule the MAC PDU on the egress CO-RNTI, the scheduling information will be received by all the eUEs, even to those not having correctly decoded the MAC PDU yet.
  - Then, all the eUEs create a (virtual) HARQ process associated to the sequence number (SN) of the MAC PDU, which is contained in the scheduling information.
- Adaptive Modulation and Coding
  - In LTE standard, UEs are not permitted to deliberately decide about packet transmission and the related configurations. That is instructed by the eNBs.
  - Two-hop topology: Common or different MCS for the transmission over the two physical links
- eNB MAC co-scheduler
  - Schedules collaborative packet transmission for the eUEs participating on the VL in the uplink phase
  - It schedules PDU transmission from the eUEs that have replied with a positive BSR

Collaborative Transmission Flow

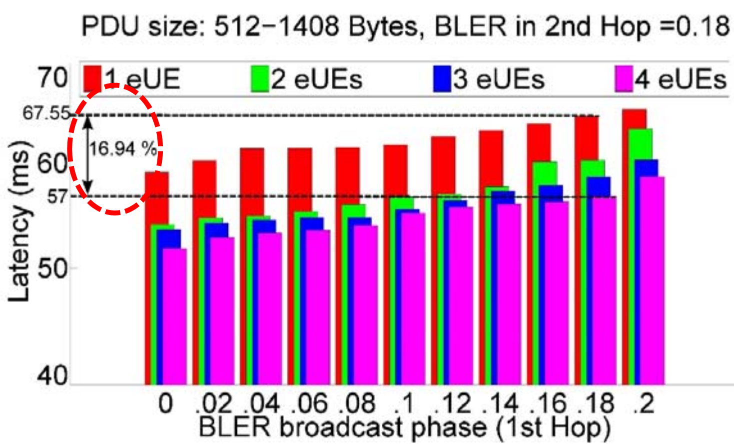


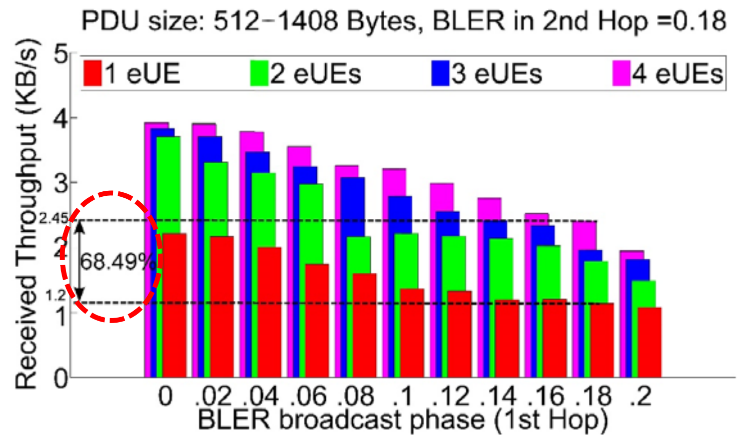
Performance Evaluation

- OpenAirInterface (OAI)
  - Open-source software for 4th generation mobile cellular networks
  - Fully compliant with the 3GPP standards
  - Implementation code with built-in capabilities for transition between real experimentation and repeatable and scalable emulation
- Experimentation
  - Topology: 2 eNBs and 4 eUEs in a 500m^2, 5Mhz bandwidth and maximum data rate on collaborative link is 12 Mbps
  - Low – Latency L2/MAC packet forwarding
  - eUE benefits and improves its performance by exploiting multiple eNB communication

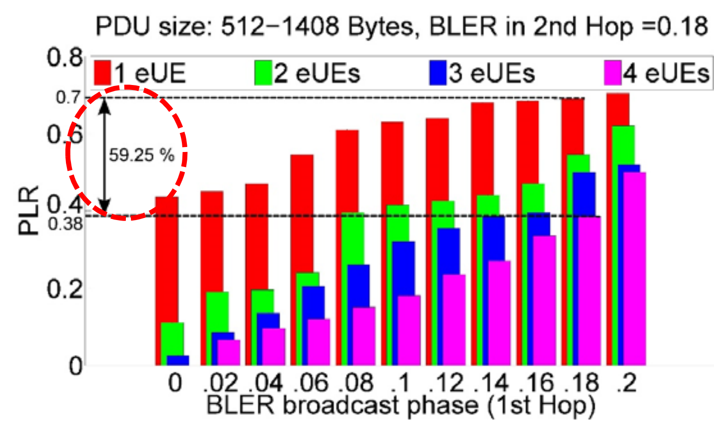
Parameter	*Value*	*Parameter*	*Value*
Carrier Freq.	1.9 GHz	*Traffic Type*	UDP
Bandwidth	5MHz	*Fading*	AWGN Ch..
Frame Duration	10ms	*Pathloss*	−50dB
TTI	1 ms	*Pathloss Exp.*	2.67
UEs	1, 2, 3, 4	*Mobility*	Random

Efficient L2/MAC forwarding for low latency communication

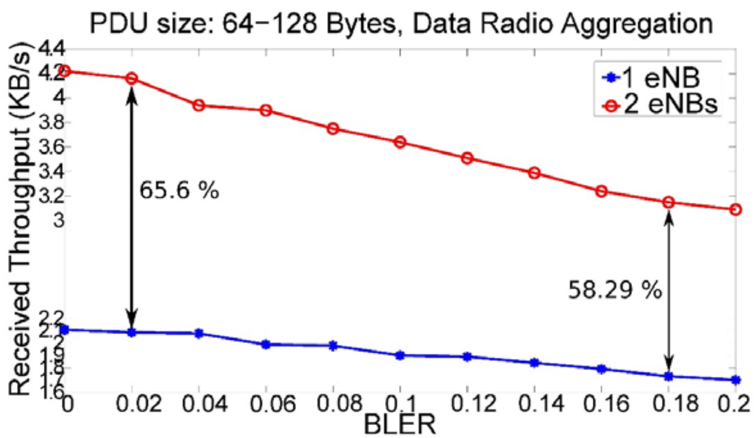




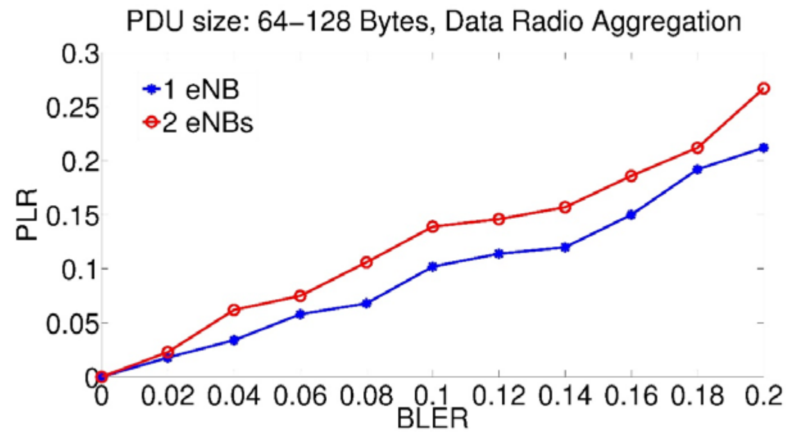
- When using 4 collaborative eUEs
  - in a coarse communication environment 1st and 2nd hop = 0.18 BLER
  - Low latency up to 16.94% improvement
  - Received Throughput improves up to 68.49 %
  - PLER reduces up to 59.25%
  - 3GPP defines QCIs 1 & 4 for GBR bearers for VoIP and Video streaming to 100ms and 300ms respectively
    - Obtained results are <



An eUE experiences communication service from two-eNBs concurrently



Throughput



Packet Loss Rate

- eUE improves its throughput performance (up to ~65 %)
  - when it receives a dual eNB connectivity comparing to a sole eNB association
- UDP constant bit rate traffic of 2.1 KB/s is transmitted by both eNBs to the same eUE for different BLER probabilities
- As BLER increases the PLR increase and that affects throughput rate perfromance.

Thank you

- EURECOM
  - OpenAirInterface
    - http://www.openairinterface.org/
  - Code Available at SVN repository:
    - https://svn.eurecom.fr/openairsvn/openair4G/branches/lolamesh

- University of Thessaly and CERTH
  - NITLAB – Network Implementation Testbed Laboratory
    - http://nitlab.inf.uth.gr