

Performance Analysis and Energy Efficiency of Random Network Coding in LTE/LTE-A

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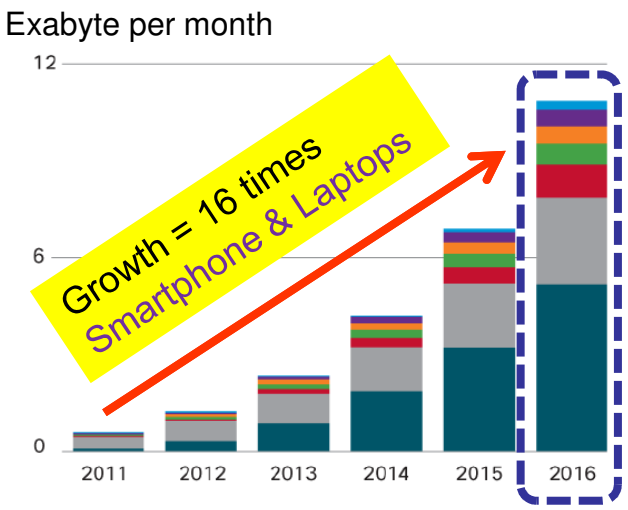
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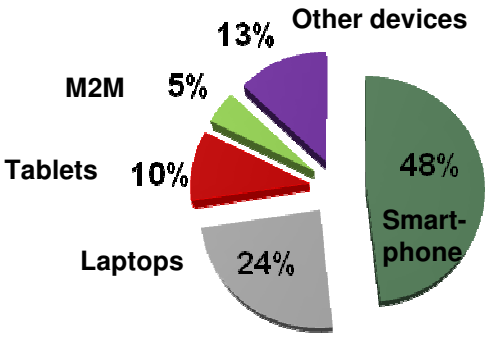
- Traffic Growth and Energy Challenge
- LTE Protocol Architecture
- Hybrid-ARQ (HARQ) Protocol
- Random Network Coding (R-NC)
- Simulation Setups and Results
- Conclusions and Future Work

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Global Mobile Data Traffic Growth

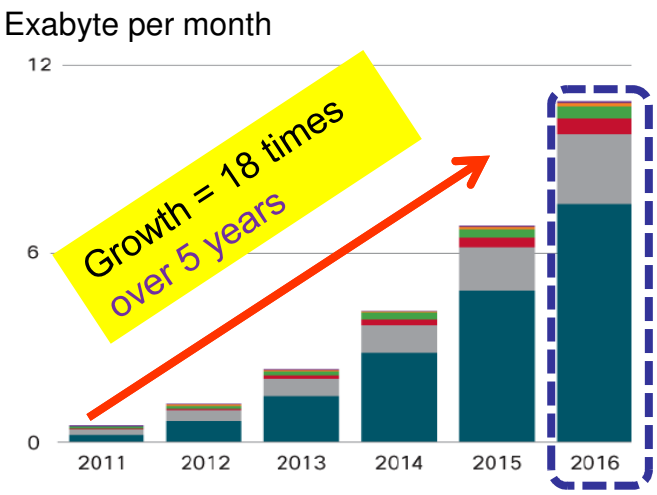
Mobile Traffic Usage by 2016

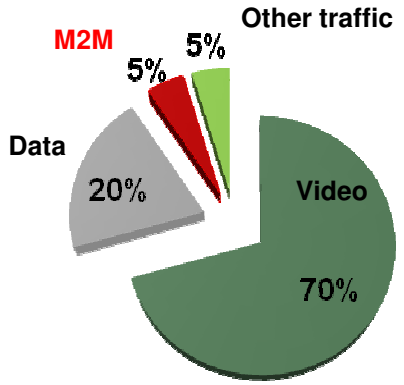




Smartphone and Laptops share of traffic is 72% by 2016

Mobile Data Traffic Growth by 2016





Mobile video content will generate 70% of traffic by 2016

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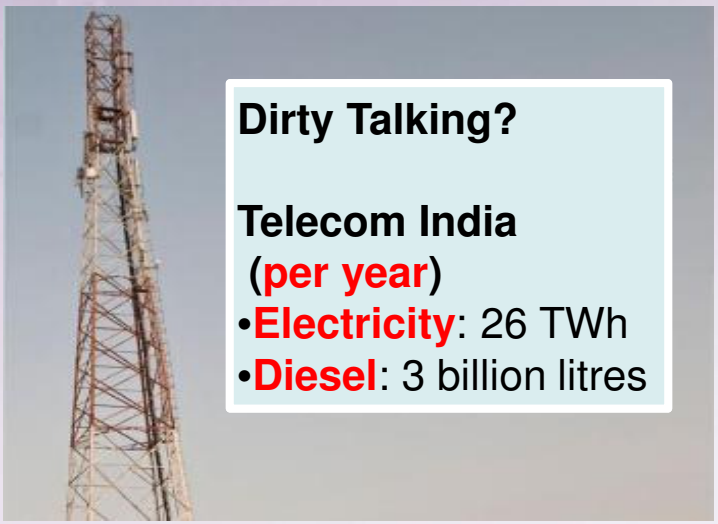
Energy and CO_2 emission Challenges





5 million Base Towers

Base Stns cause 60-80% of total network power consumption



Dirty Talking?

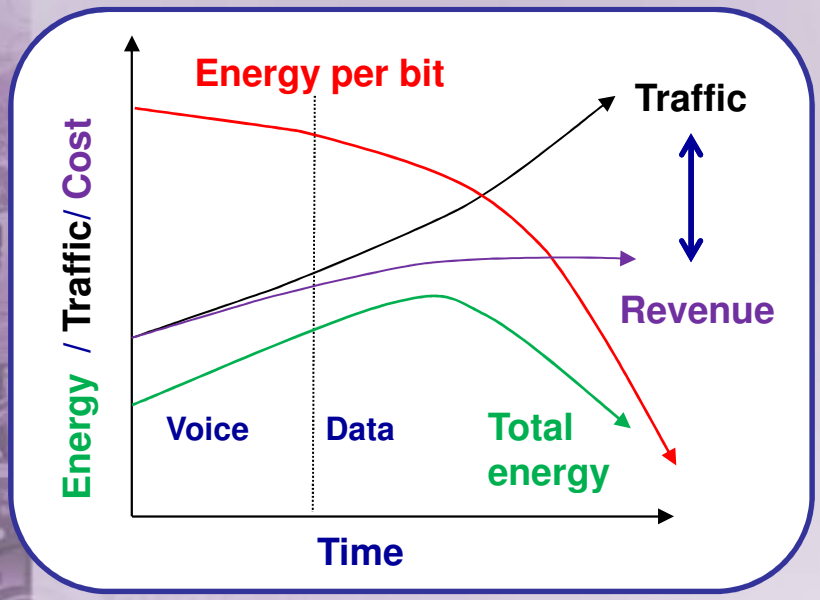
Telecom India (per year)
- **Electricity**: 26 TWh
- **Diesel**: 3 billion litres



0.8% World (290 Mtones)

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Key Challenge



Trends:

- **Exponential** growth in **traffic**
- **Increase base stations** / area for higher capacity
- **Revenue** growth is **constrained** and dependent on new services

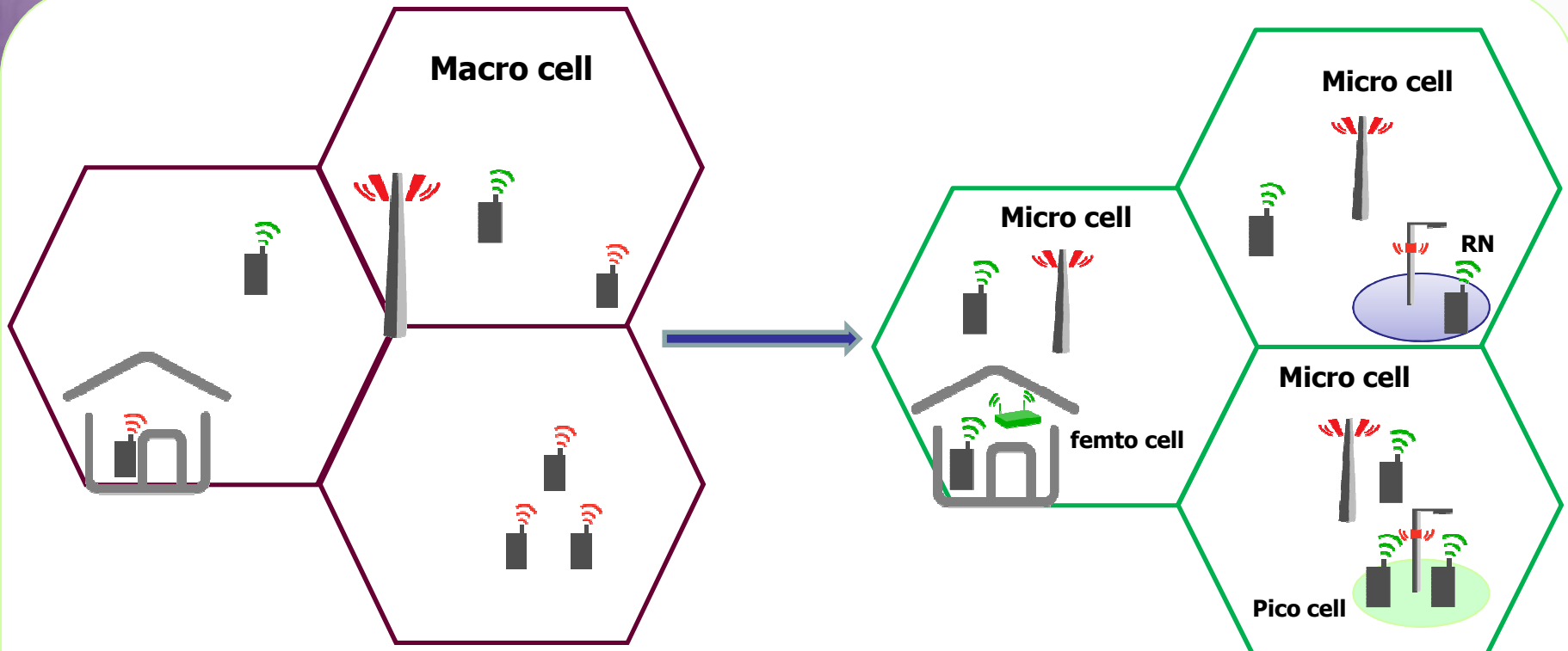
Energy use cannot follow traffic growth without significant increase in energy consumption

→ **Reduce** Energy use per data bit delivered (Joule/bit)

Challenge how to meet traffic demands while preventing the cost, energy requirements, and CO_2 emissions from scaling directly with traffic.

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Heterogeneous Networks (HetNets) – LTE A (Rel. 10)



- Offload traffic to small cells and relays
- Bring the user closer to the traffic source
- Replace Large macro base stations with Small base stations

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LTE Protocol stack - HetNets suitability?

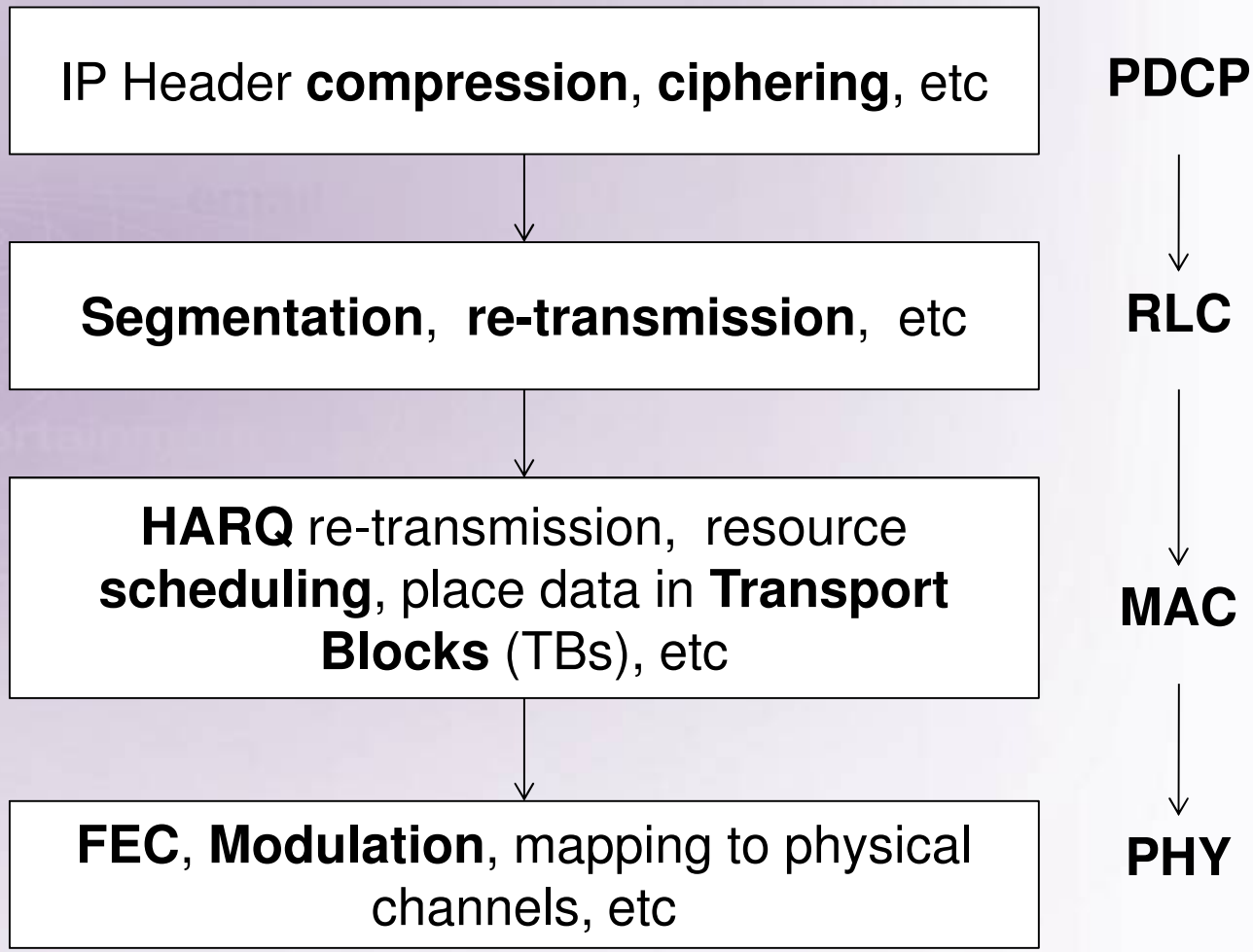
HetNets promise capacity/coverage enhancements at the price of increased cell density and inter-cell interference

Research on cooperation and coordination between base stations for LTE-A:

- Research is mainly focused on PHY layer techniques
- Upper layer protocols preserve the design proposed for macro-cellular single-point data delivery
- Hybrid ARQ MAC HARQ is optimised for single-point transmission, but has limited capabilities to exploit the potential of multi-point/multi-hop scenarios

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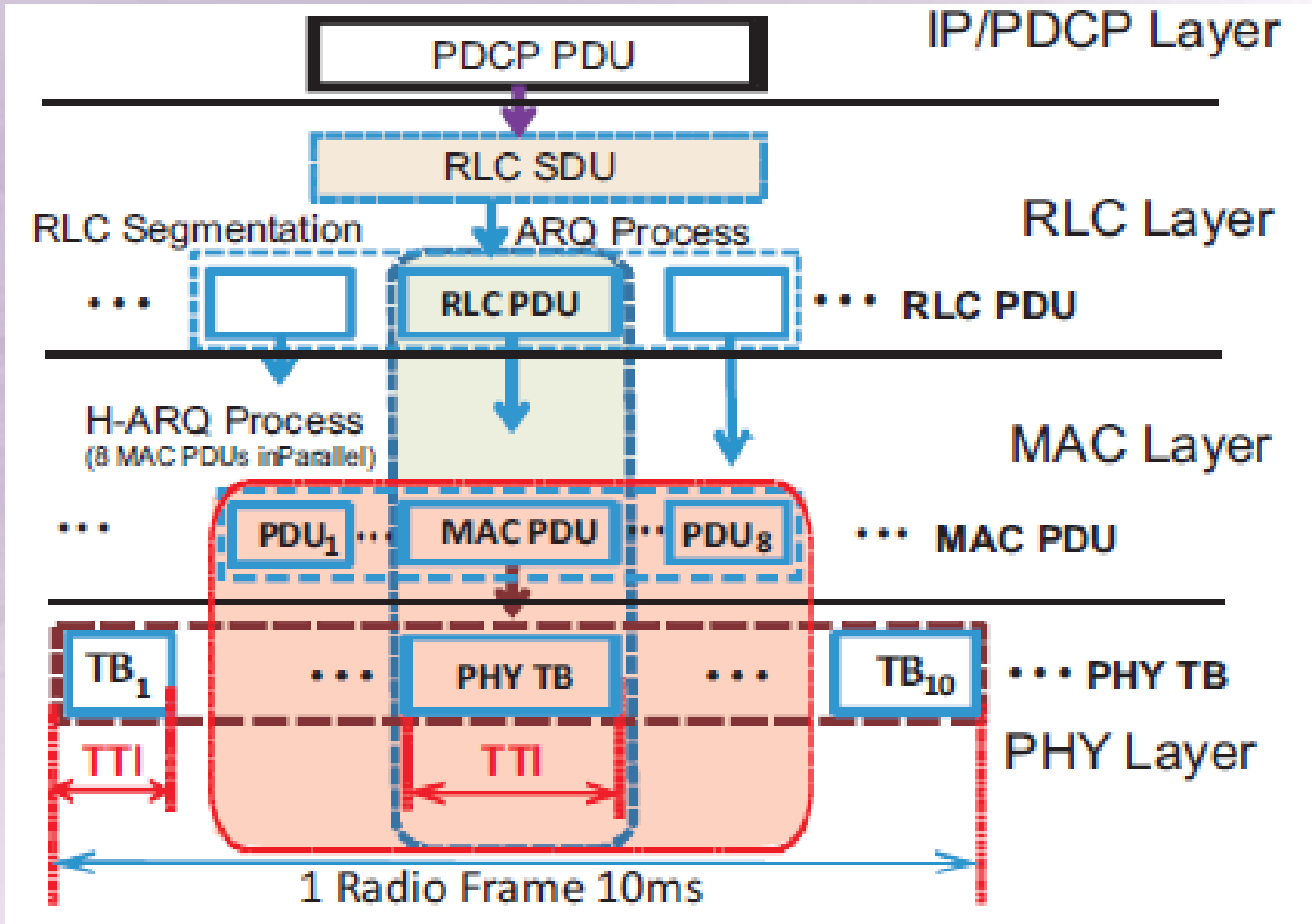
LTE-A Protocol architecture



PDCP: Packet Data Conversion Protocol **PDU:** Packet Data Unit **RLC**: Radio Link Control
HARQ: Hybrid-ARQ **TB:** Transport Block **TTI**: Transmission Time Interval

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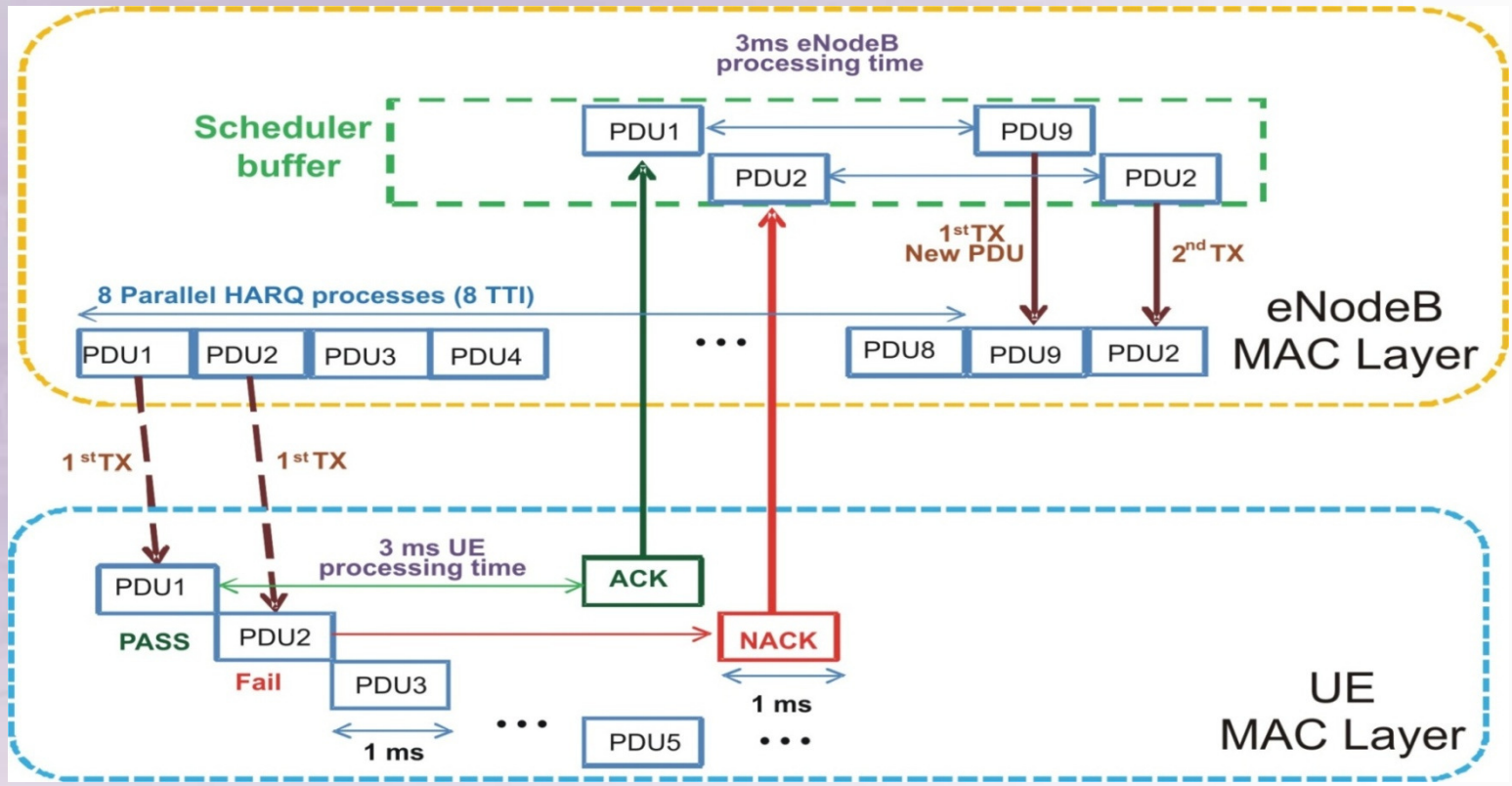
LTE Protocol architecture - Data Flow from IP Layer to PHY Layer



PDCP: Packet Data Conversion Protocol **RLC**: Radio Link **SDU:** Service Data Unit
PDU: Packet Data Unit **RLC**: Radio Link Control **HARQ:** Hybrid-ARQ **TB:** Transport Block
TTI: Transmission Time Interval

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HARQ Protocol – Transmission process



MAC layer transmits groups of 8 MAC-PDUs using 8 parallel HARQ processes within blocks of 8 consecutive TTIs.

HARQ ensures reliable data services by re-transmission of lost packets

Users sends one ACK/NACK message for every transmitted packet

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HARQ scheme – Disadvantages

High signalling overhead and complexity (re-transmission process, ACK/NACK reporting)

HARQ scheme is not suitable for:

- **Multi-hop deployments**
  - Complex synchronization of multiple HARQ processes
  - more overhead and re-transmission delays (HARQ per link)
- **Multimedia streaming and delay-sensitive applications**
  - high complexity and delays
  - major challenge for video applications (fast-battery-drain)
- **Energy-efficient**
  - high energy consumption at the UE (costly UE ACK/NACK feedback - battery and resources)
- **M2M Communications energy-efficient**
  - Remove HARQ in Cat. 1 M2M LTE UEs to reduce the device cost

Video + M2M > 75% Traffic → HARQ results in Energy and Rate Loss → ACK/NACK Reduction Techniques

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3GPP Standards – (ACK/NACK bundling)

In 3GPP, an ACK/NACK bundling technique is proposed to reduce uplink overhead in LTE-A:

- **Multiple ACK/NACKs** for each UE are **combined**, and an **ACK/NACK** is reported if all the **bundled transmission blocks** are correctly/wrongly received (re-transmit all bundled blocks).

Time- and Spatial-domain bundling are supported for Rel-10 TDD UEs

Spatial bundling is proposed for coverage limited FDD UEs in Rel-11

Problems (Bundling):

- **degrades** the **downlink** performance
- **increases** the system **complexity**

A trade-off between the downlink performance and ACK/NACK overhead is essential to select a suitable bundling.

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Random Network Coding Solution

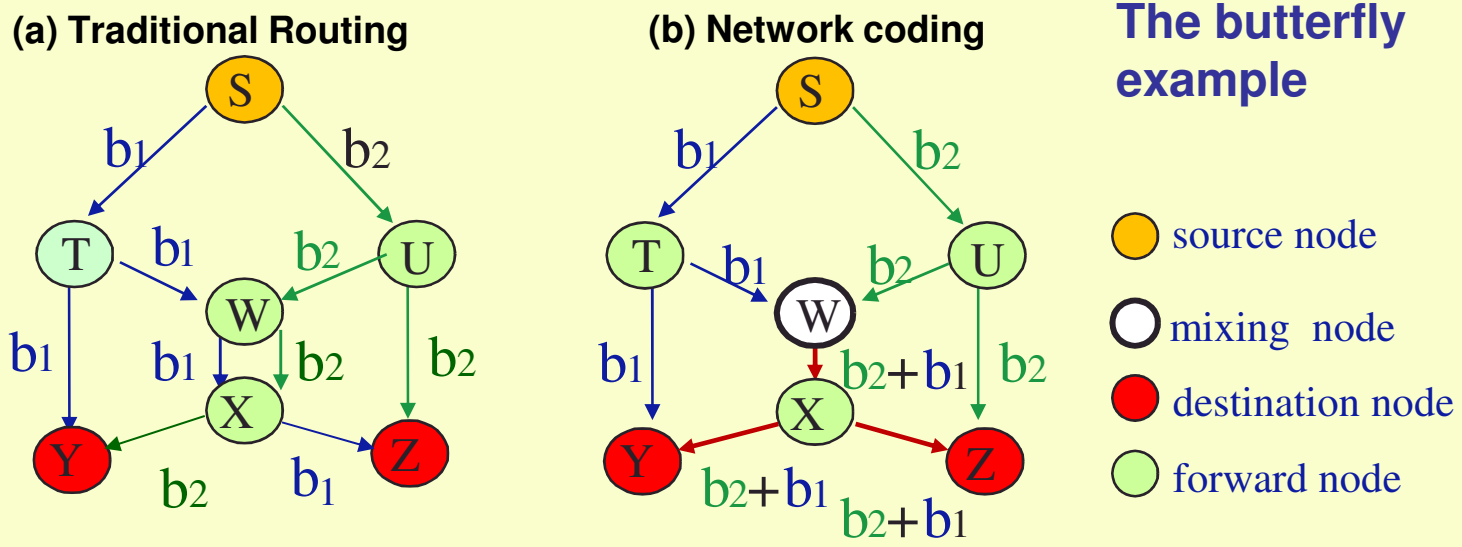
- Random Network Coding (R-NC)
- How does R-NC work ?
- Why replace HARQ with R-NC ?
- R-NC practical applications: Fiction?
- Simulation setups and Results

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Network Coding (NC)

In **NC** nodes not only store-and-forward received data packets but also mix them into output packets

NC maximizes network throughput and reduces the amount of energy required to multicast packets



- Nodes store-and-forward packets
- Throughput = 1 bit/ time unit

- Nodes mix packets
- Throughput = 2 bits/ time unit

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Random Network Coding (R-NC)

Real Networks - packets suffer from random delays and losses

Random Network Coding:

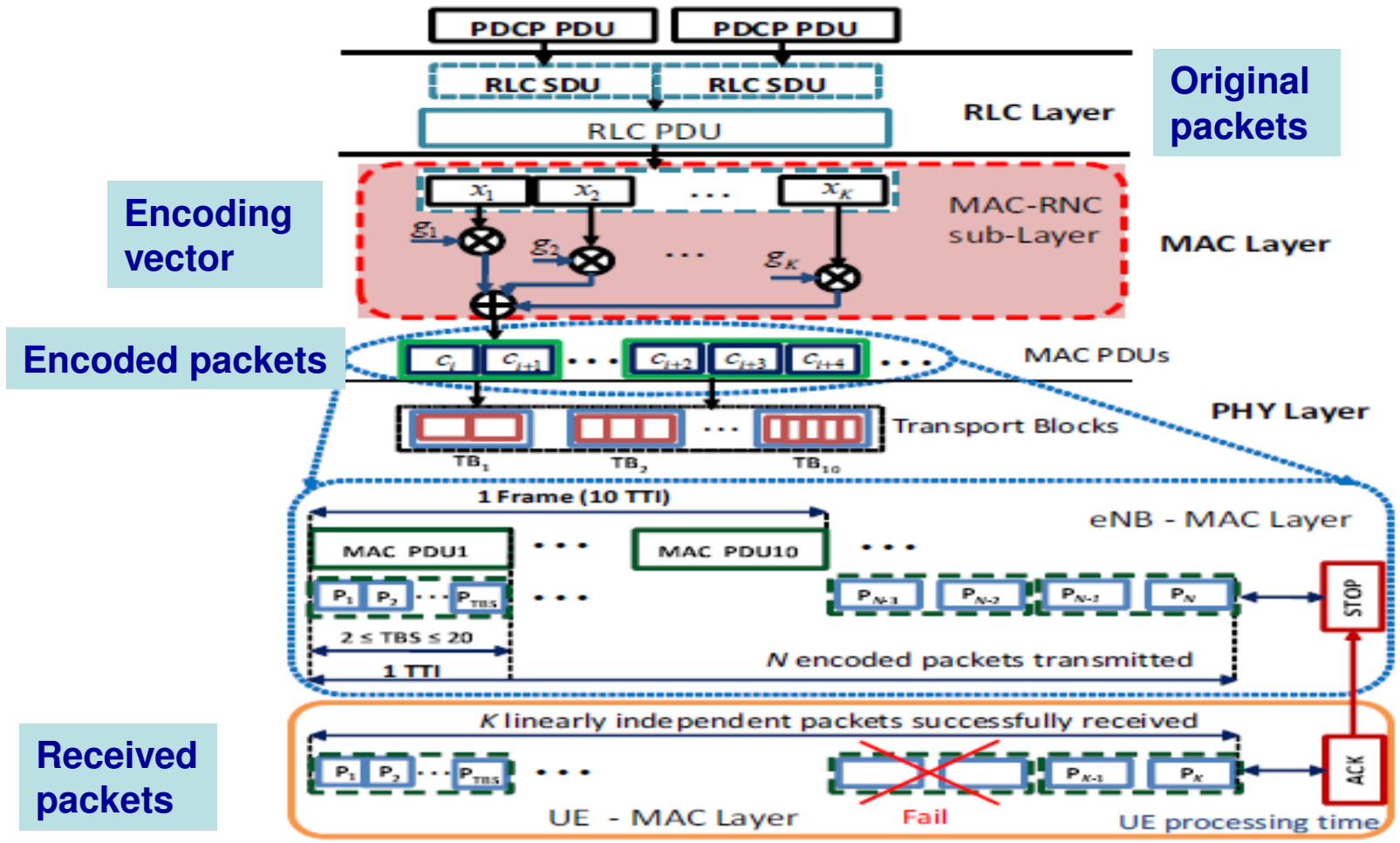
- **Packet** are combined **randomly (**borrows the combining idea from network coding)
- **But** is applied inside **one base station** (not in a network)
- Base station **generates** multiple **random linear combinations** of data packets for **robust delivery** to a terminal.

Proposed R-NC scheme for LTE-Advanced is used for:

- **Short to medium size messages** (rateless coding solution)
- **Throughput enhancement and Energy saving**

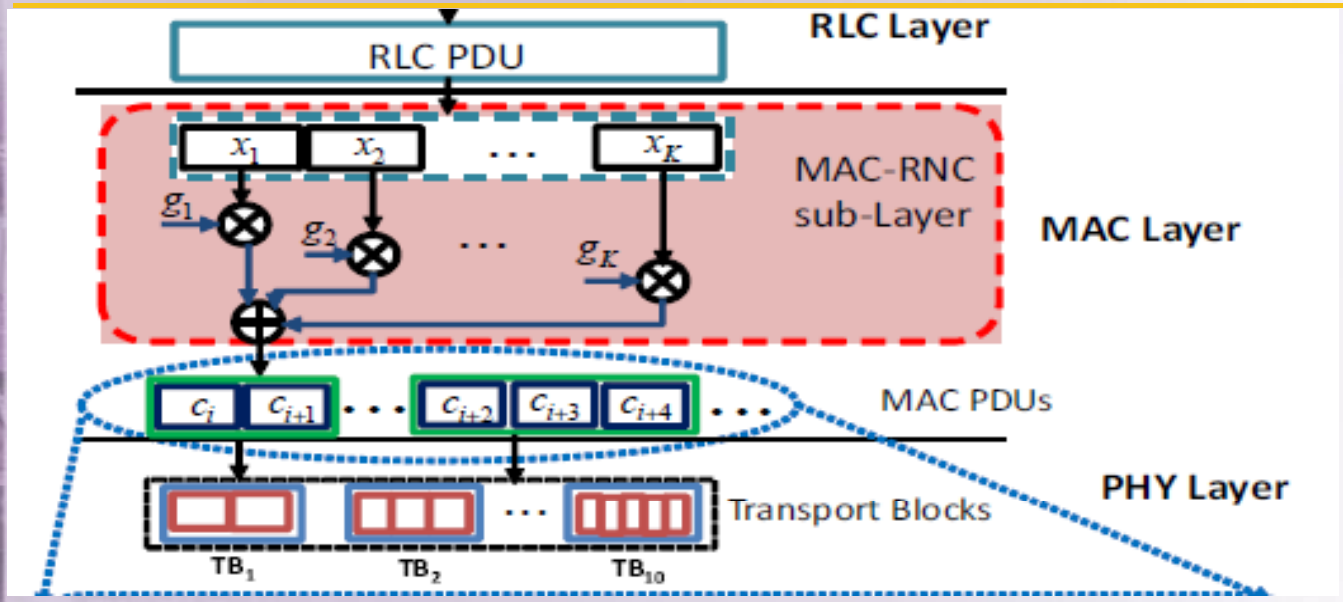
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R-NC Integration into LTE MAC Layer



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How does R-NC scheme work ?



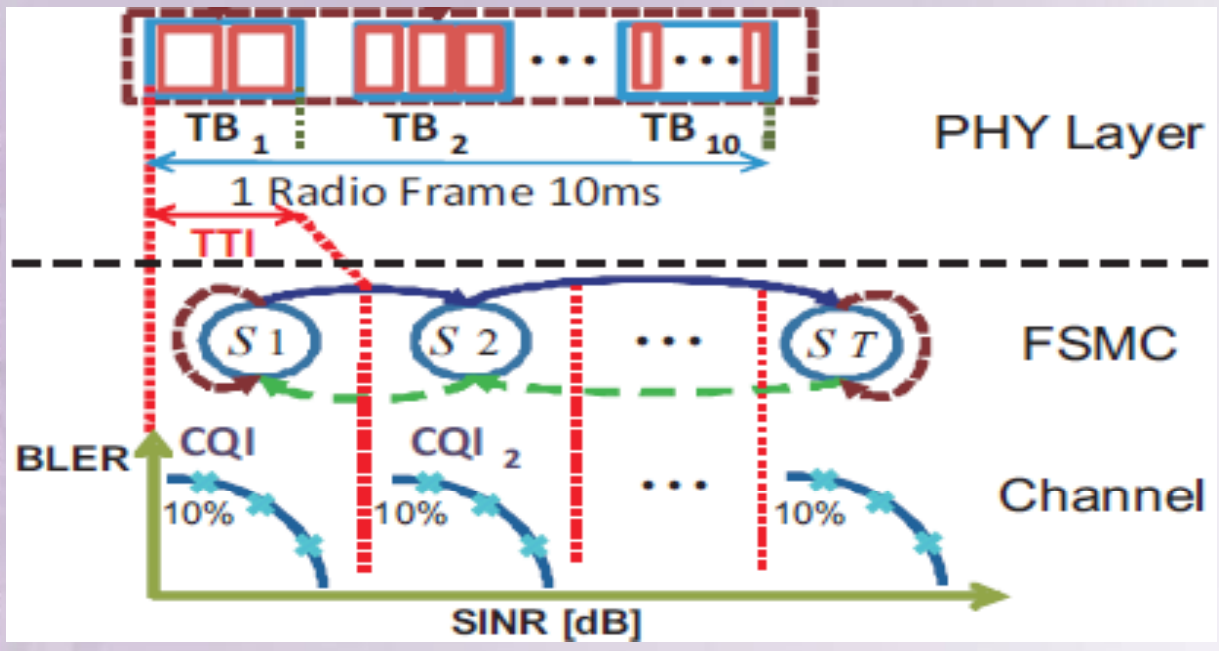
MAC Layer
R-NC

RLC PDU (**source message**) is:

- **segmented** into K packets {x_1, x_2,..., x_K}
- **randomly encoded**, using encoding **coefficients** {g_1, g_2, ..., g_K}
- **combined** packets {c_1, c_2, ...} are **placed** into **MAC PDUs**
- **MAC PDUs** are put in **TBs** and **transmitted without** any **feedback**
- **UE** sends an **ACK feedback** for **correct** reception of the RLC PDU

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Finite-State-Markov-Chain (FSMC) model



FSMC channel model in LTE

PHY layer

- **MAC PDUs** are mapped to **TBs**, based on **CQI values**

Channel

- TBs are transmitted over Rayleigh fading channels
- **Channel dynamics** are approximated using **FSMC model**
- FSMC **states** corresponds to different **CQI values**

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Why Random Network Coding ?

Architecture

- MAC Layer R-NC is a simple replacement to HARQ

R-NC scheme significantly reduces signalling overhead

- Only one ACK is sent when UE decodes the source message

R-NC handles packet errors and channel changes very robustly

- flexibly adapts the transmission rate to the channel conditions

Redundancy and data protection across the RAN ONLY!

- Small round-trip delay (MAC layer LTE)

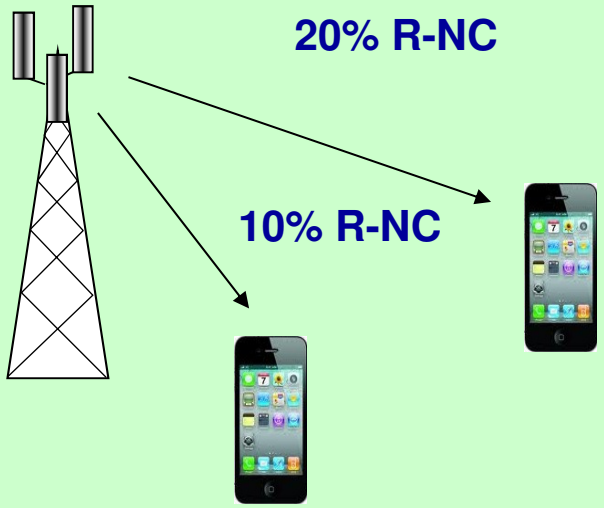
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R-NC practical applications: Fiction?

R-NC has recently been deployed in a multicast video streaming application on iPhone platform

Systematic R-NC to ensure reliability with low overhead

- 1st stage, transmit all packet uncoded
- 2nd stage, transmit random linear combinations to compensate packet loss (1st stage).



Percentage of R-NC packets for channels with BLER =10%, 20%

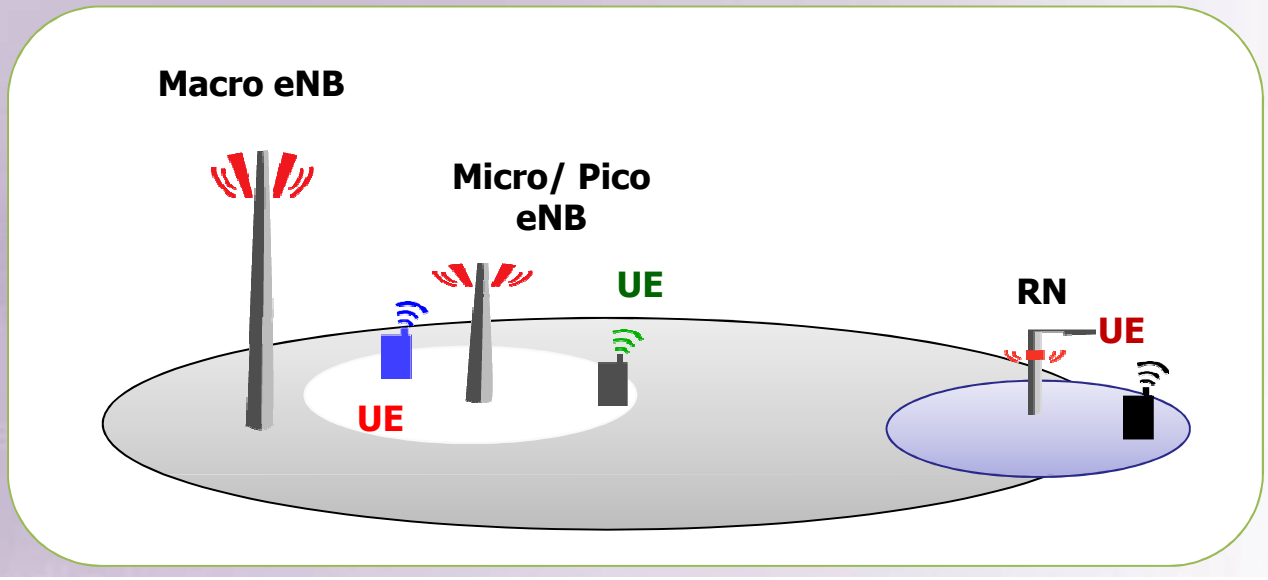
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Simulation Parameters

Parameter	Value
Traffic model	Downlink full buffer
ISD	500 or 1732m
System bandwidth	20MHz (per cell sector)
Transmission scheme	SISO
Frame structure	LTE-FDD, Frame duration 10ms
Carrier frequency	2.0GHz
System layout	multi-cell (19 macro-cells) with 5 RNs per cell-sector
Pathloss	eNB-UE, eNB-RN, RN-UE [3]
Penetration loss (PNL)	20dB (except eNB-RN:0dB)
Shadowing	Shadow fading: Log normal Std deviation: 8dB(eNB-UE), 6dB(eNB-RN), 10dB(RN-UE)
Scheduling	Round robin
Terminal speed	3, 30 and 120km/h
Max Tx power	eNB:46dBm/sector, RN:38dBm
Max Antenna gain	eNB:14dBi, RN:5dBi, UE:0dBi
Antenna height	eNB:25m, RN:5m, UE:1.5m
Noise figure	RN:7dB, UE:7dB
Relay location	0.8 of sector radius
Max. HARQ retransmissions	3

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Single-point and multi-point transmission setups



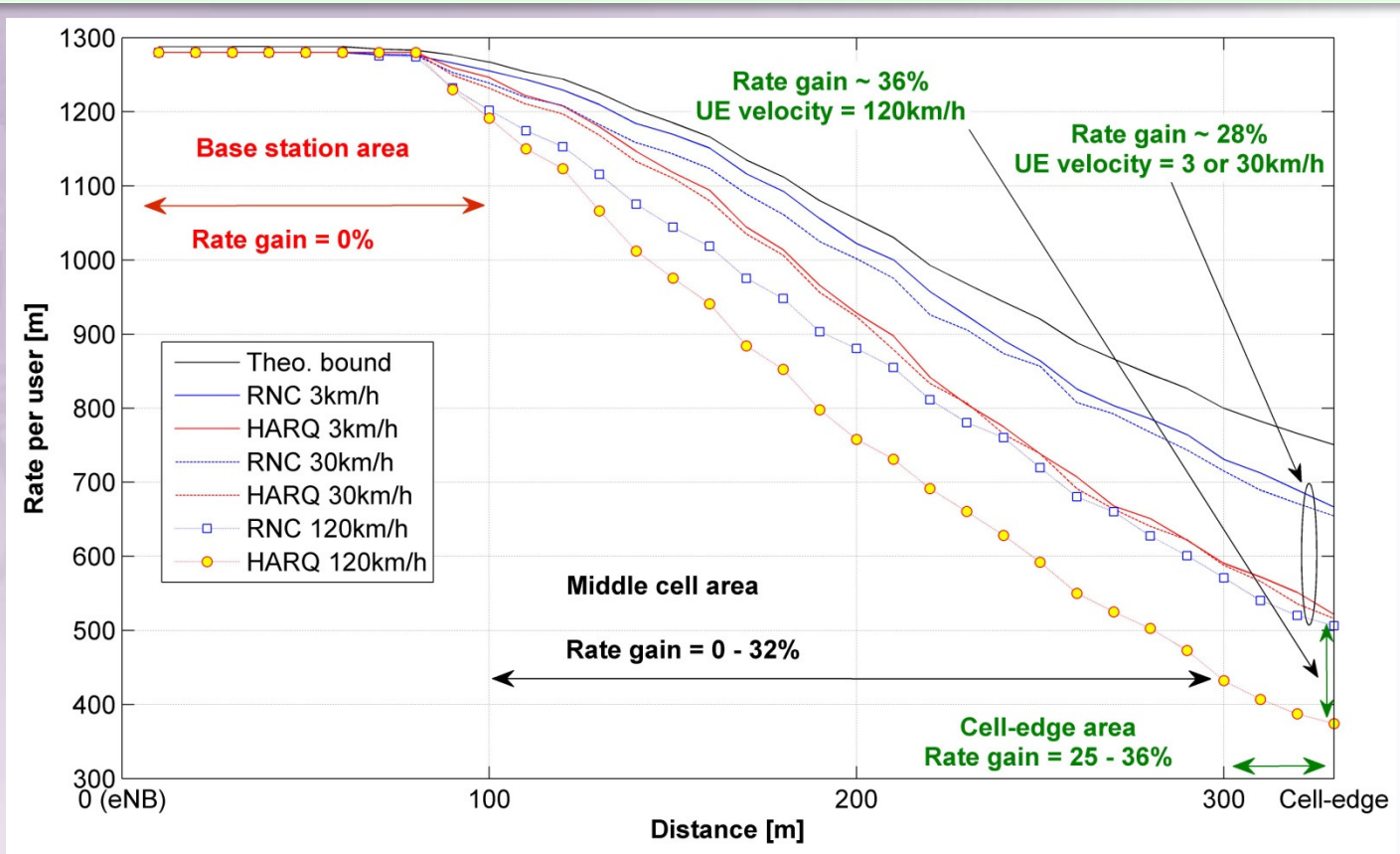
A performance comparison of MAC R-NC and MAC HARQ protocols

- Single-point and multi-hop/multi-point, different macro cell sizes (ISD=500, 1732m), traffic load values, time-delay limits
- Energy consumption ratio (ECR) – total energy (in joules) spent per delivered bit to the UE, ECR [Joule/bit]
- Energy reduction gain (ERG) - the percentage of energy saved by the test system when compared to a baseline system.

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Single-point: Rate gain – UE mobility

UE speed 3, 30, and 120 km/h, ISD = 500 m, delay-limit = 32 TTI

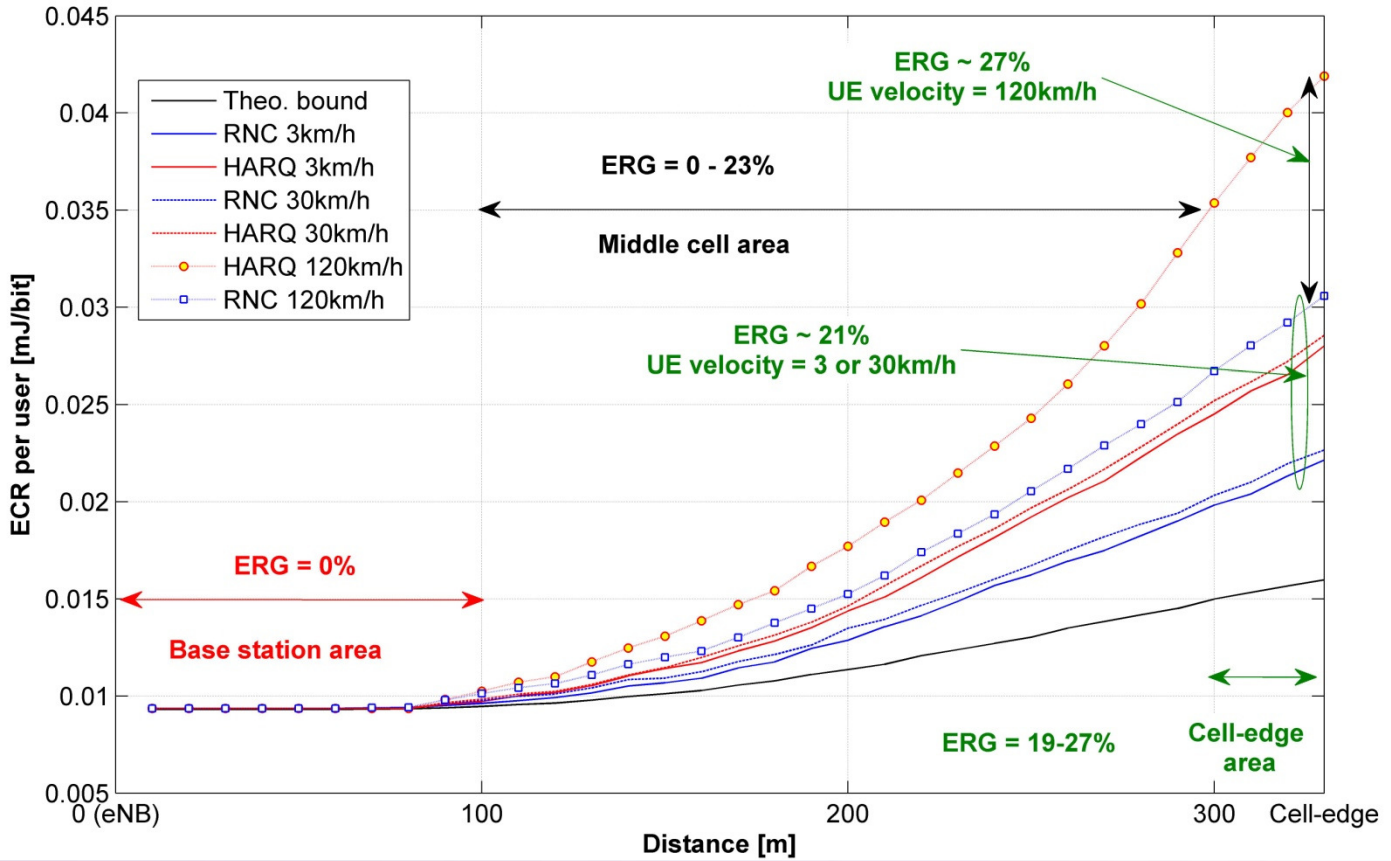


MAC R-NC offers rate gains of 22- 32% (middle cell) and 26-35% (cell edge)

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Single-point: Energy gain – UE mobility

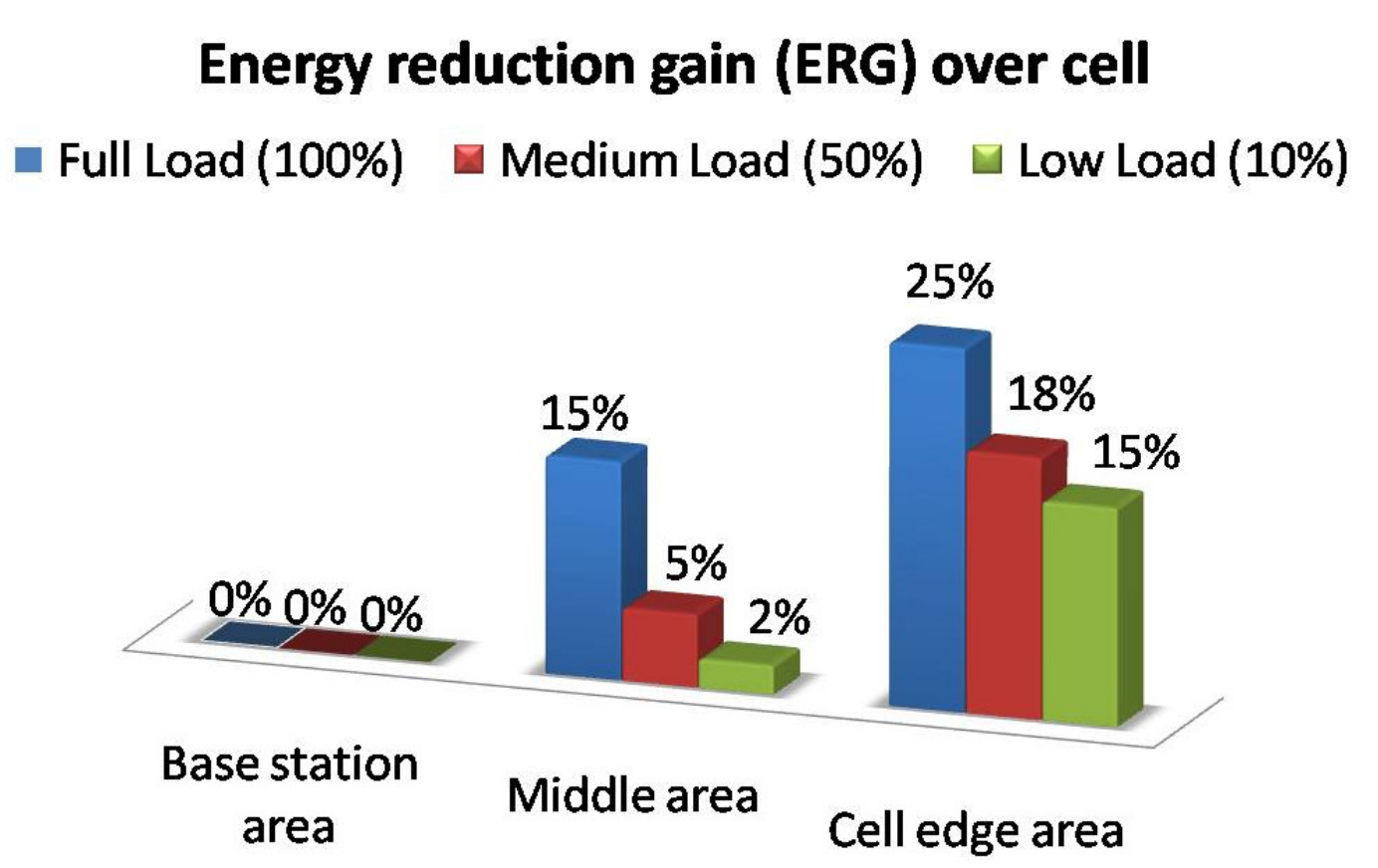
UE speed 3, 30, and 120 km/h, ISD = 500 m, delay-limit = 32 TTI



MAC R-NC offers ERG of 19- 27% (middle cell) and 21-27% (cell edge)

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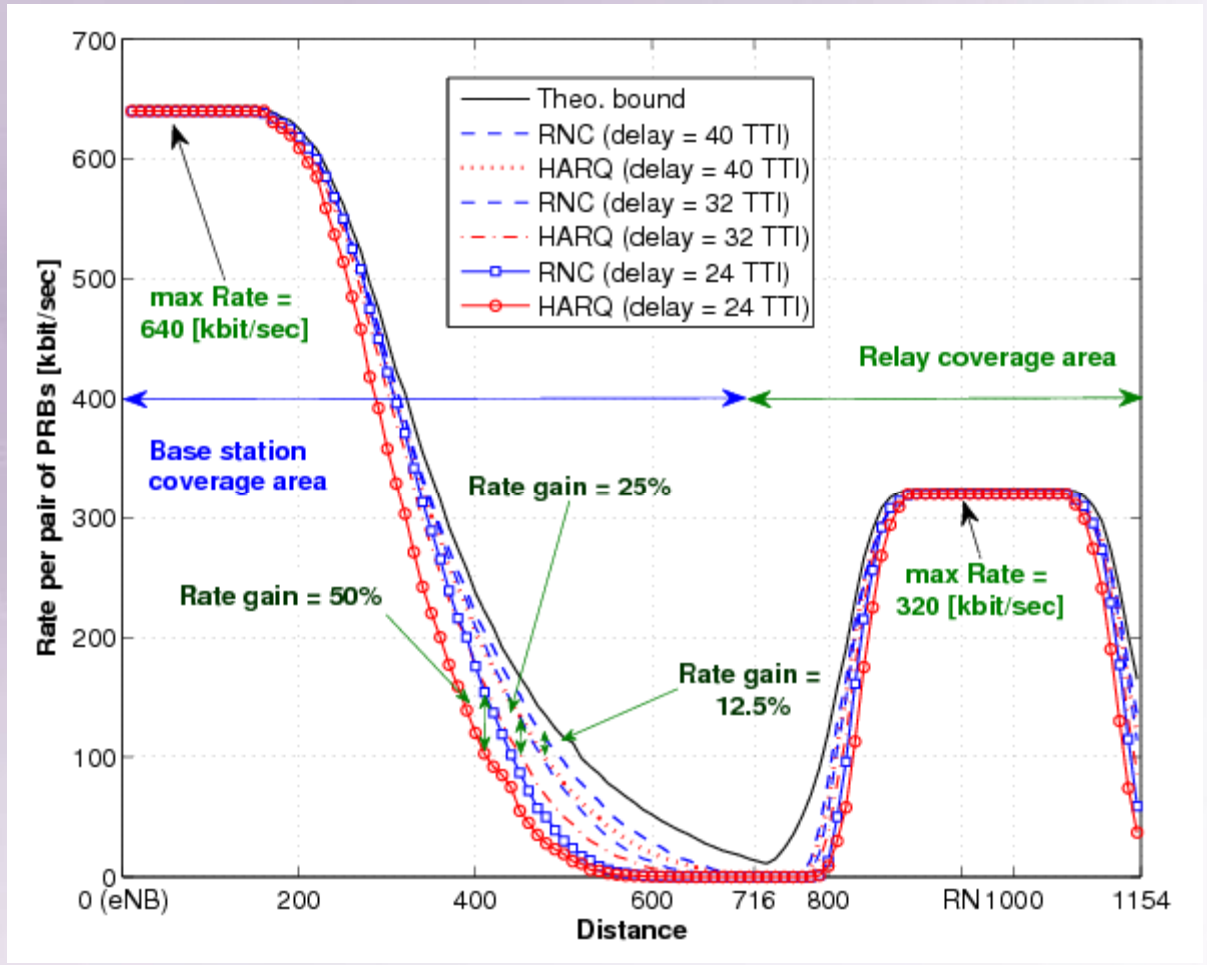
Single-point: Energy gain – Traffic load



Energy gain of MAC R-NC with different traffic load values over the cell (ISD = 500 m, delay-constraint = 32 TTI)

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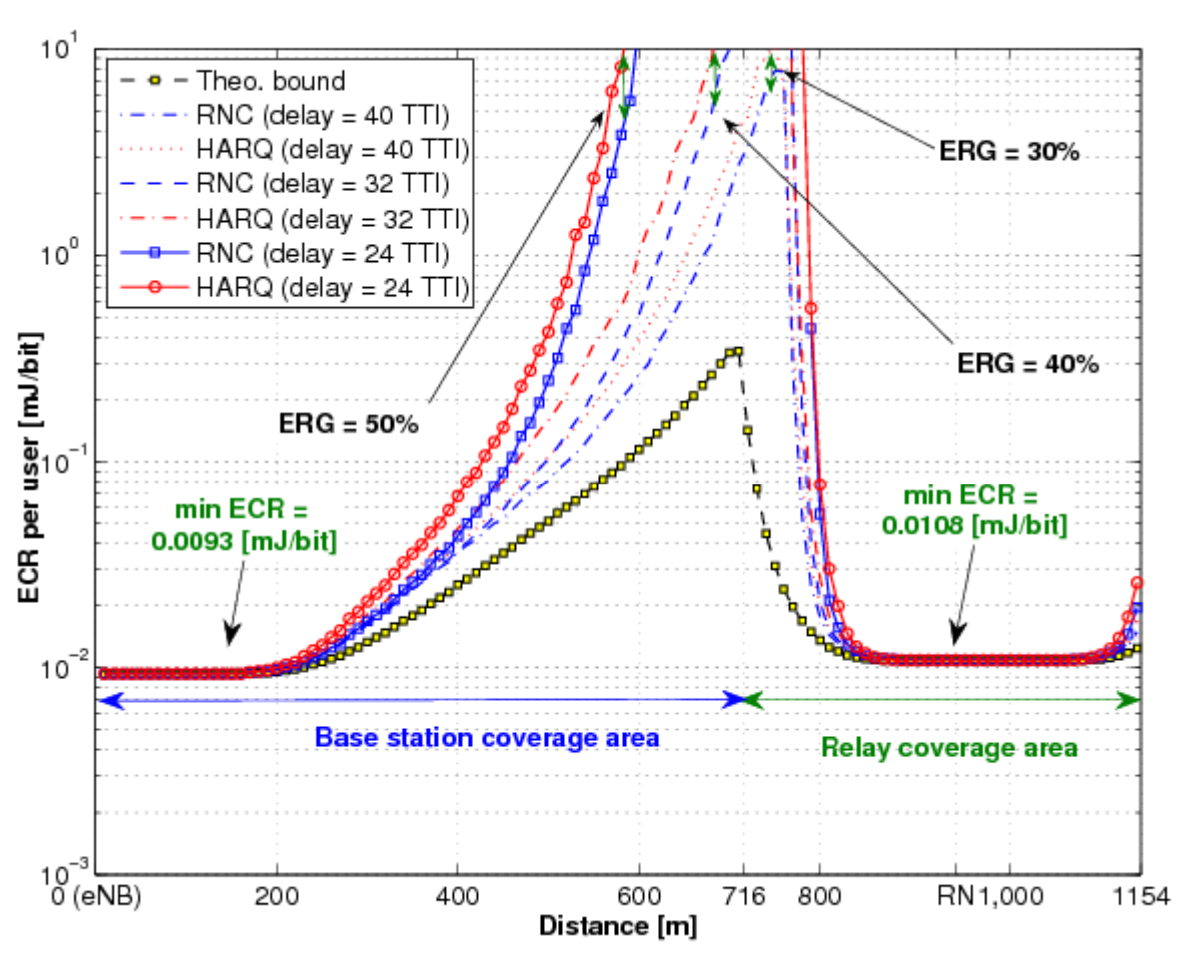
Single-point Relay assisted:
Rate gain – delay constraints



MAC R-NC deployment offers normalized rate gains of 12.5 - 50% for the delay-limit delivery with limits set to 24, 32, and 40 TTIs (ISD= 1732m)

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Single-point Relay assisted: Energy gain – Traffic load



MAC R-NC deployment offers ERG of 30 - 50% at the cut-off distance for the delay-limit delivery with limits set to 24, 32, and 40 TTIs (ISD= 1732m)

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Conclusions

Novel MAC R-NC protocol to replace state-of-the-art MAC HARQ in future E-UTRAN heterogeneous architectures

Energy efficiency and throughput enhancement

- **R-NC reduces signaling overhead compared to HARQ**
- **ERG = 25%, Rate gain = 36%**
- **Simple and flexible encode/decode process**

R-NC technique can reduce delay and offer more energy efficient transmission of delay critical traffic

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Future work

Energy/Spectrum efficient Multimedia delivery services for LTE-A Heterogeneous Networks

- Reduced ACK messages overhead (save UE battery)
- Content-aware resource allocation
- Unequal error protection (UEP) coding

Cooperation between collocated users (M2M)

- Reduce base station re-transmission (save energy and resources)

Feasibility of future network access platforms supporting R-NC performance

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Thank you



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