# Simulation Based Energy Efficiency Analysis of DUDe 5G Networks

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# Short Resume

Chrysostomos-Athanasios Katsigiannis was born in 2001 in Athens, Greece. In 2016 he received the Michigan Certificate of Proficiency in English and in 2018 he received the Goethe Zertifikat B2 (B2 Certificate for the German Language).

Later, in 2019 he graduated high school from Elliniki Paideia and began studying as an undergraduate student in the Department of Computer Engineering and Informatics at the University of Patras in September 2019.

He has been a member of the Distributed System and Telematics Lab since 2022 and his fields of interest are 5th generation mobile telecommunication networks and artificial intelligence.

# Outline

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# Introduction

- The rise of 5G is expected to significantly increase mobile traffic and the number of connected devices, challenging resource allocation and network throughput.
- Downlink/Uplink Decoupling (DUDe) in HetNets allows separate connections for uplink and downlink, optimizing cell association and resource allocation.
- Traditional cell association based solely on downlink signal strength is inefficient in HetNets due to varied transmission power and interference levels.
- DUDe can improve 5G energy efficiency by enabling dynamic resource allocation, intelligent power management, and potentially reducing infrastructure needs.
- This paper seeks to validate earlier findings by examining system performance across different user numbers and dB values, aiming to fill research gaps and provide insights for network optimization.

# DUDe Energy Efficiency Overview

- DUDe offers key advantages such as reduced energy consumption by separating downlink and uplink channels to minimize operational energy needs, thereby contributing to environmental sustainability.
- DUDe's effect on resource distribution shows potential for fairer user spread across cell types by considering the capacity limits of Macro, Micro, and Pico cells, improving network efficiency.
- Key DUDe benefits include lower energy consumption by separating uplink and downlink channels, reducing network's environmental impact.
- DUDe also aims to boost network performance and reliability by cutting downlink and uplink interference and allowing more adaptable resource allocation, enhancing user experience during peak times.

# Mathematical Model

- The paper employs a specific mathematical model to evaluate the minimum distance between users and base station antennas, focusing on assessing path loss under various conditions such as line-of-sight and non-line-of-sight.

- This approach allows for the detailed calculation of path loss by incorporating factors like the three-dimensional distance between users and antennas, carrier frequency, and user height, aiming to adapt to diverse environmental conditions.

- Following the assessment of distances, the study progresses to determine the Signal-to-Noise Ratio (SNR), which is pivotal for identifying the most suitable antenna type to ensure the best possible connectivity for users.

# Energy Efficiency Algorithm

- The pseudo algorithm of our experiments

```
//Initialize variables
Macro_cells
Micro_cells
Pico_cells
N = total number of UEs
occurrences_for_scenarios
SNR_matrix = zeros(N, occurrences_for_scenarios)
// calculate best SNR for each UE for occurrences_for_scenarios
for i in range(N):
 for j in range(occurrences_for_scenarios):
// calculate SNR for current occurrences_for_scenarios
SNR = calculate_SNR(UE_i, occurrences_for_scenarios _j)
SNR_matrix[i][j] = SNR
 end
end
// calculate standard SNR value for each UE for each occurrences_for_scenarios
standard_SNR = zeros(N, occurrences_for_scenarios)
for i in range(N):
for j in range(occurrences_for_scenarios):
// calculate standard SNR for current snapshot
standard_SNR[i][j]=sum(SNR_matrix[i][j])/occurrences_for_scenarios
// calculate transmit power for each UE for each occurrences_for_scenarios
transmit_power = zeros(N, snapshots)
end
end
for i in range(N):
for j in range(occurrences_for_scenarios):
// calculate transmit power for current snapshot
transmit_power[i][j] = calculate_transmit_power(UE_i, standard_SNR[i][j])
// build coupled scenario and distribute UEs in the network
coupled_power = zeros(N)
end
end
for i in range(N):
// if transmit power is less than 20 or 30 dbm, keep value
if transmit_power[i][-1] < 20 if transmit_power[i][-1] <30:
coupled_power[i] = transmit_power[i][-1]
// if transmit power is above 20 dbm, change value to 20 dbm
else:
coupled_power[i] = 20 or 30
// build decoupled scenario and distribute UEs in the network
decoupled_power = zeros(N)
end
for i in range(N):
// calculate transmit power using decoupling technology
decoupled_power[i] = calculate_decoupled_transmit_power(UE_i, standard_SNR)
// compare energy efficiency between coupled and decoupled scenarios
end
if sum(coupled_power) > sum(decoupled_power):
output("Decoupling technology is more energy efficient.")
else:
output("Coupling technology is more energy efficient.")
```

# Energy Efficiency Algorithm

- The algorithm begins by initializing variables for the Macro, Micro, and Pico cells, UEs, and simulation snapshots, aiming to map out the network's coverage across different cell types and user dynamics.
- It calculates the SNR for each user equipment (UE) within the network for each snapshot, storing these values in a matrix to assess connectivity quality.
- After determining SNR values, the algorithm computes and records the average SNR for each UE across all snapshots to establish a standard SNR matrix, which helps in evaluating consistent network performance.
- The algorithm constructs DUCo and DUDe scenarios, adjusting UE transmit power based on SNR and transmit power thresholds, and runs simulations over numerous snapshots to ensure consistent, reliable outcomes.

# Simulation Environment

- The 5G DUDe network features 2 Macro, 4 Micro, and 8 Pico cells, with capacities for 2000, 200, and 46 users respectively, using MATLAB for its comprehensive libraries in algorithm development.
- Users are spaced 1-2 meters apart, connecting to Macro cells for downlink and the nearest Micro or Pico cells for uplink, based on the lowest path loss calculated with MATLAB's nrPathLoss function.
- Path loss calculations help determine the best BS connection for each user by the highest SNR, ensuring efficient connectivity and reduced power usage.
- Specifications for antenna heights, gains, and transmission powers enable energy efficiency comparisons between DUCo and DUDe techniques, highlighting DUDe's advantage in scenarios with varying user densities.

# Simulation Environment

| Parameter | Value |
|---|---|
| Amount of Base Stations | Macro cell = 2<br>Micro cell = 4<br>Pico cell = 8 |
| Transmit power(dbm) | UE=20,30<br>Macro cell = 45<br>Micro cell = 33<br>Pico cell = 24 |
| BS height (m) | Macro height = 25<br>Micro height =15<br>Pico height = 10 |
| Antenna gain (dbi) | Macro cell = 21<br>Micro cell = 10<br>Pico cell = 45 |
| Bandwidth (MHz) | 20 |
| Environmental parameters | UE1=500/UE2=1000/UE3=2000<br>Position=random |
| Power Noise | Pnoise= -74+10log(Bandwidth(hz)) |

Simulation Parameters

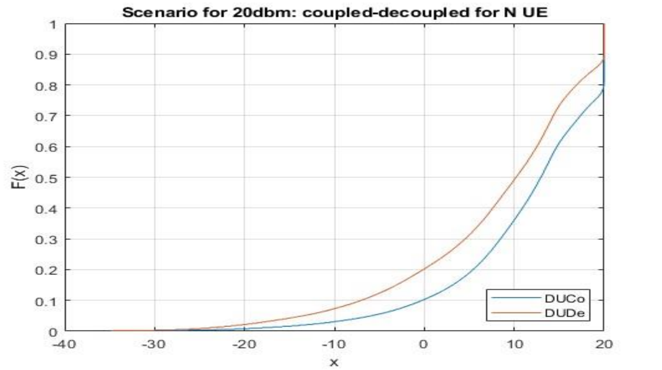
# Results Evaluation and Analysis

A. General Analysis

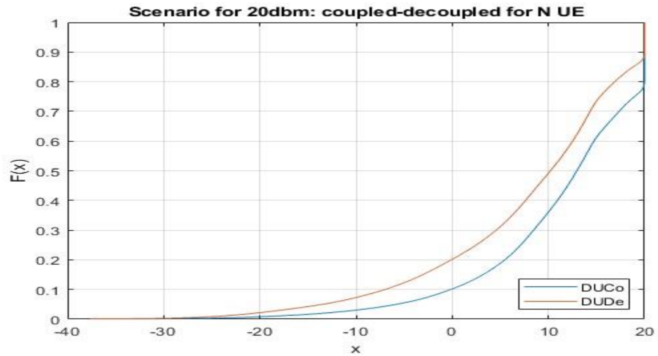
- Evaluations at 20 dBm UE power show DUDe's superior energy efficiency, achieving desired outcomes with less power, as demonstrated across Figures 5 to 7.
- DUDe outperforms DUCo with a higher connection success rate, boasting at least 20% more successful connections, underscoring its reliability and energy-saving potential.
- At an SNR of 15 dB, DUDe has an 80% chance of lower power consumption compared to DUCo's 62%, evidencing DUDe's effectiveness in reducing energy use for sustainable 5G networks.

# Results Evaluation and Analysis

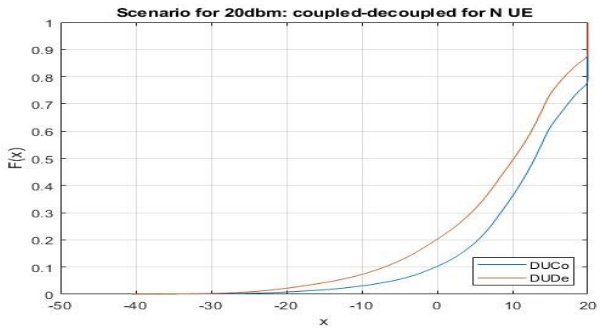
B. Result presentation of 1st scenario:




DUDe comparison with 20dbm UE limit for N=500.




DUDe comparison with 20dbm UE limit for N=1000.




DUDe comparison with 20dbm UE limit for N=2000

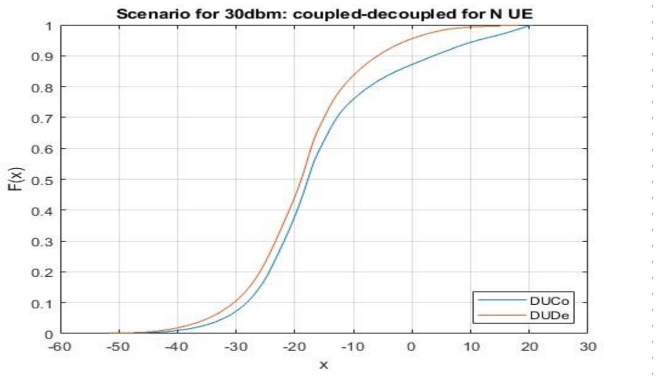
# Results Evaluation and Analysis

B. Evaluation of 1st scenario:

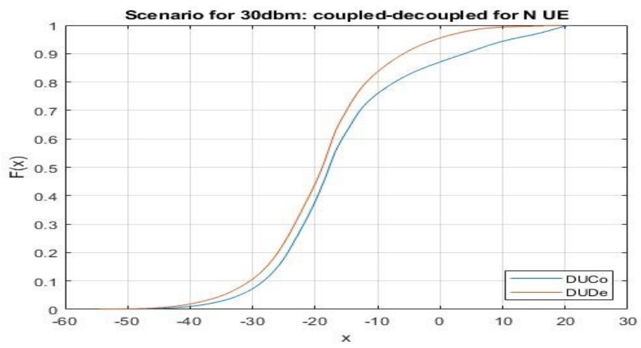
- Evaluations at 20 dBm UE power show DUDe's superior energy efficiency, achieving desired outcomes with less power, as demonstrated in the diagrams above.
- DUDe outperforms DUCo with a higher connection success rate, boasting at least 20% more successful connections, underscoring its reliability and energy-saving potential.
- At an SNR of 15 dB, DUDe has an 80% chance of lower power consumption compared to DUCo's 62%, evidencing DUDe's effectiveness in reducing energy use for sustainable 5G networks.

# Results Evaluation and Analysis

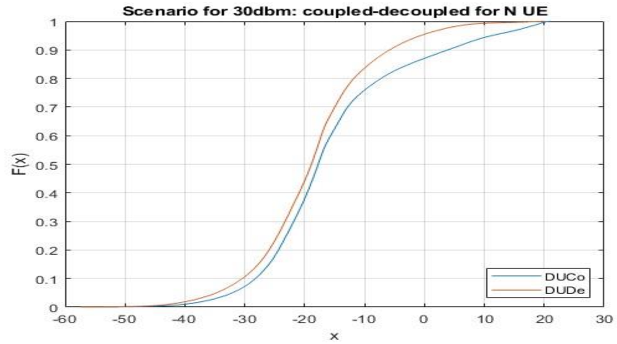
B. Result presentation of 2nd scenario:




DUDe comparison with 30dbm UE limit for N=500.




DUDe comparison with 30dbm UE limit for N=1000.




DUDe comparison with 30dbm UE limit for N=2000

# Results Evaluation and Analysis

B. Evaluation of 2nd scenario:

- Despite a 30 dBm power cap by 3GPP, DUDe remains more energy-efficient than DUCo in a second scenario, confirming its environmental benefits even with increased transmission limits.
- Data shows DUDe's higher likelihood of association at lower transmission powers, achieving over 70% connection probability with just 2 dBm, highlighting its efficiency.
- DUDe consistently outperforms DUCo in connection success rates, requiring significantly less power (e.g., 10 dBm for 100% success) compared to DUCo's higher needs, reinforcing DUDe as the preferable, more energy-efficient method for 5G networks.

# Conclusions and Future work

A. Conclusion

- Energy efficiency in 5G networks is crucial for economic and environmental benefits, supporting IoT and other services by providing sustainable connectivity.

- Comparative analysis shows DUDe is more energy-efficient than DUCo in a 5G HetNet, requiring less energy for the same network tasks.

- DUDe's potential to reduce energy consumption is highlighted by optimizing downlink and uplink transmissions, benefiting operators and users through cost savings and better experiences.

# Conclusions and Future work

## B. Future Work

- Optimizing bandwidth allocation with DUDe could further improve energy efficiency and network throughput, a key step for large-scale 5G networks.

- Future research could investigate the impact of user population sizes on DUDe's efficiency, ensuring the approach's effectiveness across different network scales.

- Ongoing exploration into energy-efficient strategies is encouraged to reduce mobile networks' environmental impact and enhance sustainable mobile communications.

# Thank You!

Questions?

Remarks?

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