CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ELECTRICAL ENGINEERING
DEPARTMENT OF TELECOMMUNICATION ENGINEERING

Activities of 6Gmobile Research Lab

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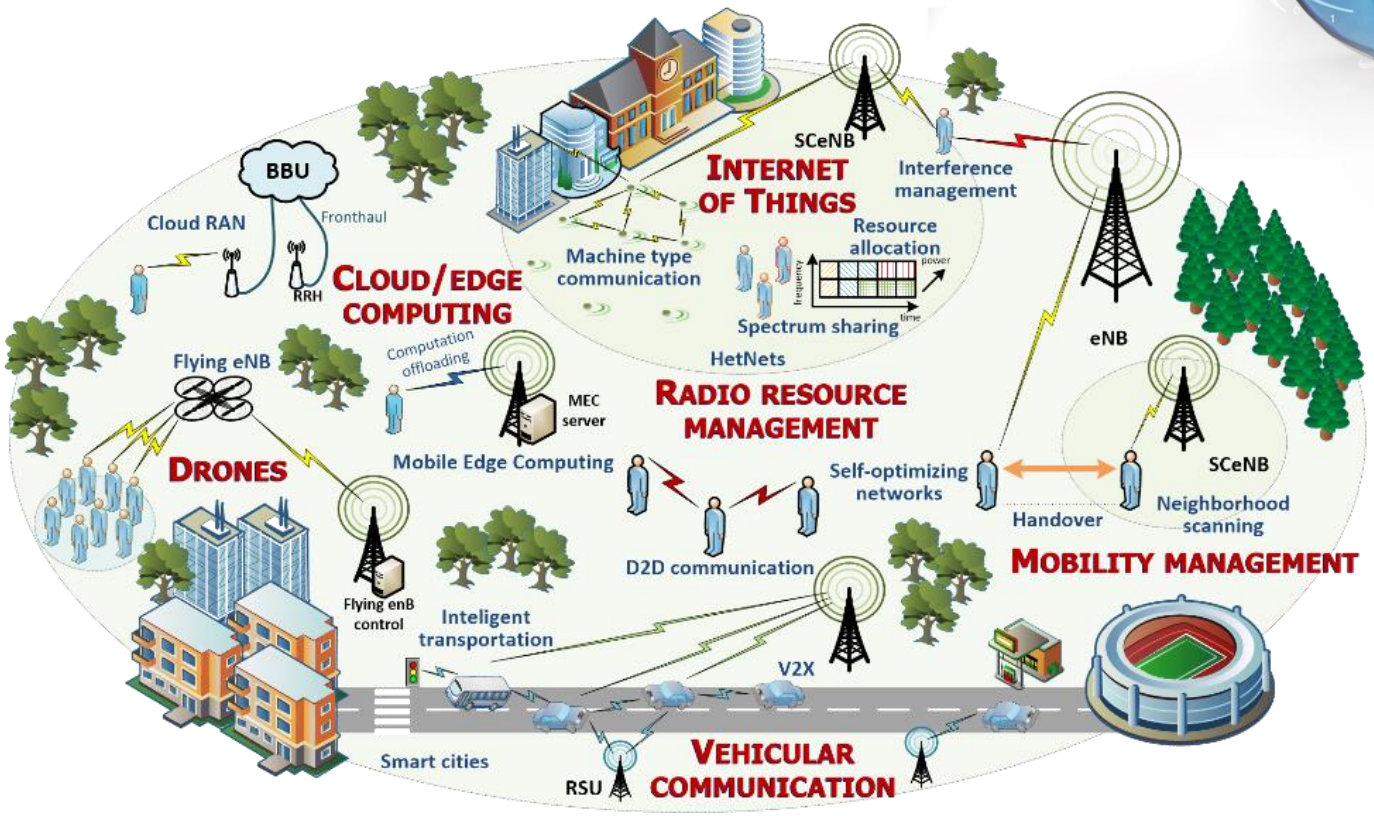
6G mobile RESEARCH LAB

Overview of activities done in 6Gmobile Lab



Focus on **key challenges** related to future mobile networks and emerging wireless technologies

- **Theoretical research** exploiting various optimization techniques, game theory, and machine learning
- **Practical verifications** in laboratory equipped with hardware and software for emulation of mobile networks

Theoretical research

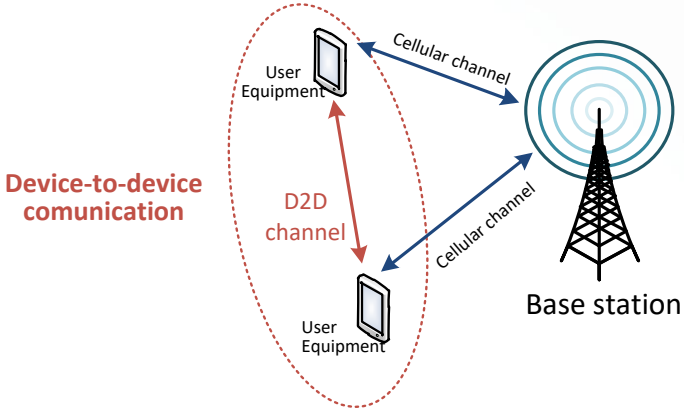
Device-to-Device (D2D) communication

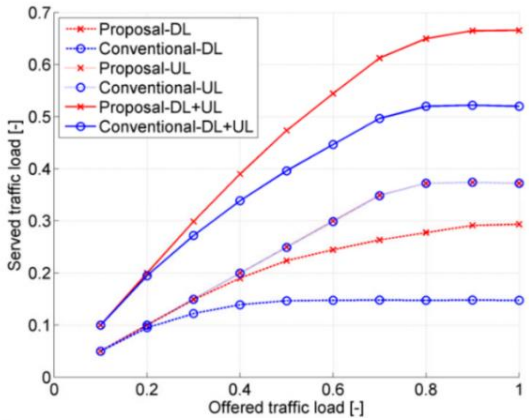
Direct communication between two devices (user equipment)

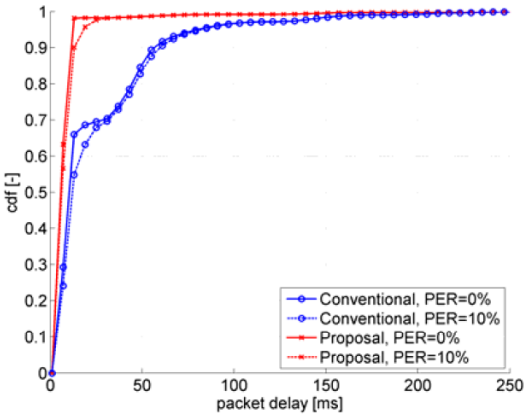
- **Data do not pass core network**, but routed directly between devices
- Introduced in 4G mobile networks (Release 12; March 2015)

Benefits of device-to-device communication

- Saving radio resources
- Shortening delay
- Reducing energy consumption





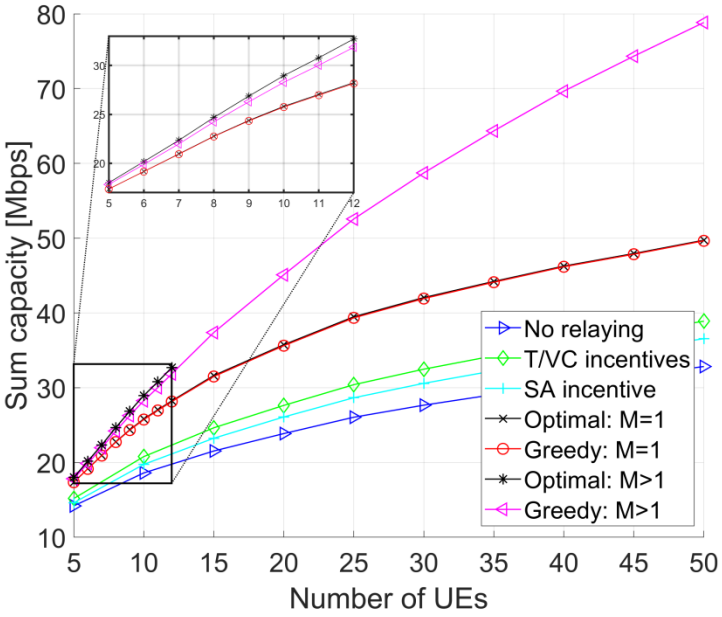


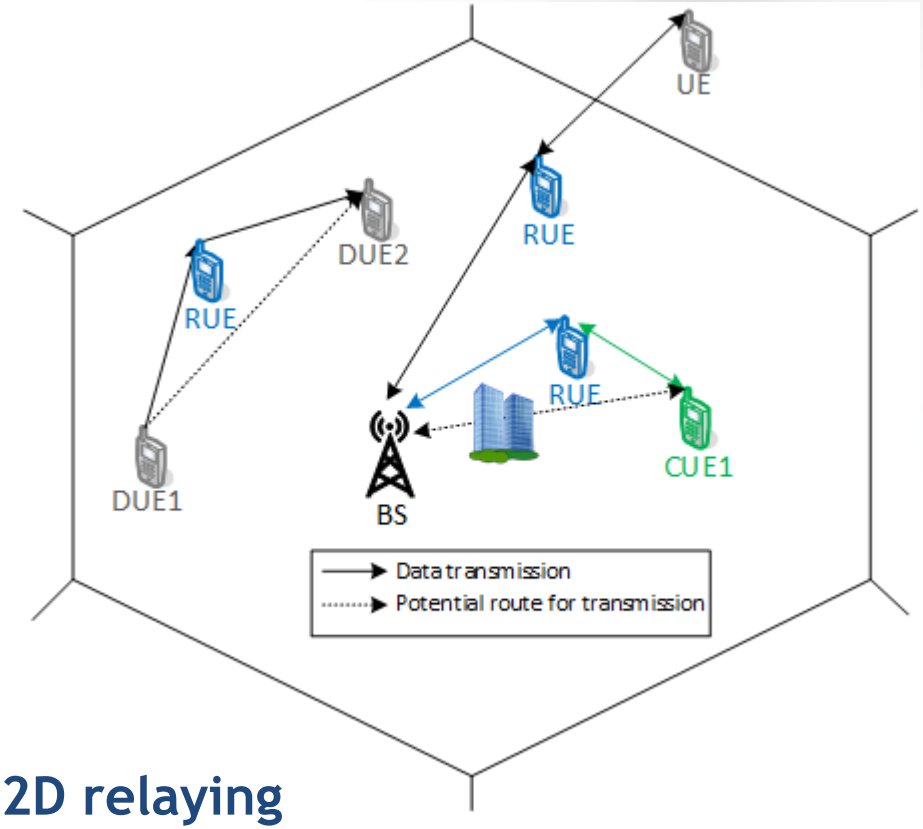
P. Mach, Z. Becvar, "Efficient Routing of Data for Femtocells," ***Wireless Days***, Niagara Falls, Canada, 2011.

Use-case of D2D communication

Why we need D2D? Why not simply use Bluetooth or Wi-Fi direct?

- Superior Quality of Service
- Longer distances
- Other interesting use-cases





D2D relaying

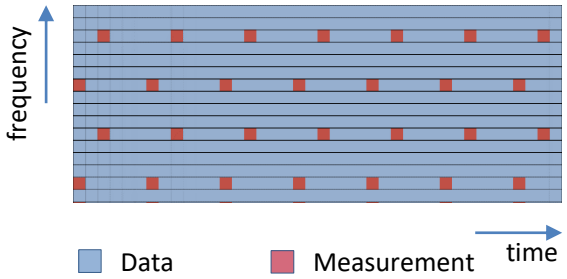
- Relaying of data between two users
- ***Enhancing*** the cell capacity
- ***Extending*** cell coverage

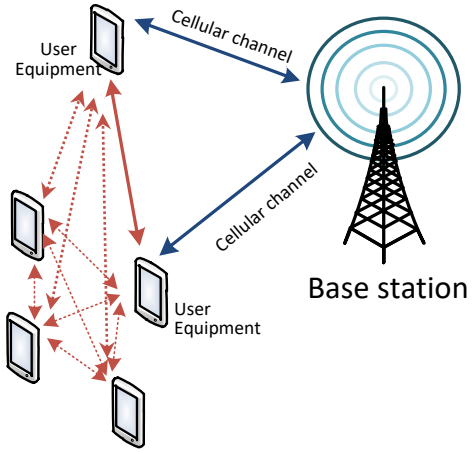
P. Mach, Z. Becvar, T. Spyropoulos, "Coping with Spatial Unfairness and Overloading Problem in Mobile Networks via D2D Relaying", ***IEEE Wireless Communications***, 2023.
P. Mach, T. Spyropoulos, Z. Becvar, "Incentive-Based D2D Relaying in Cellular Networks", ***IEEE Transactions on Communication***, 2021.
P. Mach, Z. Becvar, T. Spyropoulos, "Incentive Mechanism and Relay Selection for D2D Relaying in Cellular Networks", ***IEEE Global Communications Conference (IEEE Globecom)***, 2019.

Management of D2D communication

Management of D2D communication

- Many parameters and settings to be determined
  - Radio resource allocation, power allocation, mode selection (via base station or D2D), relay selection,…
- **Channel quality** needs to be known
  - **Communication** and **interference channels** among **all devices**
  - Optimal centralized solutions → **heavy signalling** (~ square of number of devices)
    - Measurement and reporting
- Resources for communication shared with those for measurement
  - **More measurements → less data, longer delay, higher energy consumption**

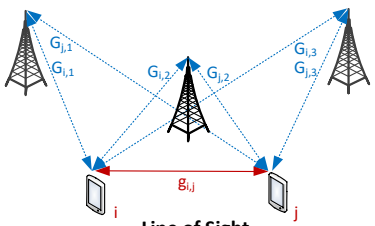




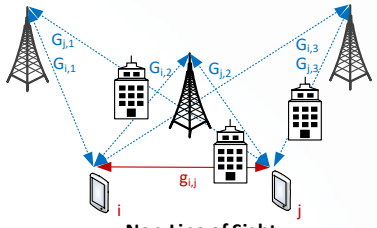
Channel quality for D2D communication

How to **determine quality of D2D channels with reasonable signaling?**

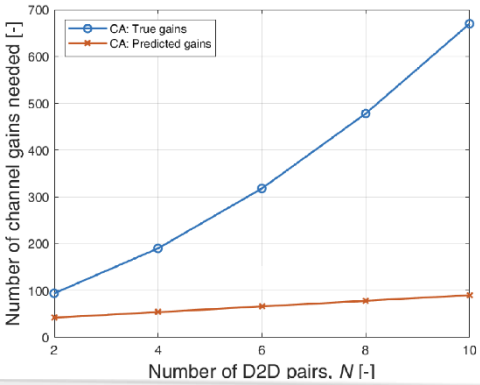
- **Known channels** to **base stations** ($G_{i,x}$, $G_{j,x}$) to extract **D2D channel quality** ($g_{i,j}$)
  - Channels to base station(s) required for general communication management
- **Ideal** environment
  - Line of sight, homogeneous channels
  - Cellular channels → Users' locations → D2D channels
  - Easy but not many practical use-cases
- **Realistic** environment (buildings, people,….)
  - Problem is **complicated**
    - No explicit relation among all channels
  - **Machine learning -** Deep Neural Network
    - Memorizes **topology** of environment and **expected channel quality**
    - **Number of measured channels linear with number of devices**

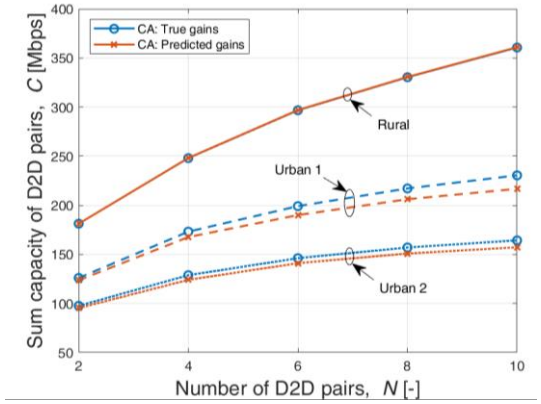


Line of Sight
Rural scenario



Non-Line of Sight
Urban scenario





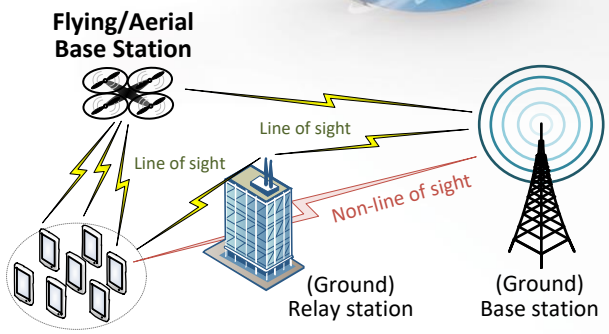
CA: Channel allocation scheme in P. Mach, Z. Becvar, M. Najla, "Resource Allocation for D2D Communication with Multiple D2D Pairs Reusing Multiple Channels," *IEEE Wireless Communications Letters*, 2019

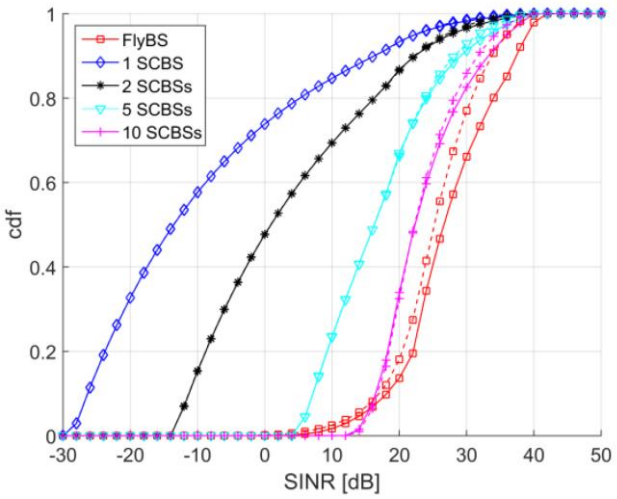
Z. Becvar, D. Gesbert, P. Mach and M. Najla, "Machine Learning-based Channel Quality Prediction in 6G Mobile Networks," ***IEEE Communications Magazine***, 2023.
M. Najla, Z. Becvar, P. Mach, D. Gesbert, "System and Method for Device-to-device Communication," ***US patent***, March 2022.
M. Najla, Z. Becvar, P. Mach, D. Gesbert, "Predicting Device-to-Device Channels from Cellular Channel Measurements: A Learning Approach," ***IEEE Trans. on Wireless Comm.*** 2020.

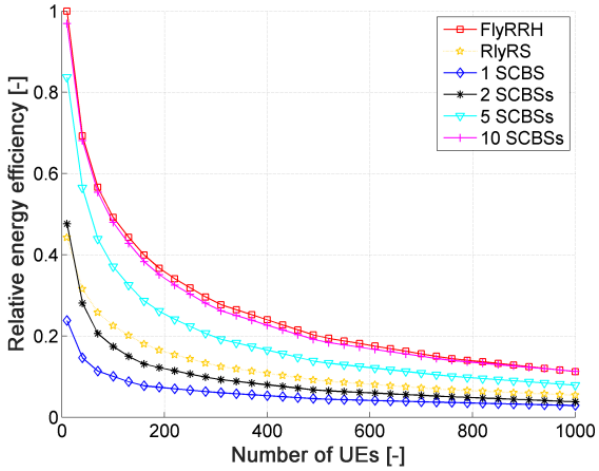
Communication in the sky

Traditional communication "on the **ground**"

- Signal attenuation problem (distance, obstacles)
  - **Ground relay stations**
    - Known for decades…
    - Limited dynamicity and flexibility
      - **Spatial-temporal traffic patterns fluctuation**
  - **Flying/Aerial base station** (FlyBS/UAV-BS/…)
    - **Relaying** communication of users to common ground base station
    - Low-cost alternative to dense deployment of ground base stations expected in 5G/6G
    - Improves energy efficiency of the user equipment





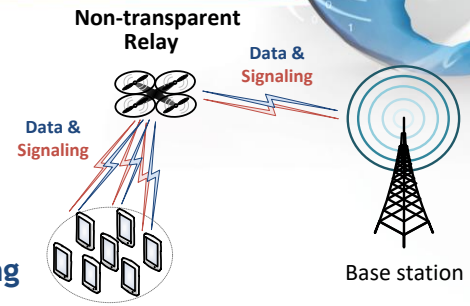


Z. Becvar, et al, "Performance of Mobile Networks with UAVs: Can Flying Base Stations Substitute Ultra-Dense Small Cells?," ***European Wireless* 2017, *Best paper award***.

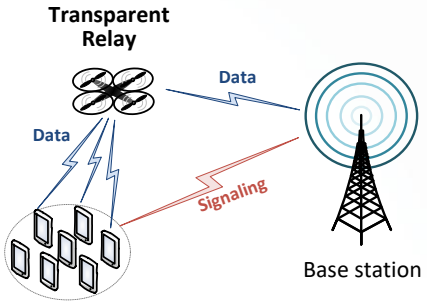
Relaying via flying base stations

Types of relays

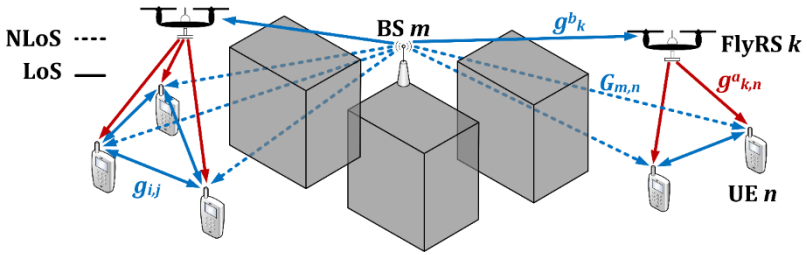
- **Non-transparent** (Type I)
  - Similar to common base station
  - Relatively **complex, heavy, expensive** and **energy consuming**

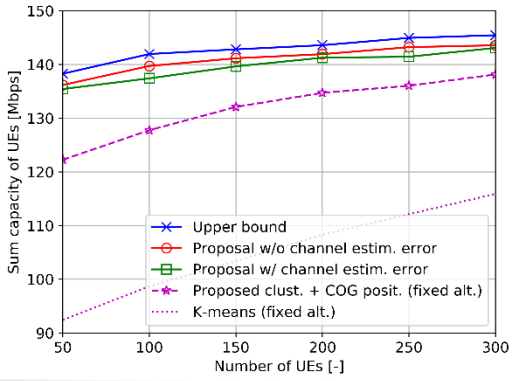


- **Transparent** (Type II)
  - **Limited functionalities,** data forwarded, but **signaling to/from base station**
  - Less complex, lighter, cheaper, and less energy demanding
    → **convenient for flying base stations**
  - **Channel quality between users and transparent relay not known**
    - Problem with association of users as well as with radio resource management
    - **Limited practical application**



- Exploit idea of DNN-based channel quality prediction (developed for D2D)
  - Determine association of users to FlyBSs
    - Agglomerative hierarchical clustering - similarity between two users ~ DNN-predicted D2D channel quality between these users
  - Determine position of the FlyBSs to server users (DNN)

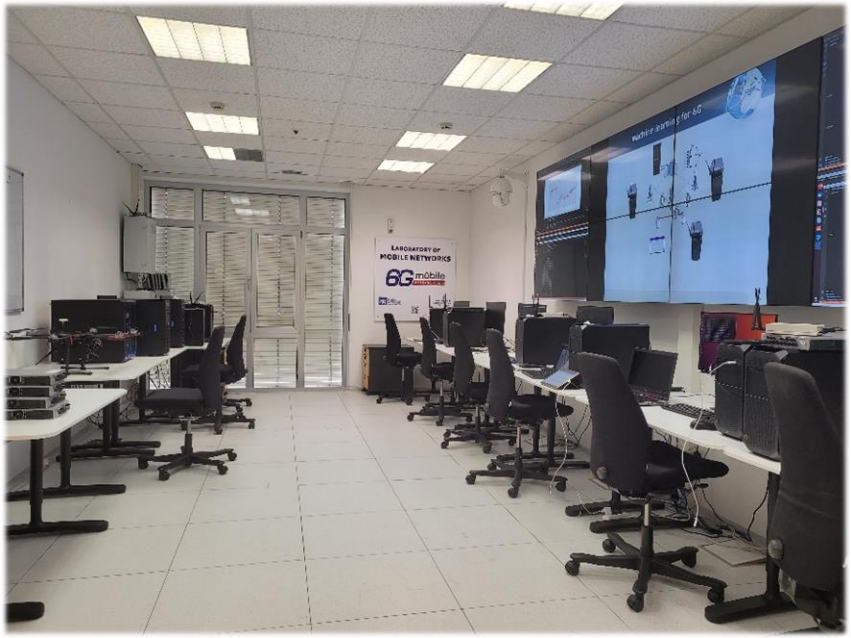




M. Najla, Z. Becvar, P. Mach, D. Gesbert, "Positioning and Association Rules for Transparent Flying Relay Stations," ***IEEE Wireless Communications Letters***, June 2021.
M. Najla, Z. Becvar, P. Mach, D. Gesbert, " Integrating UAVs as Transparent Relays into Mobile Networks: A Deep Learning Approach," ***IEEE PIMRC 2020***.

Practical verifications and demos

Our lab



HW/SW for emulation of 4G/**5G/ 6G**

- **USRPs B210/B205mini/B310** running a Software Define Radio
- **OpenAirInterface** and **srsRAN**
- **O-RAN** for intelligent radio access
- **Edge computing servers**
- **Drone** as a flying base station
- **Autonomous vehicle**
- **GPU for Machine learning**

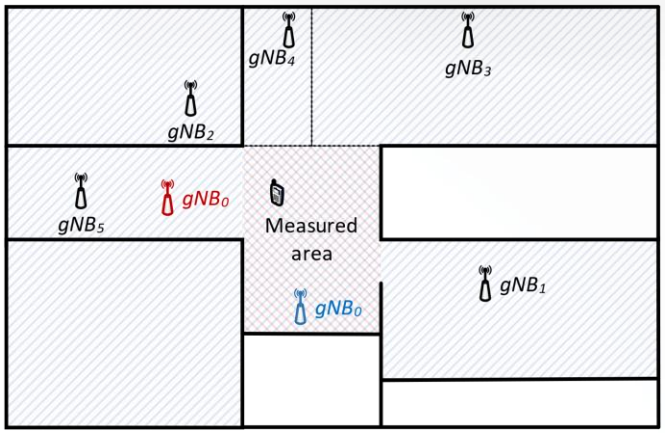
OPEN AIR INTERFACE

SRS RAN

O-RAN ALLIANCE

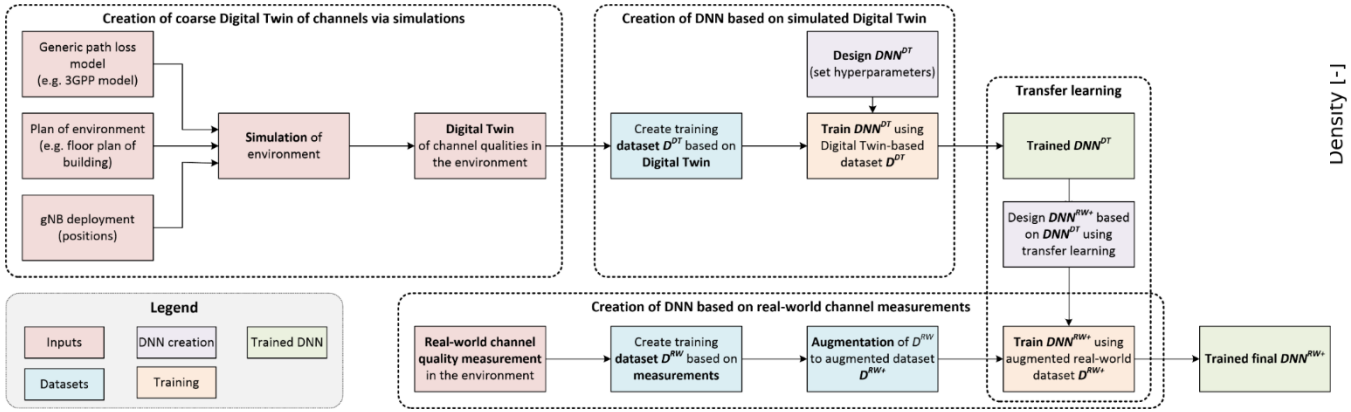
Verification of concept for D2D channels prediction

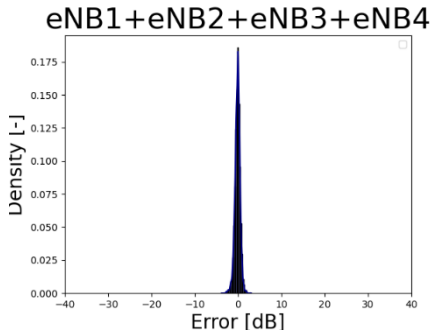
How to cope with the insufficient amount of real-world data for DNN training?



Proposed solution

- Creation of "coarse" Digital Twin to obtain simulated channel qualities => creation of **large** but **inaccurate** dataset used for DNN training
- Real-world channel measurements that is enlarged by augmentation process
- Use transfer learning to retrain part of DNN

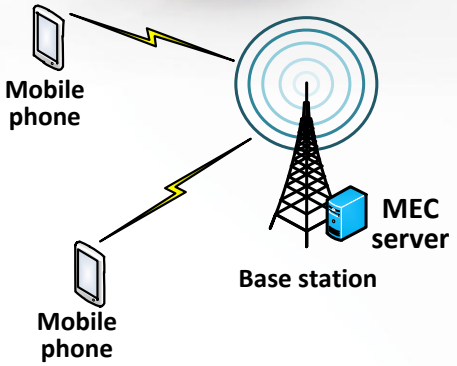




Multi-Access Edge Computing (MEC)

Mobile phones

- Communication (voice, SMS,...)
- Computer (various apps)



High demands on computation by apps

↓

Battery lifetime limitation for mobile devices

↓

Offloading of computation to a cloud

↓

High delay for a centralized cloud – **not for real-time** apps

↓

Cloud closer to users – **base stations**

FP7 project Tropic

Multi-Access Edge Computing (MEC)

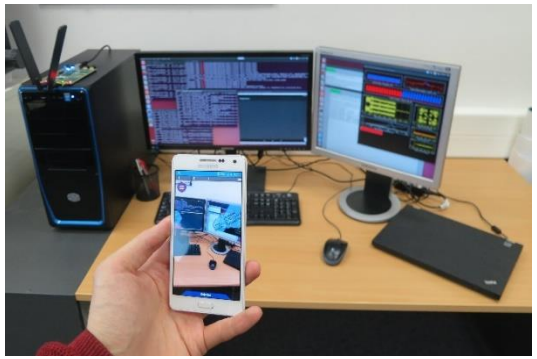
- Cloud computing/storage capabilities at the edge of mobile network
- Bringing computation closer to the users → **reducing delay**
- Offloading computation to near base stations → **preserving battery**

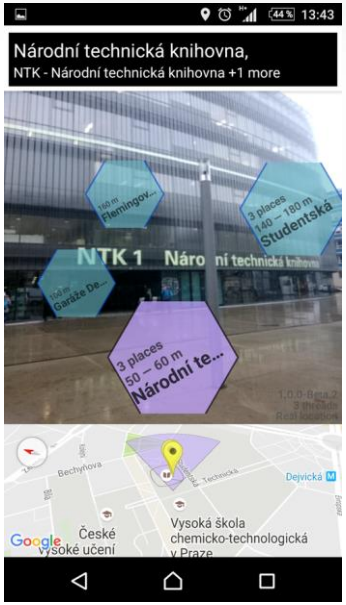
P. Mach and Z. Becvar, "Mobile Edge Computing: A Survey on Architecture and Computation Offloading," ***IEEE Communications Surveys & Tutorials***, volume 19, no. 3, 2017.

Augmented reality in edge cloud

Augmented reality with location-based **discovery of Points of Interest**

- Android app for mobile phone
- **High computation** complexity
- Allows **computation offloading**

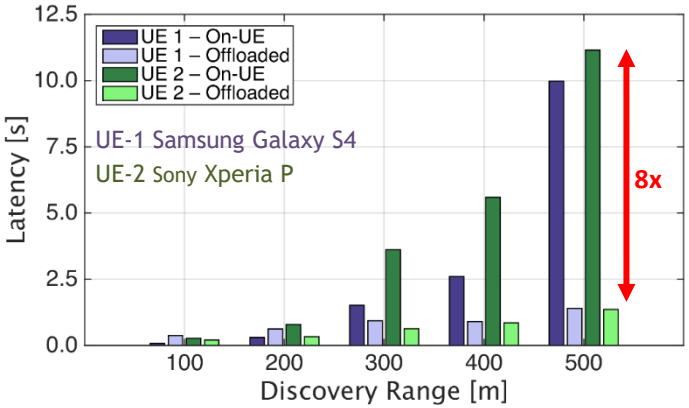




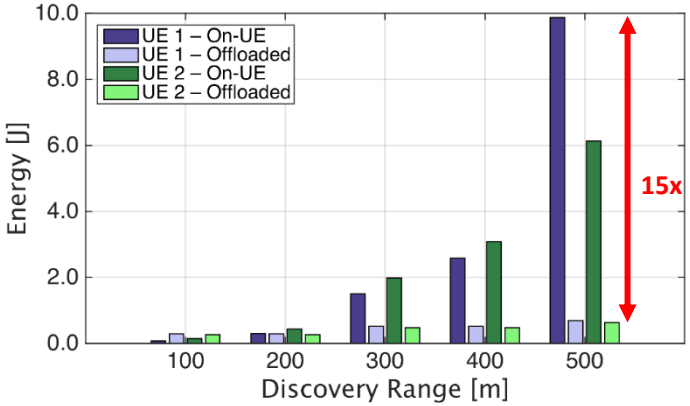
Discovery of points of interests

- **On phone**
- **Offloaded** to MEC Server

LOWER DELAY in delivery of results
(communication & computation)



LESS ENERGY consumed by smartphone
(communication & computation)



ETSI
European Telecommunications Standards Institute

Demo at **Net Futures 2015** Conference, Brussels.
Demo and **third place** in ***ACM Mobicom 2015 App Contest*** with Android application Percipio as a proof of concept of augmented reality offloadable to MEC
J. Dolezal, Z. Becvar, T. Zeman, "Performance Evaluation of Computation Offloading from Mobile Device to the Edge of Mobile Network", ***IEEE CSCN 2016***.
Demo "Augmented Reality exploiting the Multi-Access Edge Computing in OpenAirInterface testbed," at ***Joint ETSI-OSA Workshop: Open Implementations and Standardization***, 2018.

Prototyping vehicle (model) communicating via mobile networks

6G mobile RESEARCH LAB

FACULTY OF ELECTRICAL ENGINEERING CTU IN PRAGUE

Prototyping Flying Base Station - UAVs

Flying base station demonstration

Initial flight test

FACULTY OF ELECTRICAL ENGINEERING CTU IN PRAGUE

Prague, June 2018

5G mobile research lab

CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

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Thank you
Questions?

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