Relay Selection and Resource Allocation for D2D-Relaying under Uplink Cellular Power Control

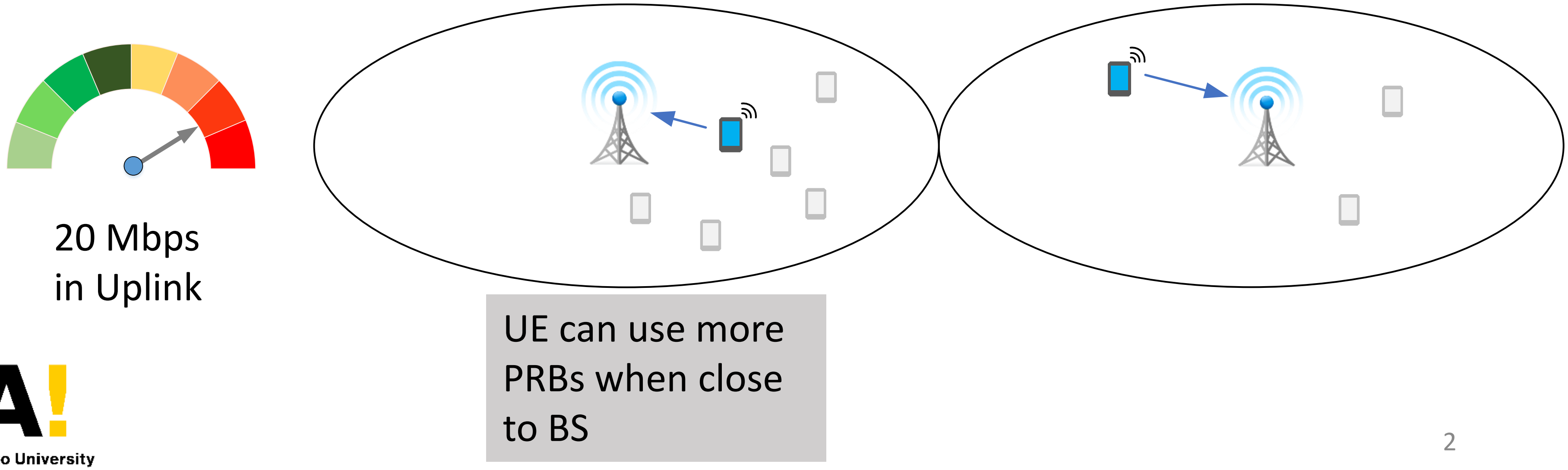
Junquan Deng, Alexis A. Dowhuszko, Ragnar Freij, Olav Tirkkonen

Department of Communications and Networking

Aalto University

Motivation

Consistent user experience is one of the most challenging objectives of 5G cellular network

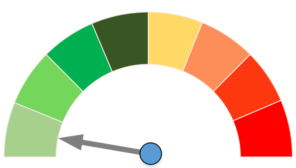


Aalto University

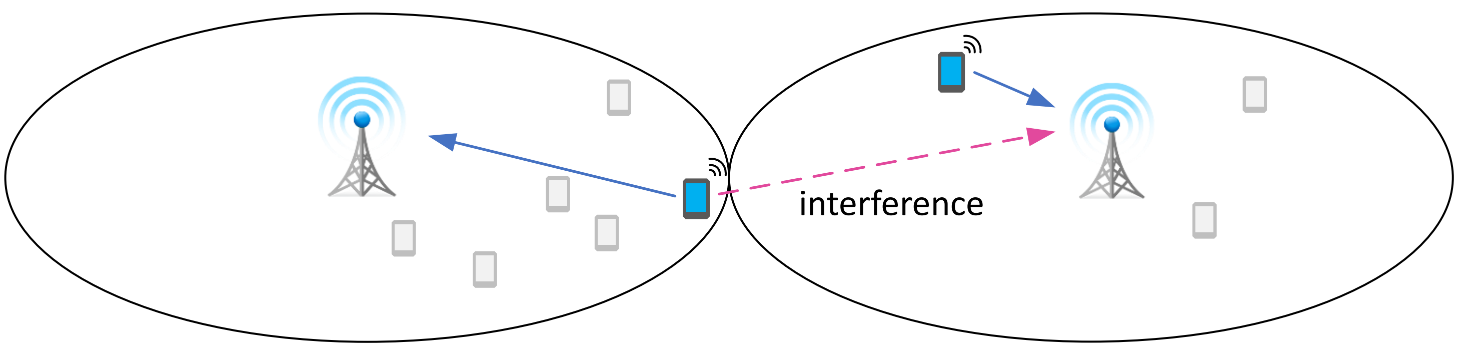
Motivation

Consistent user experience is one of the most challenging objectives of 5G cellular network.

User throughput drops dramatically when moving to cell-edge area in current cellular network !



0.5 Mbps
in Uplink



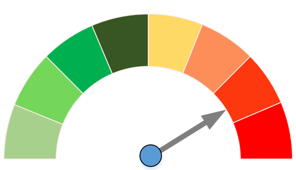
UE can only use few PRBs when in cell-edge due to limited power

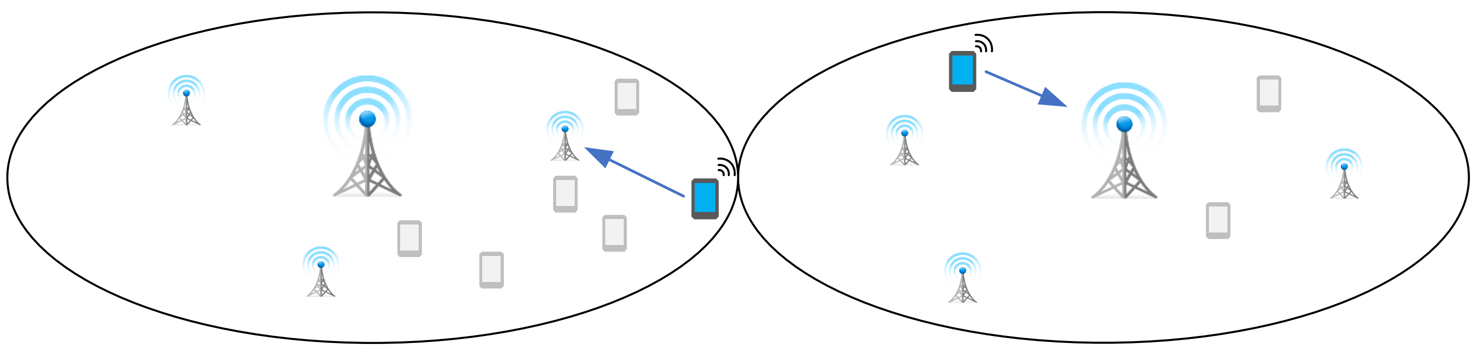
Aalto University

Motivation

Consistent user experience is one of the most challenging objectives of 5G cellular network.

One way to achieve consistent user experience is to deploy more infrastructure elements such as RRHs and small cell BSs.



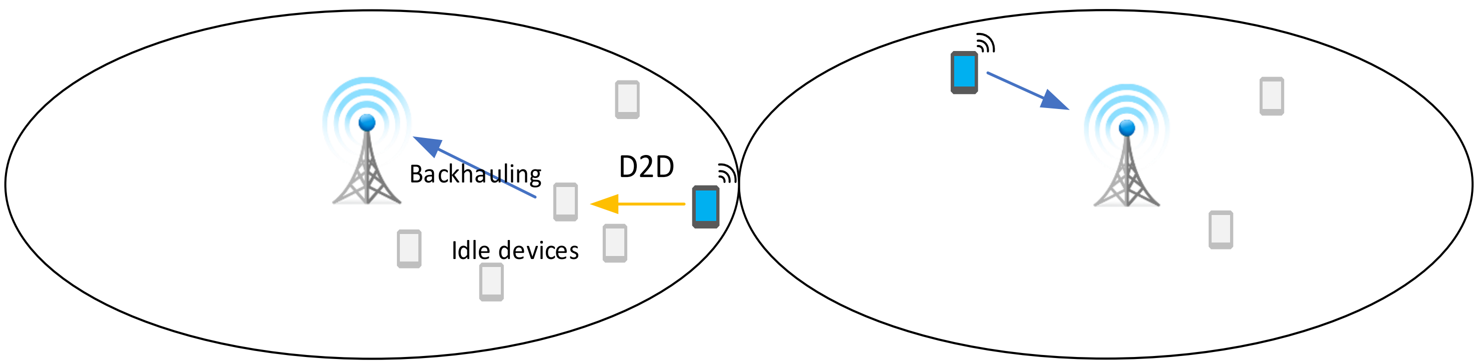


Costly

Motivation

Consistent user experience is one of the most challenging objectives of 5G cellular network.

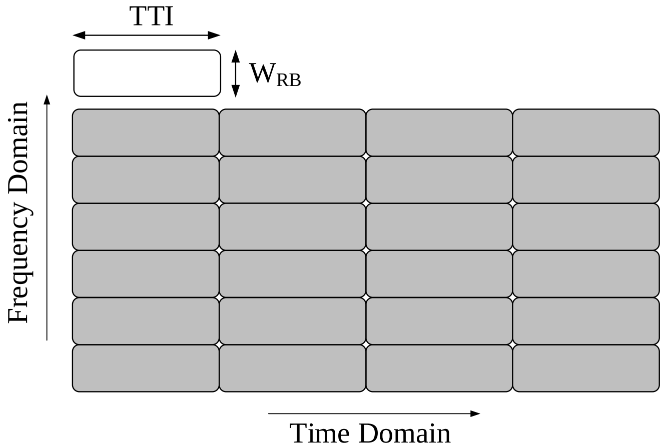
Future networks are supposed to have 10 ~ 100 times more devices. Why not use those devices to relay data traffic?



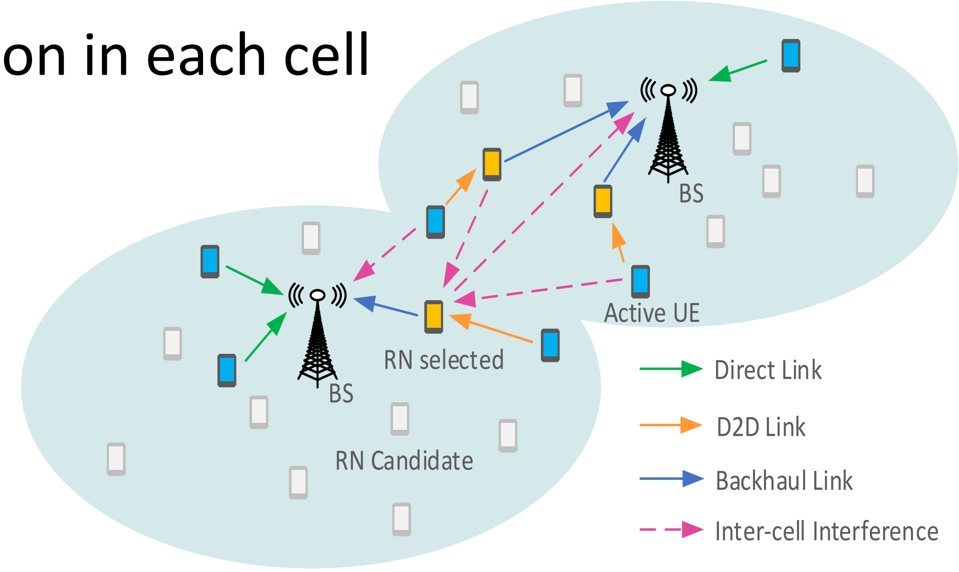
D2D Relaying

System Model

- Multi-cell uplink network considering inter-cell interference
- Using SC-FDMA on uplink to support multi-user
- Strict Transmission Power Control (TPC)
- Multiple half-duplex Relay Node (RN) candidates
- Flexible Physical Resource Blocks (PRB) allocation for all links
- Full buffers at active UEs
- Orthogonal PRB allocation in each cell



PRBs



Multi-cell Scenario

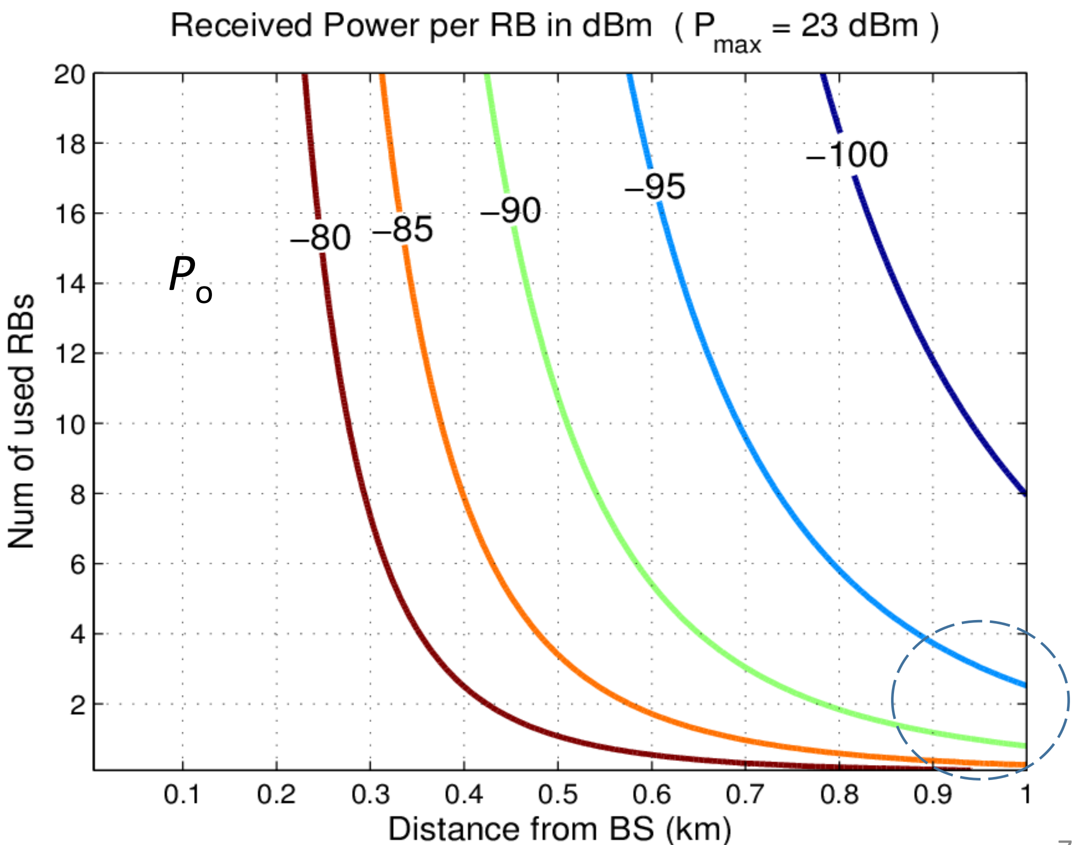
Aalto University

System Model - TPC

- Strict Transmission Power Control

$$P_{tx} = \min\{P_{max}, N_{rb}\ P_o\ L\}$$

- Mitigate near-far effect for SC-FDMA
- Control inter-cell interference
- Cell-edge users can only use few PRBs



System Model – inter-cell interference

- Inter-cell interference due to universal frequency reuse

- Interference randomization technique is adopted

- Average interference power per PRB at BS i is

$$I_i = \sum_{j \neq i} \left(\sum_{k \in \mathcal{U}_j} \frac{w_k \; P_{\mathrm{tx},k}}{L_{k,i}} + \sum_{n \in \mathcal{R}_j} \frac{w_n \; P_{\mathrm{tx},n}}{L_{n,i}} \right)$$

- The link performance depends on the SINR and the bandwidth resources it uses

$$R = N_{\mathrm{rb}} \; B_{\mathrm{rb}} \; \log_2 (1 + \gamma)$$

Aalto University

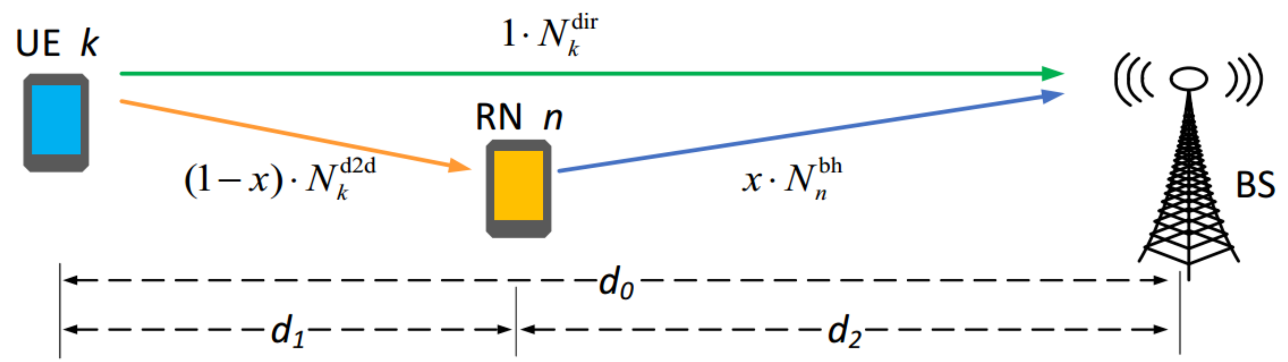
Analysis of D2D relaying under TPC

- Flexible PRB allocation both in bandwidth and time domain

- For D2D relaying, end-to-end throughput is

$$R_{k,n}^{e2e} = \min\left\{xR_n^{bh}, (1-x)R_k^{d2d}\right\}$$

- D2D relaying is used only when it helps to improve e2e performance compared to direct transmission

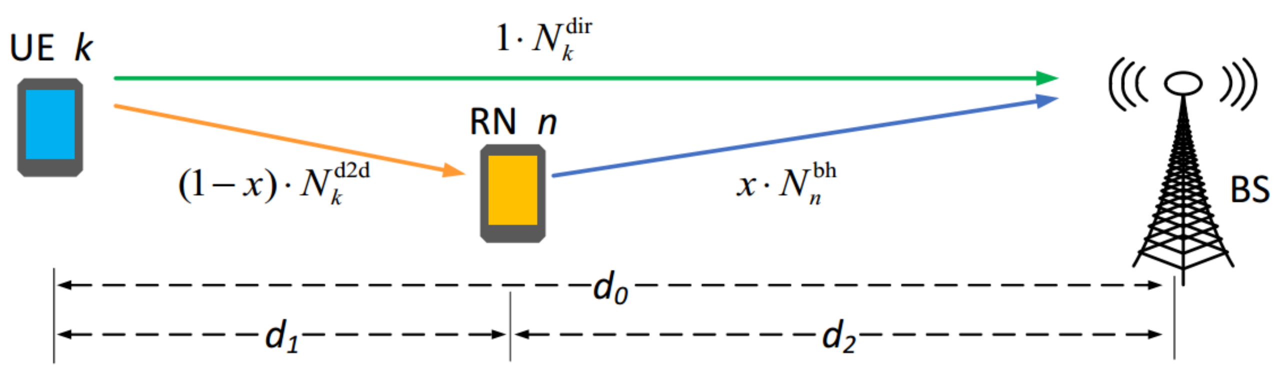


Aalto University

Analysis of D2D relaying under TPC

- To be fair, each flow can get at most N_R PRBs on average over time.
- When using D2D relaying, resource allocation is done on two dimensions.

$$
\begin{aligned}
\max_{x, N_n^{bh}, N_k^{d2d}} \quad & x R_n^{bh} \\
\text{s.t.} \quad & (1-x) R_k^{d2d} = x R_n^{bh} \\
& (1-x) N_k^{d2d} + x N_n^{bh} \le N_R \\
& 1 \le N_n^{bh} \le \left\lceil \frac{P_{max}}{P_o \; L_n^{\text{bh}}} \right\rceil \\
& 1 \le N_k^{d2d} \le \left\lceil \frac{P_{max}}{P_o \; L_{k,n}^{\text{d2d}}} \right\rceil \\
& 0 < x < 1.
\end{aligned}
$$



Analysis of D2D relaying under TPC

- A fast BH/D2D resource allocation algorithm
- In practical, PL infos are measured by devices and reported to controller at BSs

Algorithm 1 BH/D2D Resource Allocation

INPUT: $L_{k,n}^{\mathrm{d2d}}, L_n^{\mathrm{bh}}, L_k^{\mathrm{dir}}$, and average number N_R of RBs

OUTPUT: $R_{k,n}^{e2e}$, N_k^{d2d}, N_n^{bh}

1: $N_n^{bh} \leftarrow \left\lceil \frac{P_{max}}{P_o \ L_n^{\mathrm{bh}}} \right\rceil$.

2: $N_k^{d2d} \leftarrow \left\lceil \frac{P_{max}}{P_o \ L_{k,n}^{\mathrm{d2d}}} \right\rceil$.

3: Calculate R_k^{d2d} and R_n^{bh} .

4: Calculate time partition $x \leftarrow \frac{R_k^{d2d}}{R_k^{d2d}+R_n^{bh}}$.

5: **if** $(1-x)N_k^{d2d} + xN_n^{bh} \leq N_R$ **then**

6:     break;

7: **else if** $R_k^{d2d}/N_k^{d2d} < R_n^{bh}/N_n^{bh}$ **then**

8:     $N_k^{d2d} \leftarrow \left\lceil \frac{N_R - xN_n^{bh}}{(1-x)} \right\rceil$, **go to 3.**

9: **else if** $R_k^{d2d}/N_k^{d2d} \geq R_n^{bh}/N_n^{bh}$ **then**

10:     $N_n^{bh} \leftarrow \left\lceil \frac{N_R - (1-x)N_k^{d2d}}{x} \right\rceil$, **go to 3.**

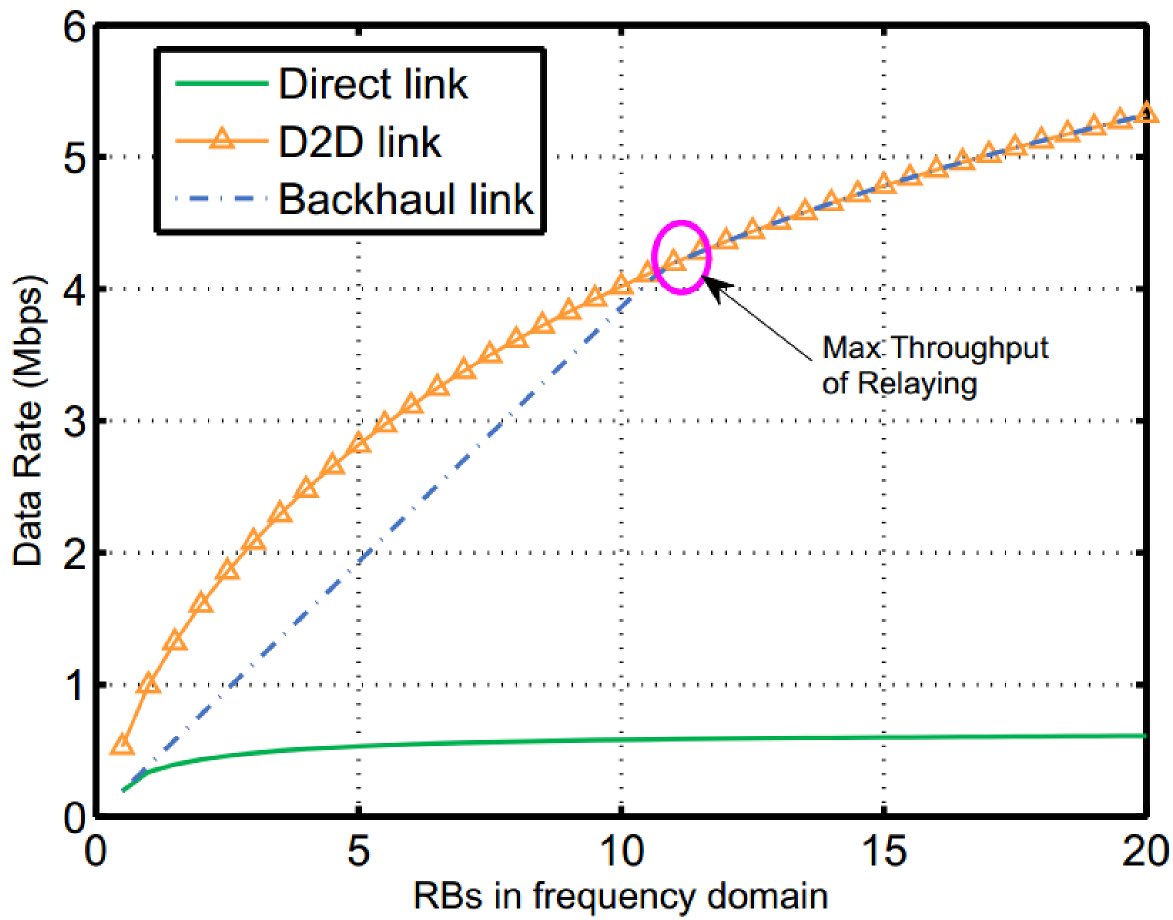
11: **end if**

12: $R_{k,n}^{e2e} = xR_n^{bh}$, return.

Aalto University

Analysis of D2D relaying under TPC

- With the help of D2D relaying, cell-edge users can use more PRBs to get higher end-to-end throughput for its traffic flow.



Analysis result with optimal RN position considering distance-dependent PL only

Joint Relay Selection (RS) and Resource Allocation (RA)

- In a cell with multiple users, one has to allocate resources among users fairly.
- To achieve the goal of consistent user experience, cell-edge users should get more PRBs if there are good RN candidates to help.
- Users close to BSs cannot occupy PRBs greedily.

- Global resource allocation constraint

$$\sum_{k \in \mathcal{U}_i} \left(N_k^{\text{dir}} + (1 - x_k) N_k^{\text{d2d}} + x_k N_{X_k}^{\text{bh}} \right) = M$$

Number of used PRBs on average over time for users close to BSs

Aalto University

Joint Relay Selection (RS) and Resource Allocation (RA) Algorithm

- **This Algorithm is heuristic, because realtime interference powers on different nodes cannot be measured and reported to controller.**

Algorithm 2 Joint RS and RA for D2D Relaying

```
There are $\hat{K}$ UEs and $\hat{N}$ RNs in current cell, the UEs in this cell are denoted by $k = 1, 2, ..., \hat{K}$, RNs are denoted by $n = 1, 2, ..., \hat{N}$, $N_R = M \big/ \hat{K}$.
for $k = 1$ to $\hat{K}$ do
    Calculate $N_{\max}$ using (4), $N_k^{dir} \leftarrow \min(N_{\max}, N_R)$, calculate $R_k^{dir}$ using (11).
    for $n = 1$ to $\hat{N}$ do
        if $L_n^{\mathrm{bh}} \geq L_k^{\mathrm{dir}}$ or $L_{k,n}^{\mathrm{d2d}} \geq L_k^{\mathrm{dir}}$ then
            $R_{k,n}^{e2e} = 0$, break;
        else
            Calculate $R_{k,n}^{e2e}, N_k^{\mathrm{d2d}}, N_n^{\mathrm{bh}}$ using Algorithm 1.
        end if
    end for
    $R_k^{e2e} \leftarrow \max\left(R_k^{dir}, R_{k,1}^{e2e}, ..., R_{k,\hat{N}}^{e2e}\right)$, and assign the best relay $X_k$ for UE $k$. If $R_k^{e2e} = R_k^{dir}$, direct link is used for UE $k$.
end for
```

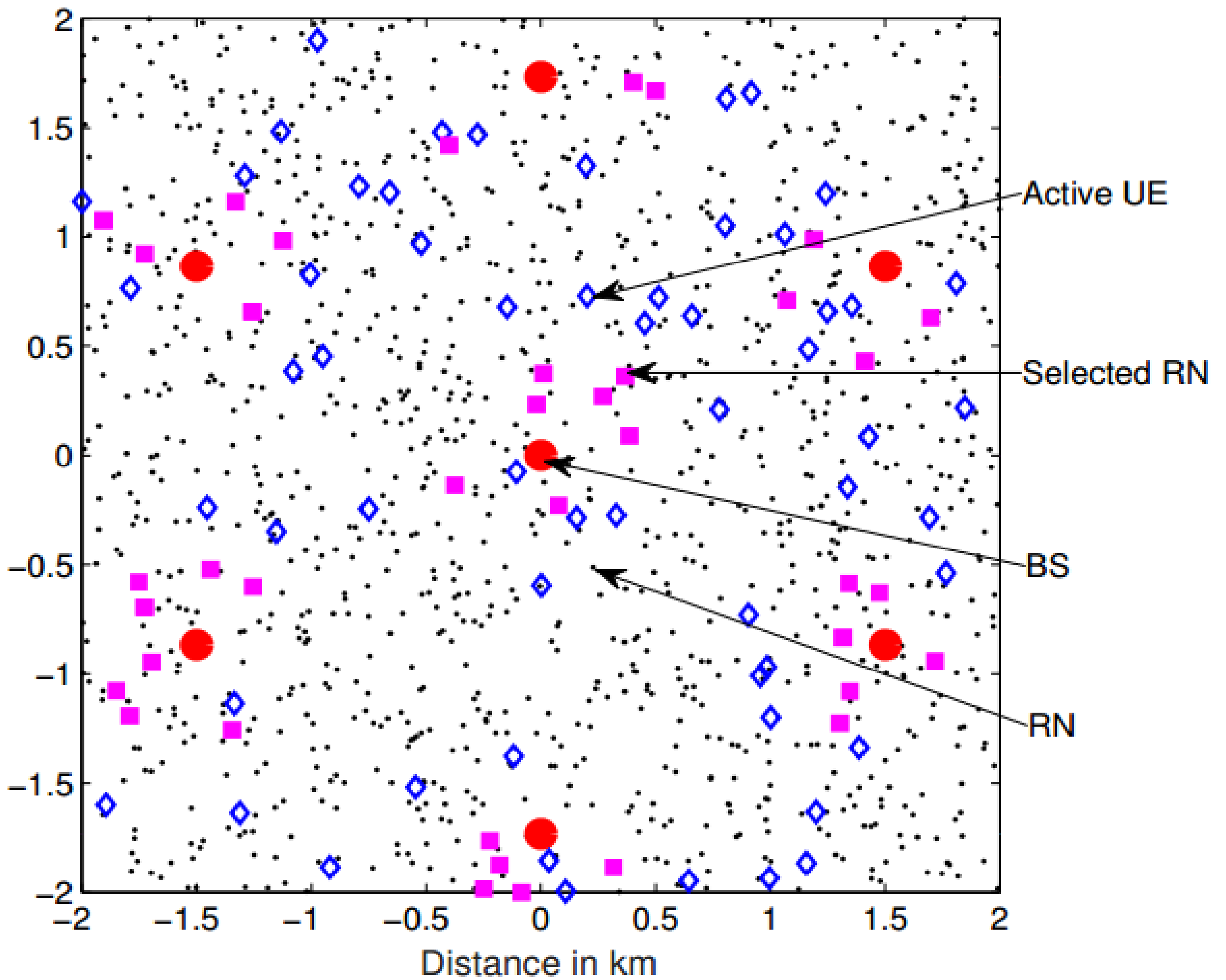
Aalto University

Evaluation of D2D Relaying

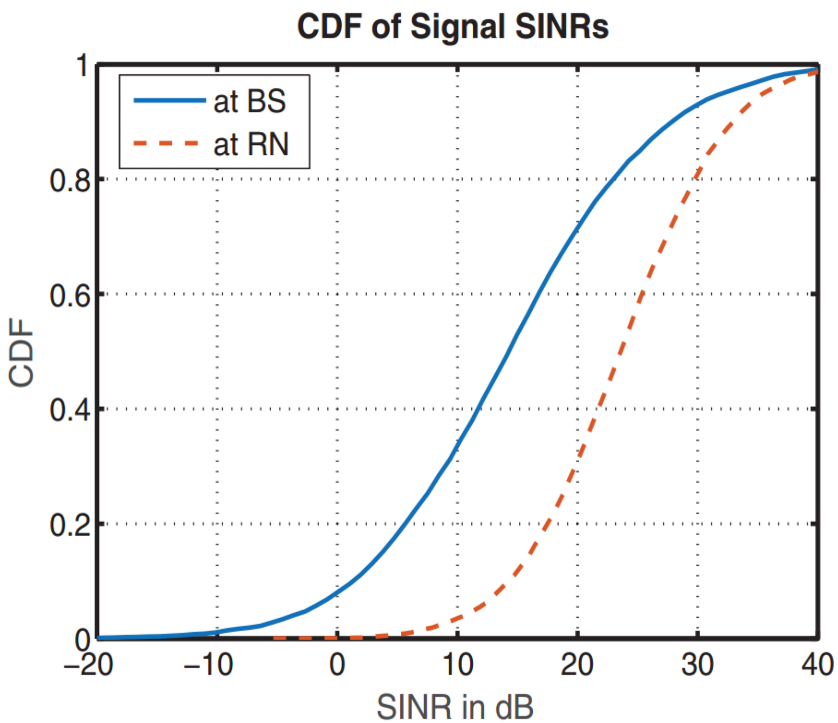
- Urban environment with a propagation exponent α =3.76 and log-normal shadowing.
- Devices are uniformly distributed inside the multi-cell scenario.
- Inter-cell interference power levels are first estimated, and then to be refined during simulation in an iterative process

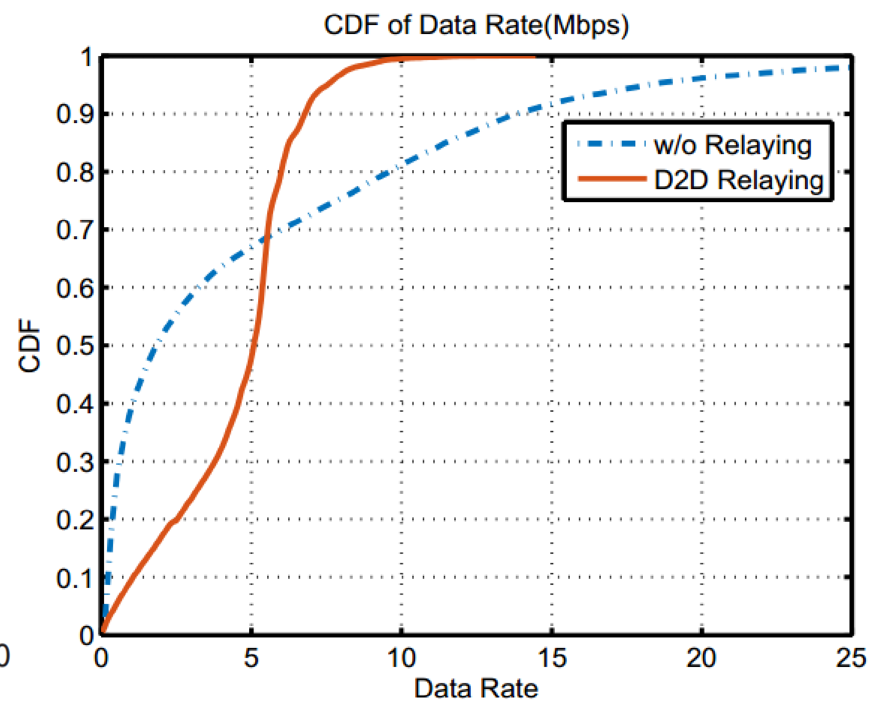
Evaluation of D2D Relaying

- **Selected RNs are those that can use more PRBs on backhaul link and are simultaneously close enough to cell-edge UEs to get higher D2D SINRs.**



Evaluation of D2D Relaying



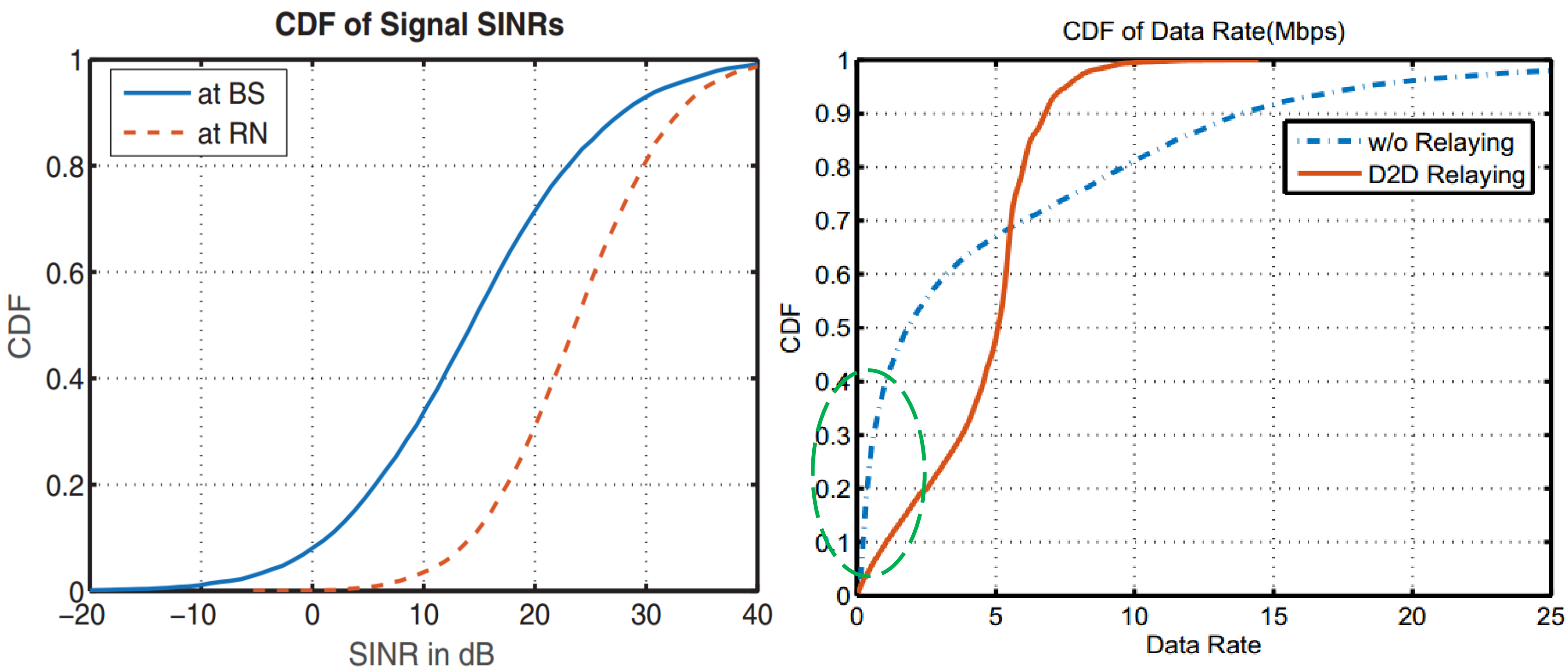


Actual SINRs depends heavily on the locations of transmitting nodes in neighbor cells.

More effective interference coordination techniques rather than randomization would give better performance.

Aalto University

Evaluation of D2D Relaying



Cell-edge performance improves a lot by D2D relaying.

Scenario	Average	10th	50th
w/o D2D Relaying	5.05 Mbps	0.23 Mbps	1.8 Mbps
with D2D Relaying	4.86 Mbps	0.95 Mbps	5.0 Mbps
D2D Relaying Gain	-3.8%	313%	178%

Aalto University

Related Work

- Cooperative communication.
- Multi-hop Cellular Network (MCN).
- Coverage extension by using D2D relaying.
- Outage analysis of D2D relaying considering the device spatial distribution .
- Distributed Beamforming using D2D at first hop.

Aalto University

Conclusion

- Uplink power control, resource allocation and relay selection are considered in an unified framework to address the D2D relaying problem.
- By proper resource scheduling, D2D-relaying under power control increases throughput performance for cell-edge users significantly, which results in consistent user experience.

Aalto University

Thanks!

Q&A?