Upper Bound Capacity of Infrastructure-less D2D Communication in LTE-Advanced

ComNets Hamburg, Prof. Timm-Giel

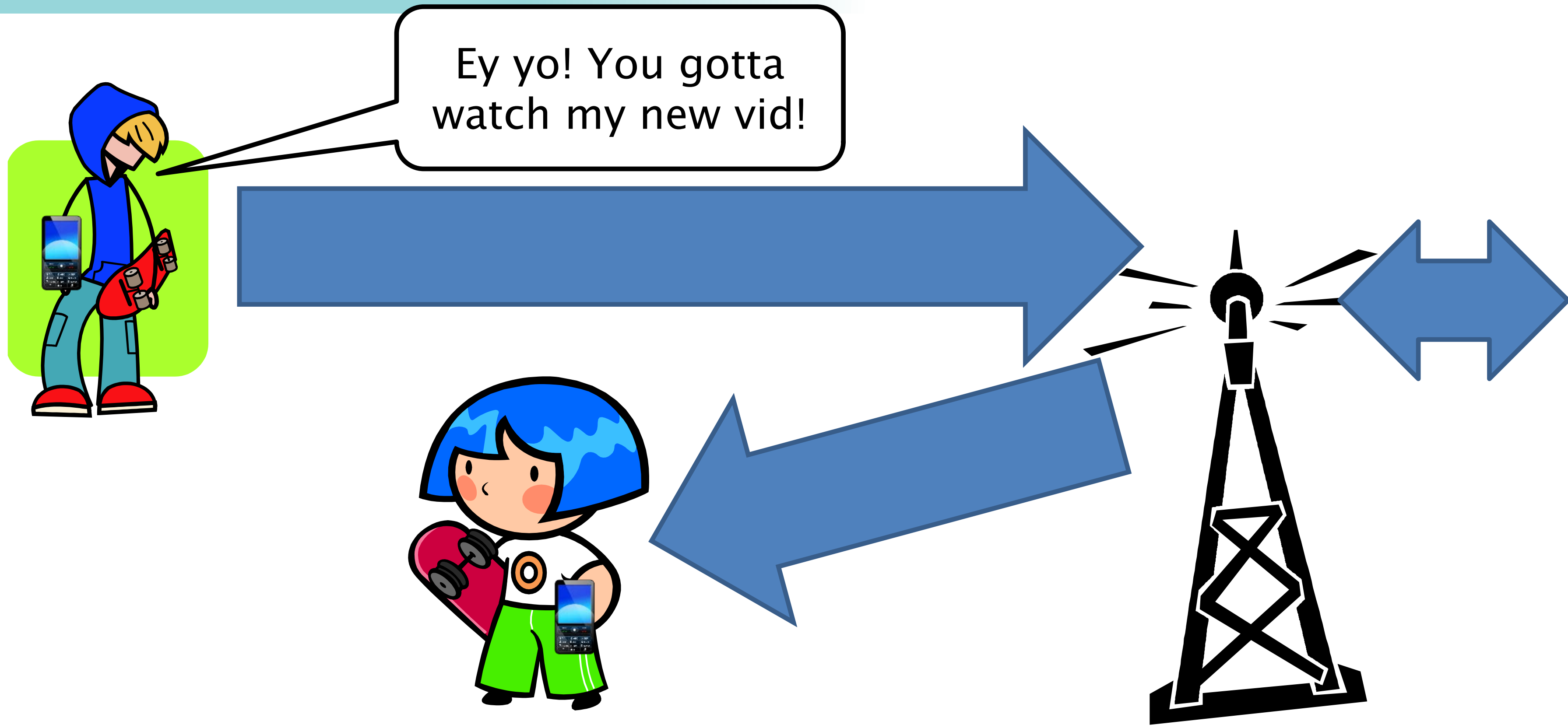
<u>Maciej Mühleisen</u>, Jan Habermann

Outline

ComNets
Institute of Communication Networks
TUHH

- Motivation
- D2D Communication
- Optimal Schedule
- Simulation Model
- Results
- Conclusion & Outlook

Motivation

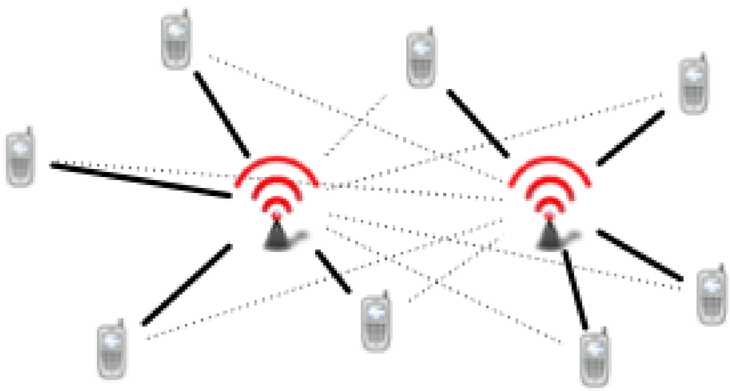


Motivation

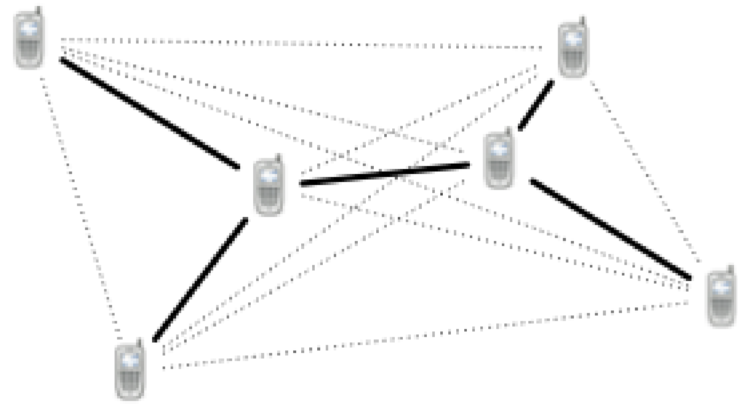
Motivation / Idea: Using LTE in Device-to-Device (D2D) mode to transmit data of people „close“ to each other

Motivation

D2D communication allows nodes to communicate with each other without involving a base station!



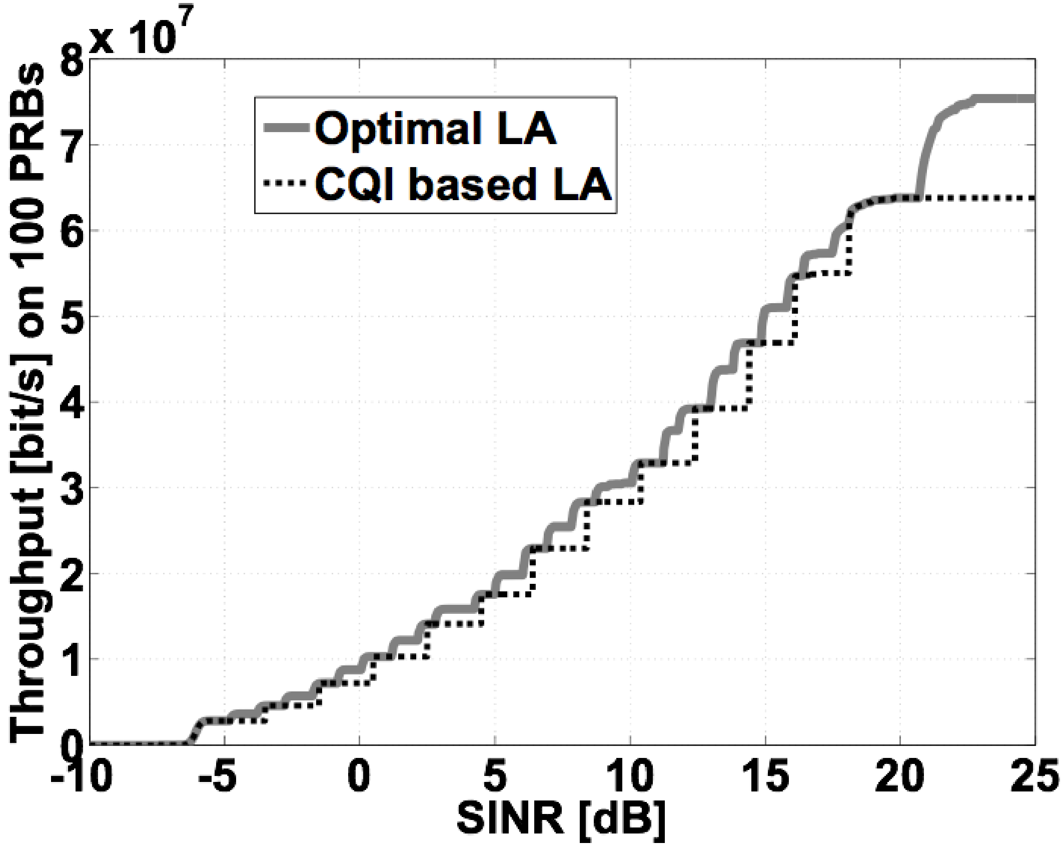
Default "star"-topology (Cellular Network)



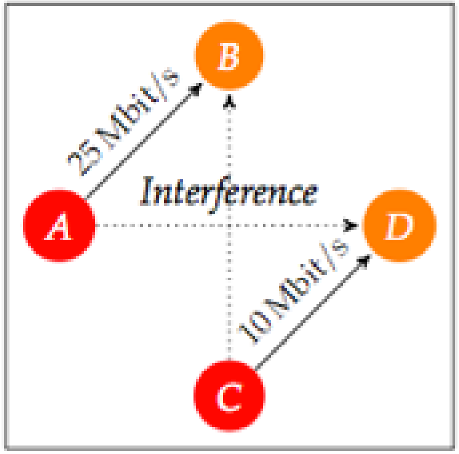
Network with D2D communication

Serving link
Interfering link

Different Modulation and Coding Schemes (MCS)
are used based on the Channel Quality Indicator (CQI)



Resource Management Challenges



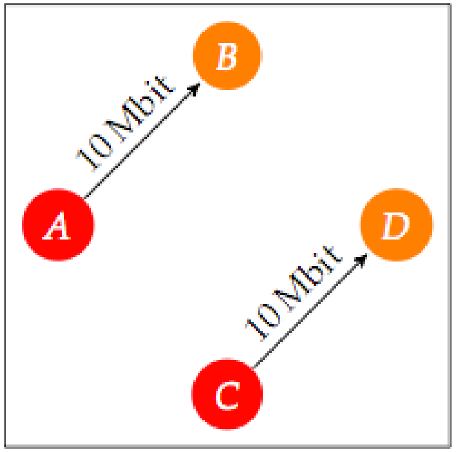
- Transmitting on the same Physical Resource Blocks (PRBs) causes interference
- Interference becomes a major issue

Optimal Schedule

ComNets
Institute of Communication Networks
TUHH

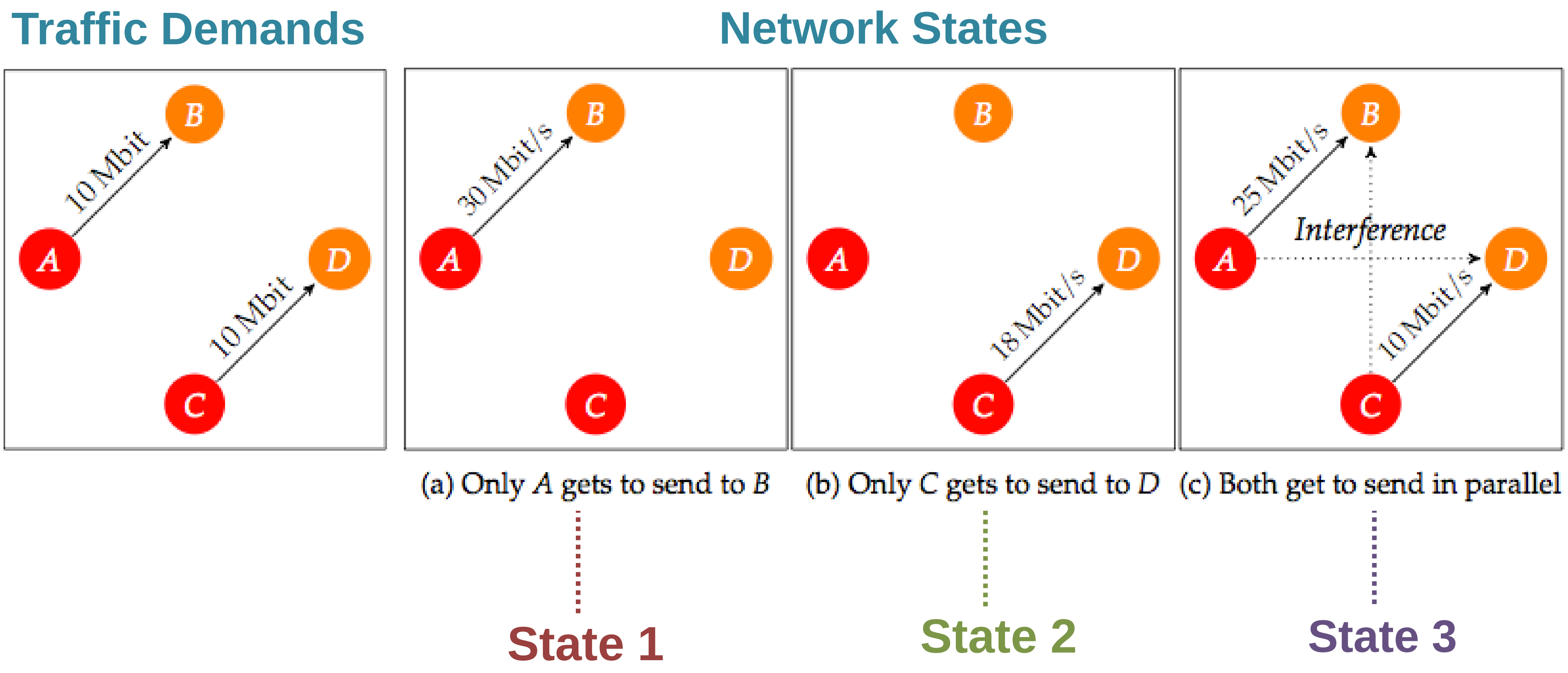
Example with four nodes and only two demands:

Traffic Demands



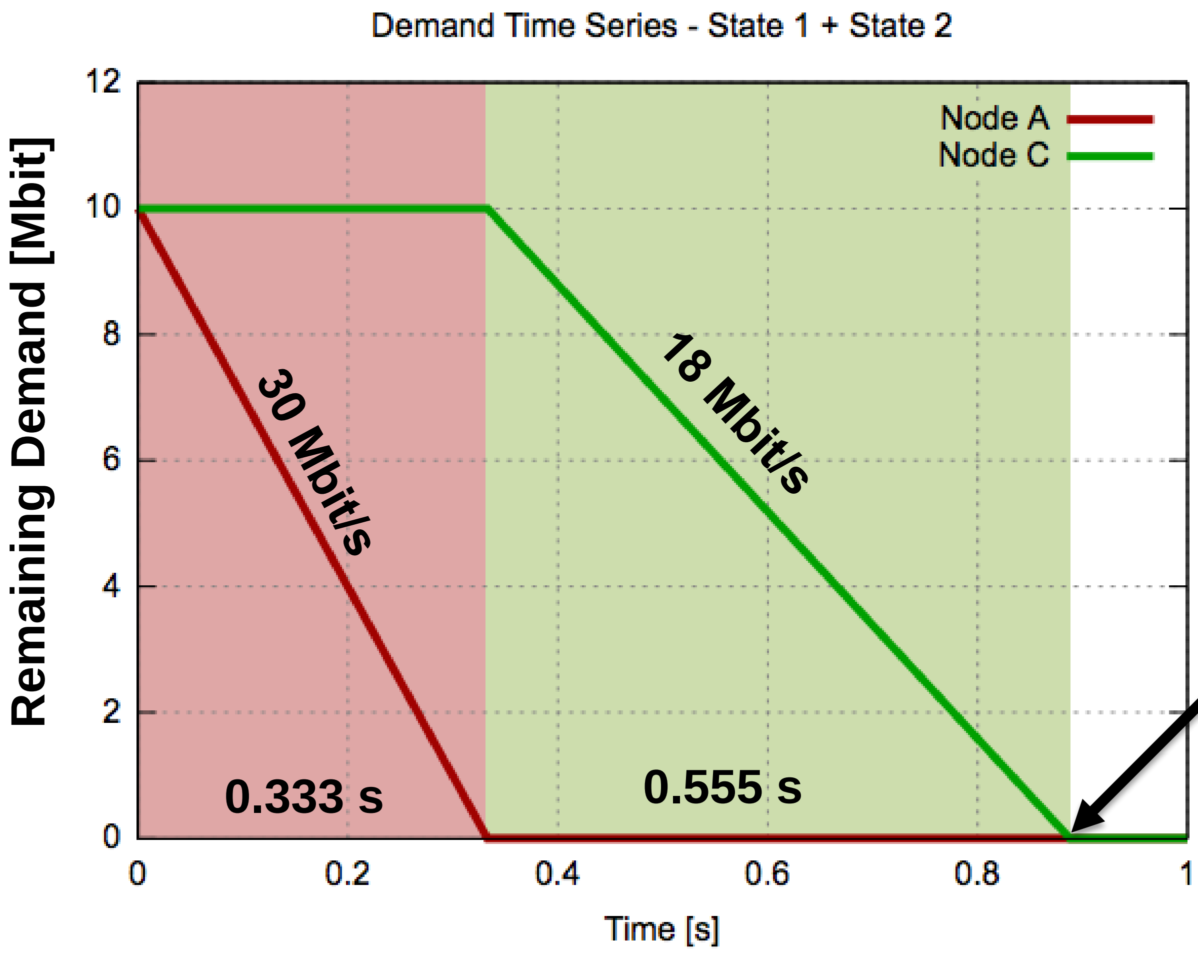
Optimal Schedule

Example with four nodes and only two demands:



Optimal Schedule

Example with four nodes and only two demands:

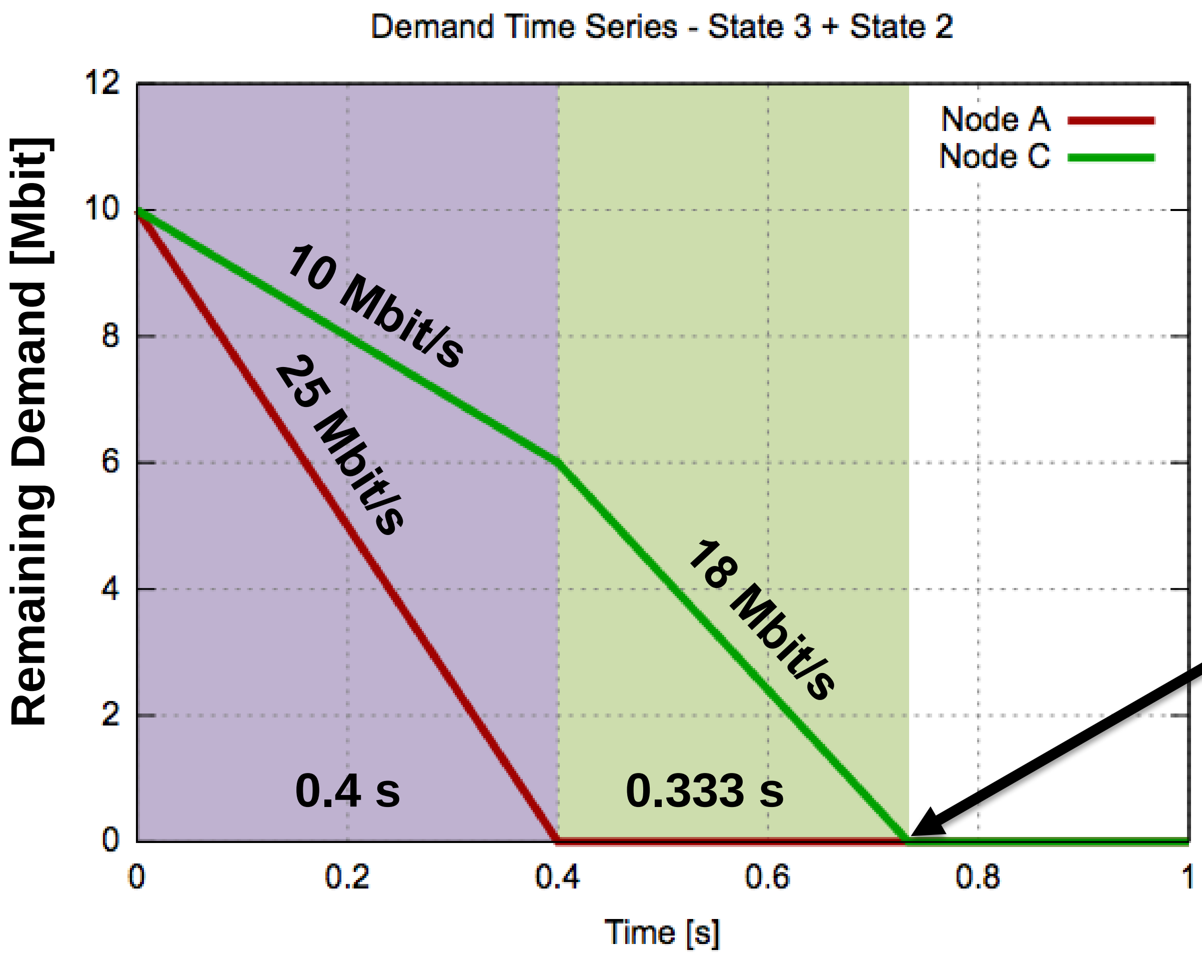


End of the scheduling round
(t = 0.888 s)

➔ **22.5 Mbit/s**

ComNets
Institute of Communication Networks
TUHH

Example with four nodes and only two demands:



End of the scheduling round
(t = 0.733 s)

➔ 27.3 Mbit/s

Optimal Schedule

Feasible Network States

General assumptions:

- Every node either transmits on all PRBs or not at all (TDMA)
- No node can have more than one outgoing link
  (cannot sent to multiple recipients at once)
- No node can receive from more than one transmitter at a time
- No node can transmit and receive at the same time

Problem: Which states should be active and how long should they be active to maximize the capacity of the network?

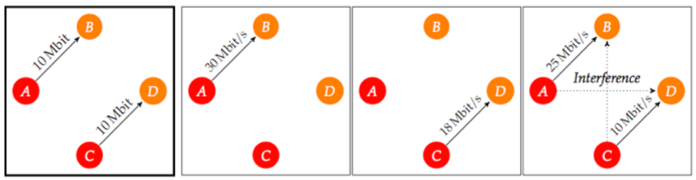
Optimal Schedule

ComNets
Institute of Communication Networks
TUHH

Problem formulation through Linear Programming

Source: PhD Dissertation S. Max, "Capacity and Efficiency of IEEE 802.11n in Wireless Mesh Operation", Aachen, 2011

1. Generate all feasible network states and specify demands (buffer fill levels)



2. Convert network states and demands to matrices

3. Solve the Linear Program:

$$\mathcal{S} = \{S_1, S_2, \ldots, S_n\}$$

$$\textbf{min} \quad \sum_{i=1}^{|S|} t_i$$

$$\textbf{s.t.} \quad \sum_{i=1}^{|S|} t_i \cdot S_i \geq D$$

Example

$$\textbf{min} \quad t_1 + t_2 + t_3$$

s.t.

$$t_1 \cdot \underbrace{\begin{pmatrix} 0 & 30 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_1} + t_2 \cdot \underbrace{\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 18 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_2} + t_3 \cdot \underbrace{\begin{pmatrix} 0 & 25 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 10 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_3} \geq \underbrace{\begin{pmatrix} 0 & 10 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 10 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{D}$$

<u>**Solution:**</u> **0 s** S_1 + **0.333 s** S_2 + **0.4 s** S_3

Optimal Schedule

Baseline 1:

One big network state
in which **all nodes** with demands
transmit **simu**ltaneously**!**

Baseline 1 may violate the constraints of the feasible network states!

e.g. a node may receive from multiple sources at the same time

Baseline 2:

Sequentially, one node after another

Simulation Model

ComNets
Institute of Communication Networks
TUHH

Used simulation software:

- **openWNS**: Open source system level simulation platform
- **IMTAphy**: LTE / LTE-Advanced system level simulator

Assumptions / Limitations:

- Only demands to the nearest neighbor
- Demands (amount of bits to transmit) are constant
- The solver is an omniscient entity that knows the locations, velocities, etc. of every node

Simulation Model

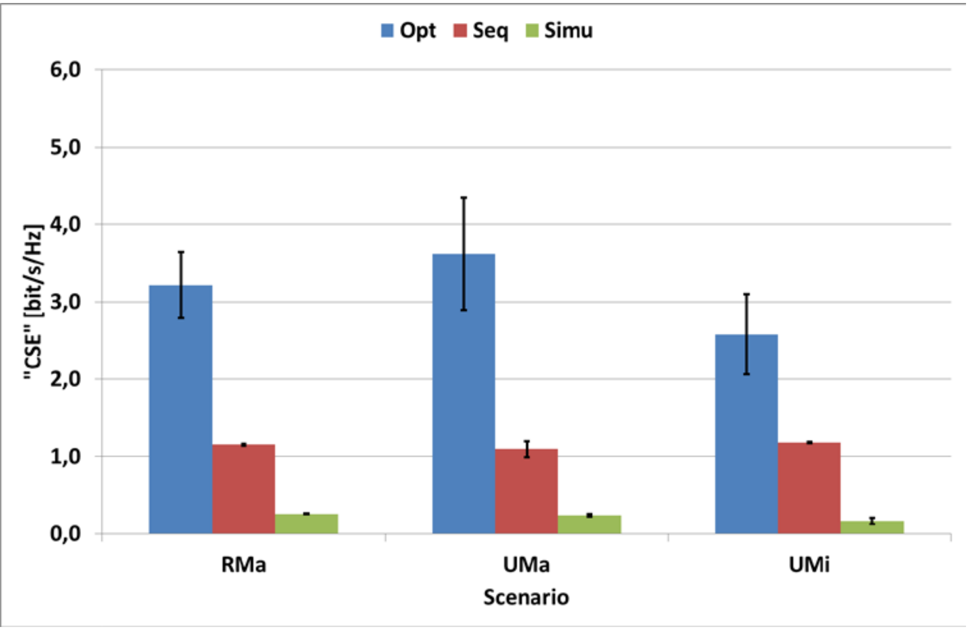
ComNets
Institute of Communication Networks
TUHH

Parameter	Value
Bandwidth	3 MHz (15 PRBs)
# of Nodes	15, 21
Channel Model	ITU M.2135 UMa, UMi, RMa
TX Power	23 dBm per PRB
Deployment	random in circle according to scenario “site radius” (area of **three** sectors (cells))
Traffic model	2 Mbit to nearest neighbor
Small-Scale Fading	**disabled**
Error model	**Link adaptation enabled but no packets dropped**
Drops (seeds)	10
Sim. Time	50 s (multiple opt. rounds)
Scheduling	TDMA, **Opt**imal, **Seq**uential, **Simul**taneous

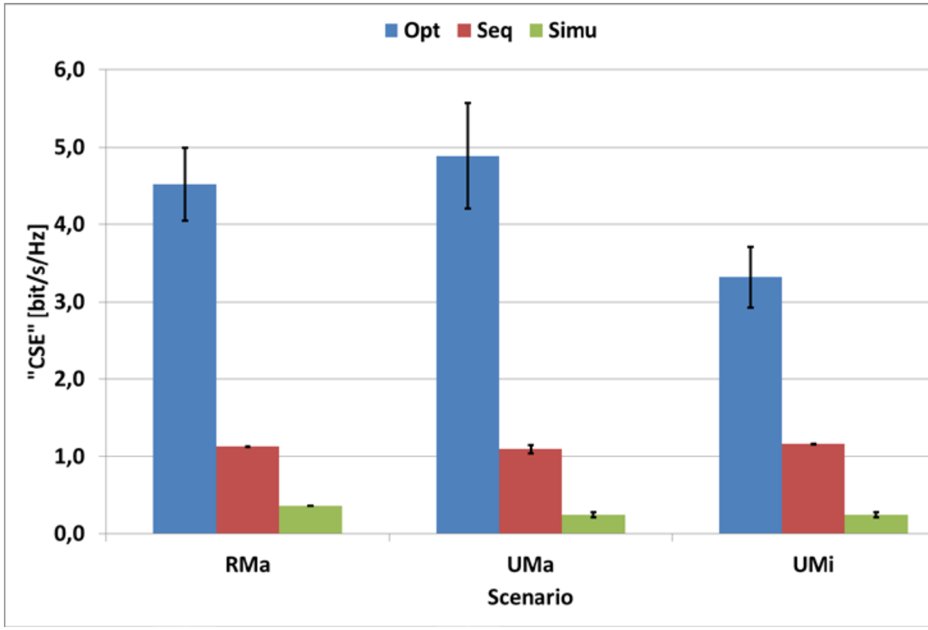
Results

ComNets
Institute of Communication Networks
TUHH

Total Amount of Received bit / SimTime / 3 cells / 3 MHz



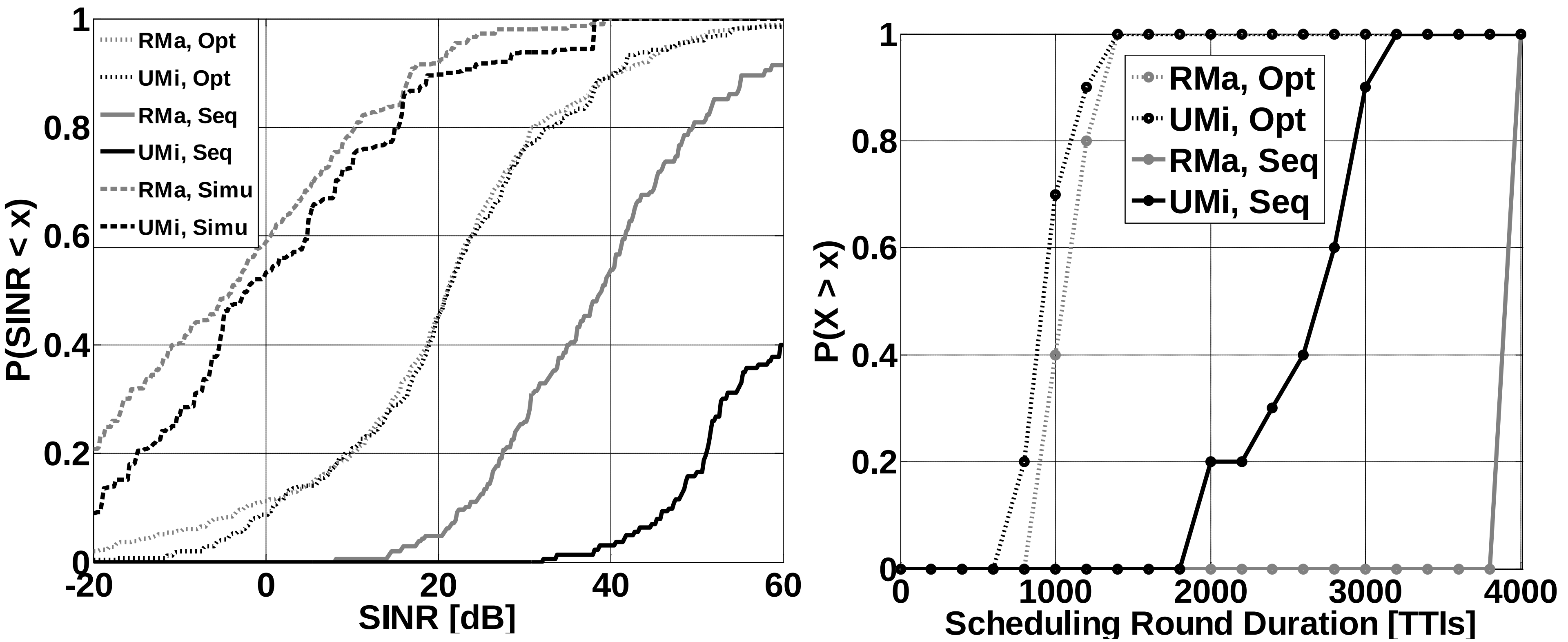
15 Nodes



21 Nodes

- Simultaneous transmission has extremely low performance (solver “gave up”)
- Sequential transmission results in 1 bit/s/Hz
- **CSE increased by factor 2.5 to 5 for optimized schedule**
- More users ➔ higher CSE (normalization effect, comparable?)
- Scenario with more interference ➔ higher CSE
- Strong dependence on actual positions (confidence intervals)

Results: 21 Nodes



- Sequential operation results in very high SINR
- Users need 2.5 (UMi), 4.0 (RMa) seconds to transmit 2 Mbit sequentially
- Low SINRs remain a problem, even with optimized schedule

Conclusion & Outlook

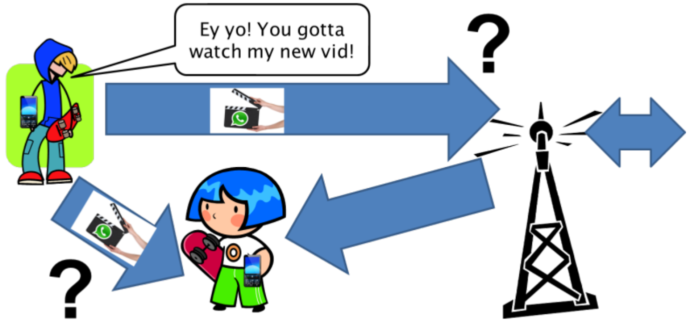
ComNets
Institute of Communication Networks
TUHH

Conclusion

- The optimal schedule obtained by Linear Programming assures very high spectral efficiency
- It can be used as upper bound to evaluate distributed / adaptive / heuristic scheduling algorithms

Outlook

- Option to communicate over eNB ➔ extend Linear Program
- More realistic traffic model (demands)
- Extend to frequency domain
- Changing channel conditions
- Develop new algorithms, for example:
  - Distributed: give user terminals rights to decide
  - Adaptive: (re)schedule demands every TTI
  - Heuristic: do not include all states



Conclusion & Outlook

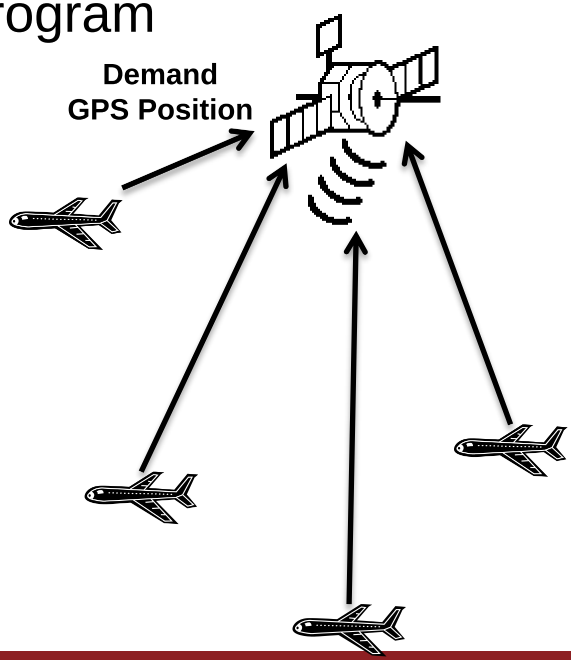
ComNets
Institute of Communication Networks
TUHH

Conclusion

- The optimal schedule obtained by Linear Programming assures very high spectral efficiency
- It can be used as upper bound to evaluate distributed / adaptive / heuristic scheduling algorithms

Outlook

- Option to communicate over eNB ➔ extend Linear Program
- More realistic traffic model (demands)
- Extend to frequency domain
- Changing channel conditions
- Develop new algorithms, for example:
  - Distributed: give user terminals rights to decide
  - Adaptive: (re)schedule demands every TTI
  - Heuristic: do not include all states



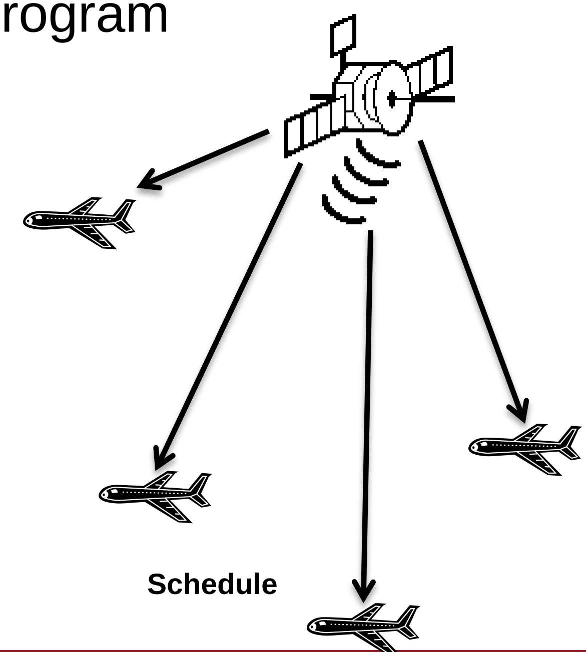
Conclusion & Outlook

Conclusion

- The optimal schedule obtained by Linear Programming assures very high spectral efficiency
- It can be used as upper bound to evaluate distributed / adaptive / heuristic scheduling algorithms

Outlook

- Option to communicate over eNB ➔ extend Linear Program
- More realistic traffic model (demands)
- Extend to frequency domain
- Changing channel conditions
- Develop new algorithms, for example:
    - Distributed: give user terminals rights to decide
    - Adaptive: (re)schedule demands every TTI
    - Heuristic: do not include all states



Thank you! Questions?

www.tuhh.de

Nuber of States