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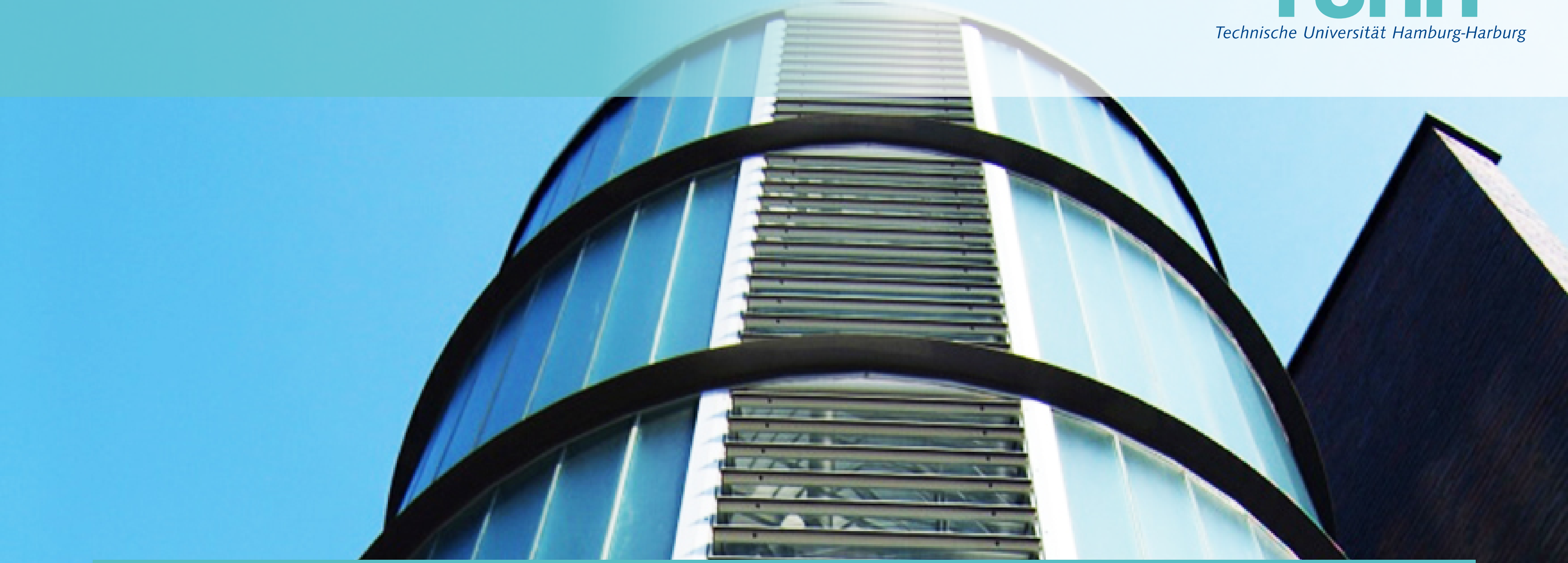

Optimal Schedule for LTE in D2D Mode

Maciej Mühleisen, Jan Habermann

Outline

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

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Grand vision: the "Airborne Internet"

Source: Airborne Internet Consortium (AIC). Airborne Internet Consortium, www.airborneinternet.org

Scheduled Airline Routes (January 2012)

Source: OpenFlights. http://openflights.org/data.html

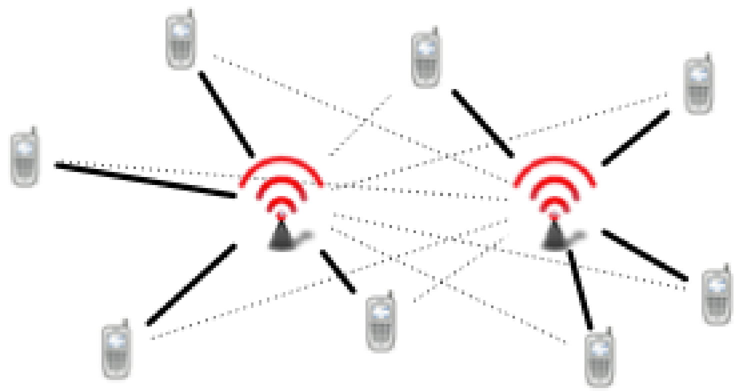
Challenges

- Coverage over the entire earth
- No ground infrastructure over large bodies of water
- Satellite-based communication is expensive and has high delays

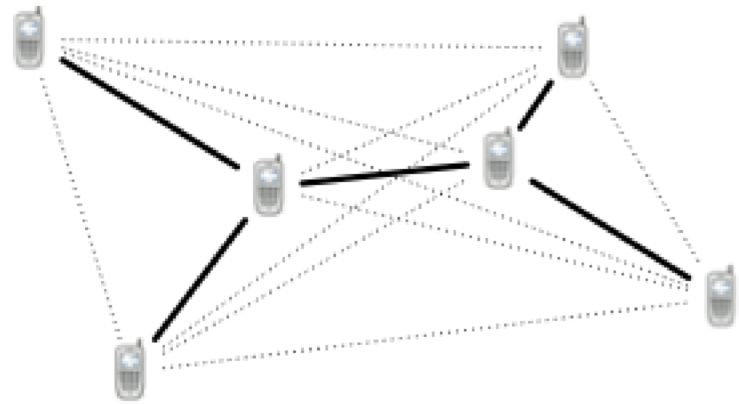
Motivation / Idea:	Using LTE in Device-to-Device (D2D) mode for direct Air-to-Air (A2A) communication between aircraft

Motivation

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



Default "star"-topology (Cellular Network)

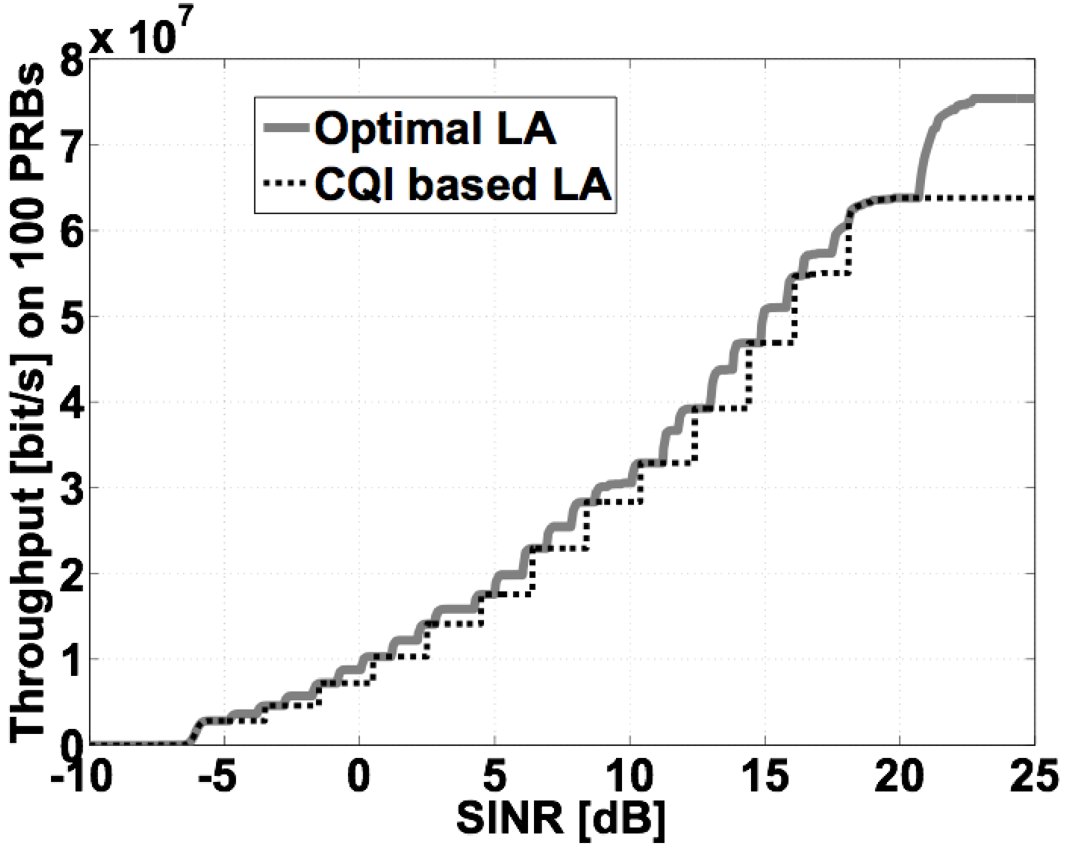


Network with D2D communication

Serving link

Interfering link

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

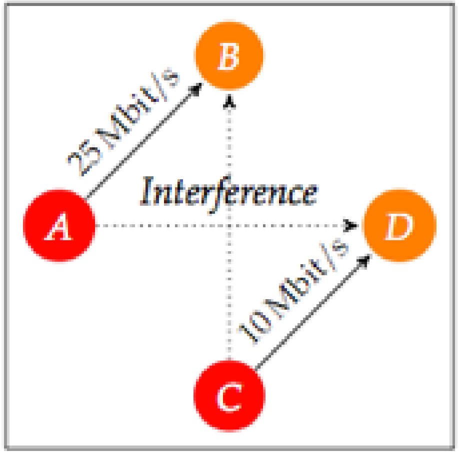


Source: Maciej Mühleisen, "Performance Evaluation of VoIP in LTE-Advanced Networks", Unpublished Ph.D. Thesis Draft, RWTH Aachen University, 2014

D2D Communication

A2A communication can not rely on a deployed ground infrastructure (e.g. across the Atlantic Ocean)

Resource Management Challenges

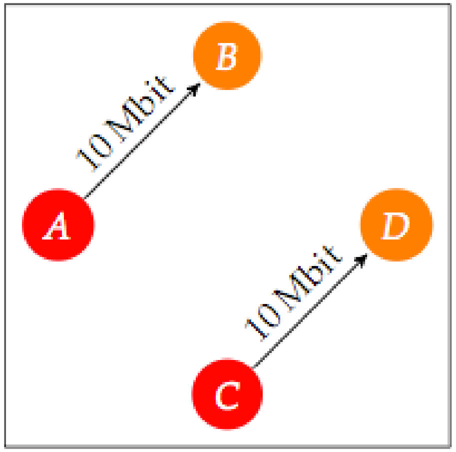


- **No central coordinator (base station)**
- **Transmitting on the same Physical Resource Blocks (PRBs) causes interference**
- **Interference becomes a major issue**

Optimal Schedule

Example with four nodes and only two demands:

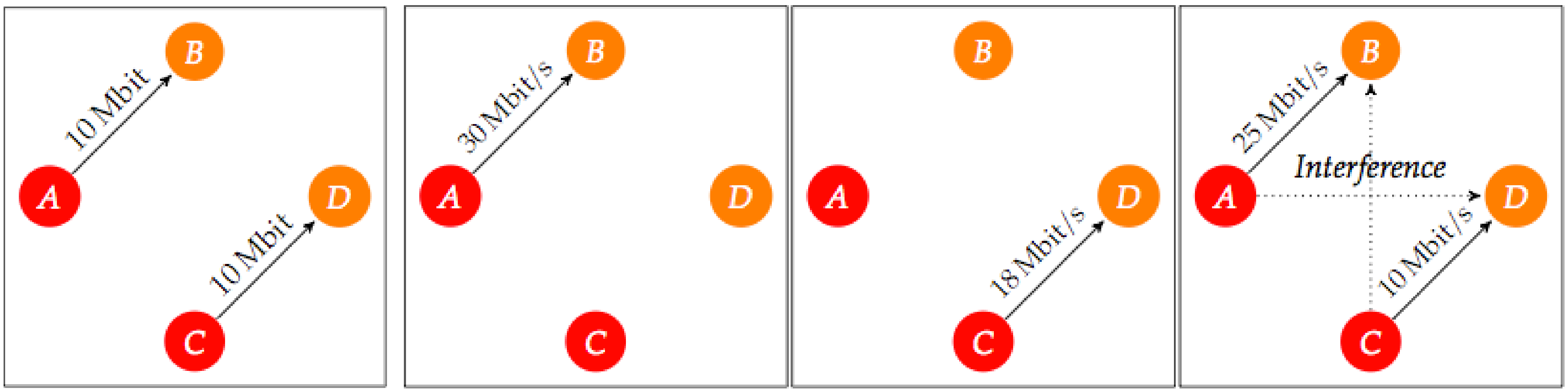
Traffic Demands



Optimal Schedule

Example with four nodes and only two demands:

Traffic Demands **Network States**

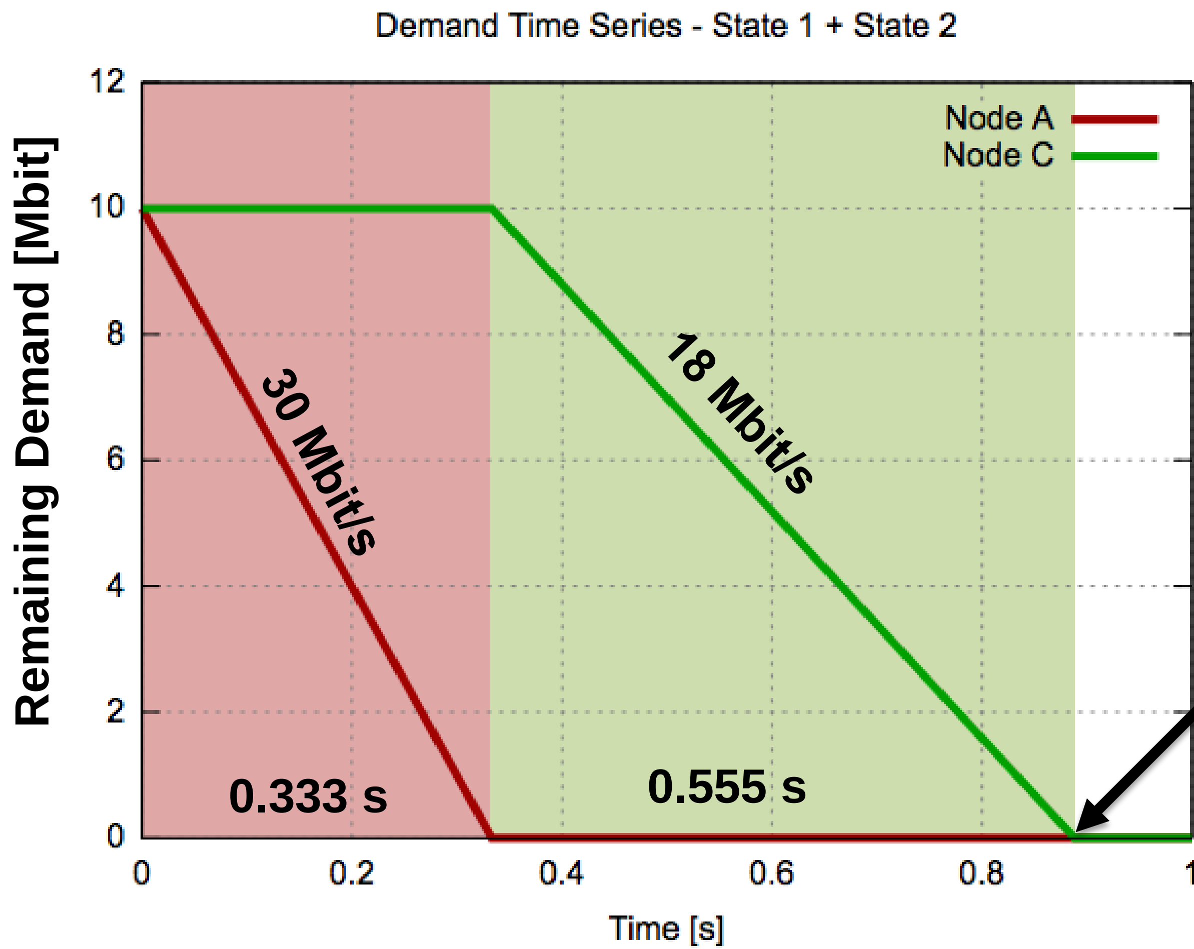


(a) Only A gets to send to B (b) Only C gets to send to D (c) Both get to send in parallel

State 1 **State 2** **State 3**

Optimal Schedule

Example with four nodes and only two demands:



End of the scheduling round
(t = 0.888 s)

➔ **22.5 Mbit/s**

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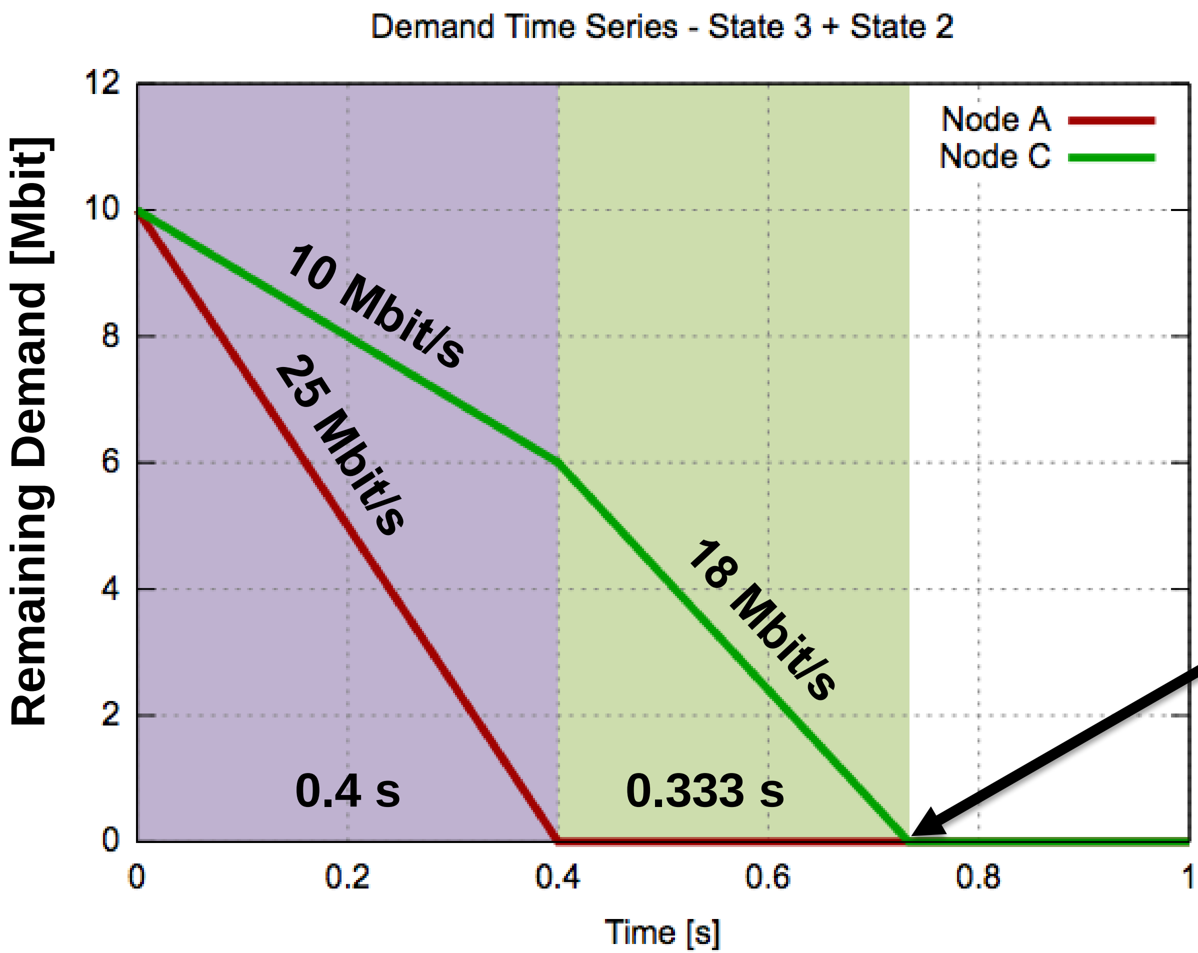
Example with four nodes and only two demands:



End of the scheduling round
(t = 0.733 s)

➔ **27.3 Mbit/s**

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?

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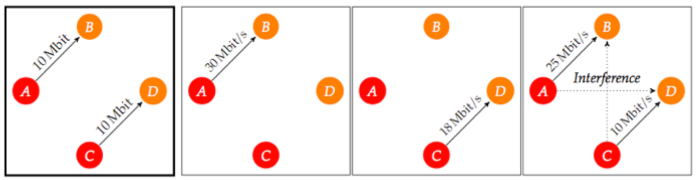
Problem formulation through Linear Programming

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

$$\textbf{min} \quad \mathbf{t}_1 + \mathbf{t}_2 + \mathbf{t}_3$$

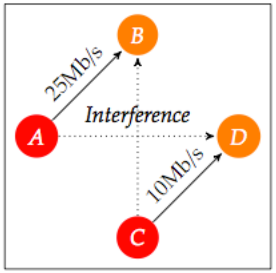
s.t.

$$\mathbf{t}_1 \cdot \underbrace{\begin{pmatrix} 0 & \mathbf{30} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_1} + \mathbf{t}_2 \cdot \underbrace{\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{18} \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_2} + \mathbf{t}_3 \cdot \underbrace{\begin{pmatrix} 0 & \mathbf{25} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{10} \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{S_3} \geq \underbrace{\begin{pmatrix} 0 & \mathbf{10} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{10} \\ 0 & 0 & 0 & 0 \end{pmatrix}}_{D}$$

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

Optimal Schedule

Providing a baseline for comparison:



The baseline only uses one big network state in which **all nodes** with demands **transmit simultaneously!**

The baseline may violate the constraints of the feasible network states!

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

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Problem:

SINR changes **(mobility)** while the actual transmissions take place

=> the “optimal” solution gets quickly out-of-date

Schedule Processing Strategies:

- **RandomShuffle**

- **ShortestStateFirst**
  Scheduling short states first should be an improvement over a random order because more states can profit from a more recent channel estimation

Simulation Model

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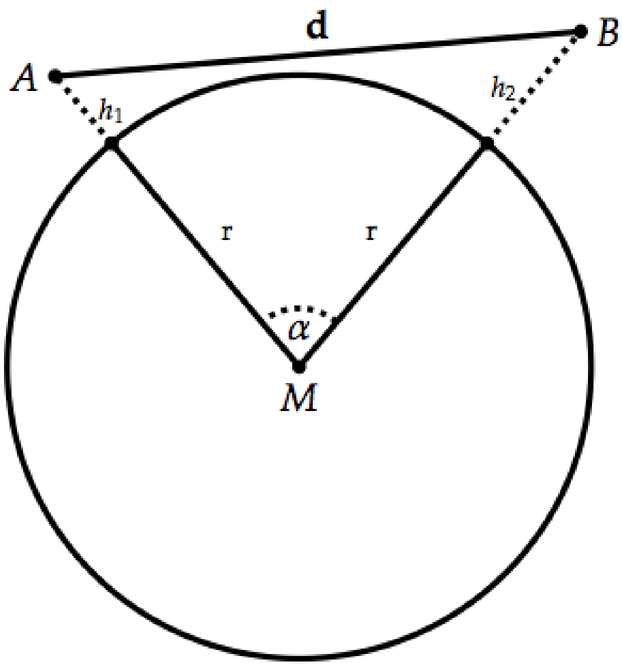
Used simulation software:

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

Assumptions / Limitations:

- Only demands to the nearest neighbor (e.g. Black-Box data transmission)
- 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



Assumptions:

- Earth is assumed to be a perfect sphere
- Free-Space-Pathloss used to calculate SINRs and estimate throughputs

$$d_{horizon}(h_1, h_2) = \sqrt{2 \cdot r \cdot h_1 + {h_1}^2} + \sqrt{2 \cdot r \cdot h_2 + {h_2}^2}$$

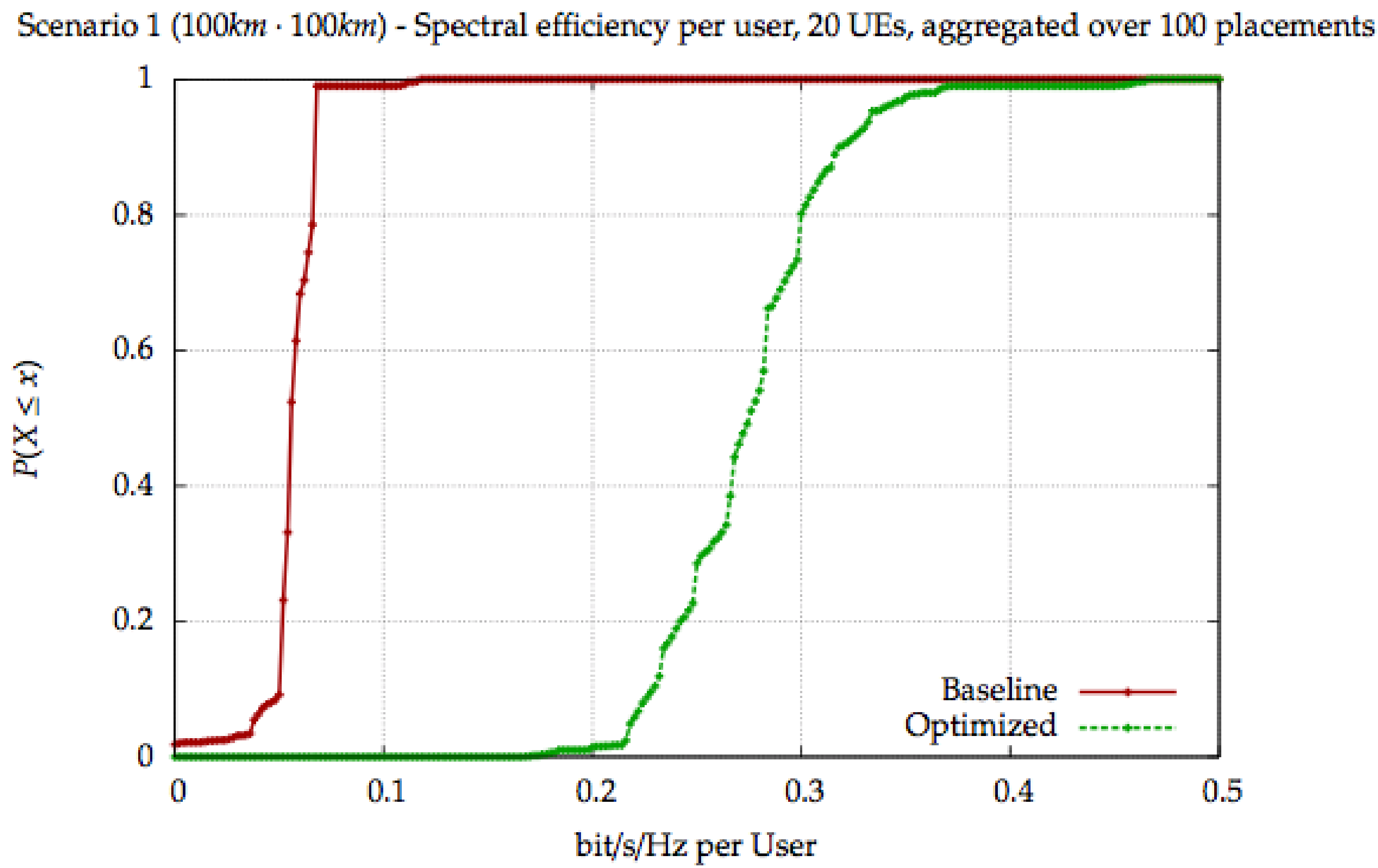
$$Pathloss[dB] = \begin{cases} 20 \cdot log_{10}(d) + 20 \cdot log_{10}(f) + 20 \cdot log_{10}\left(\frac{4\pi}{c}\right), & d \leq d_{horizon} \\ \infty, & d > d_{horizon} \end{cases}$$

Simulation Model

Parameter	Value
Bandwidth	10 MHz (50 PRBs)
# of Nodes	20
Channel Model	Free Space Path Loss with Radio Horizon; no Fast Fading
TX Power	50 W (30 dBm) per PRB
Altitude	10 km

Parameter	Value Without Mobility	Value With Mobility
Sim. Time	60 s	300 s ☹
Speed	0 km/h	1000 km/h
Schedule Order	Random	Random ShortestStateFirst
Scenario Size	100 x 100 km 500 x 500 km 1000 x 1000 km	500 x 500 km

Results: No Mobility



Results: No Mobility

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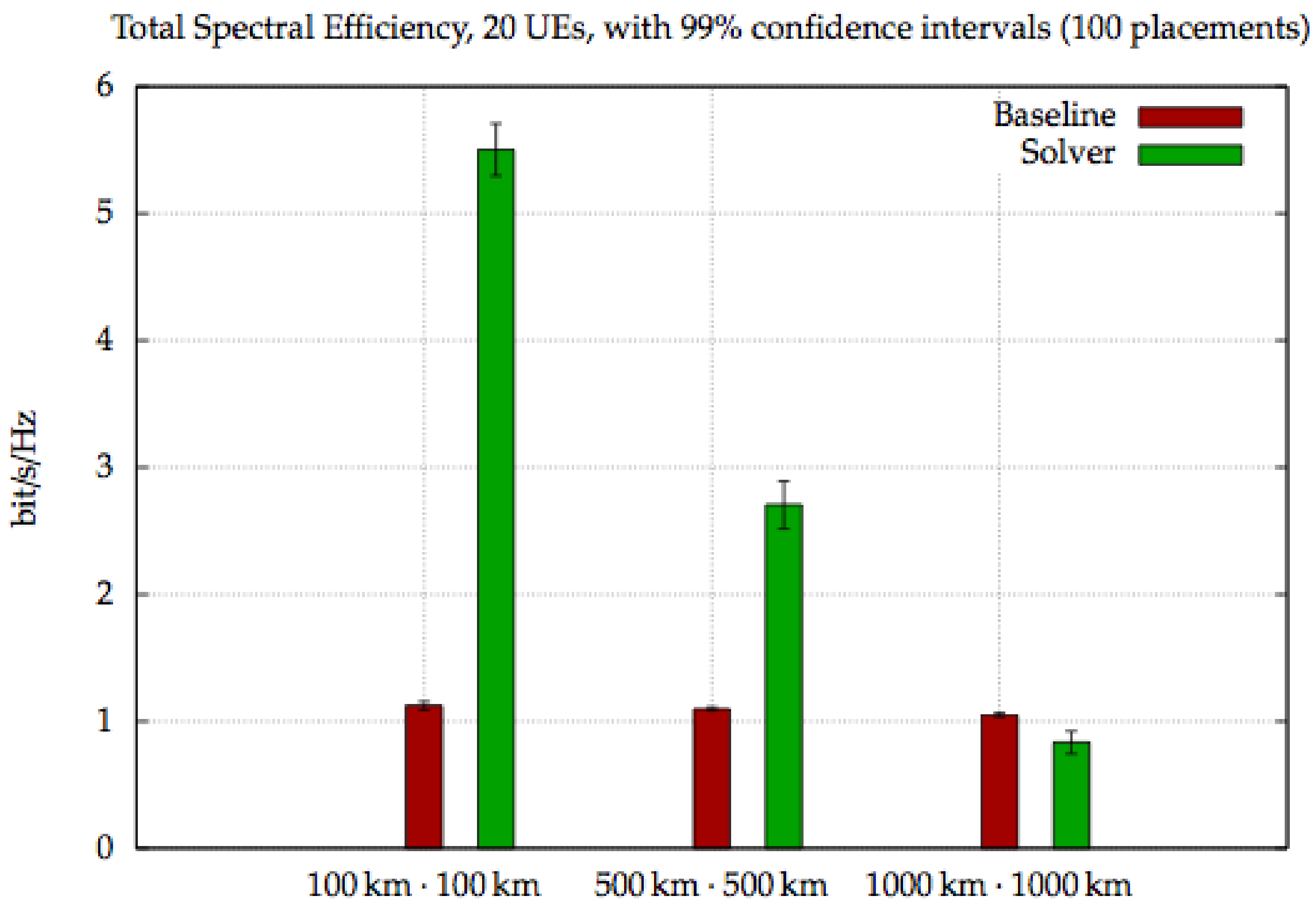
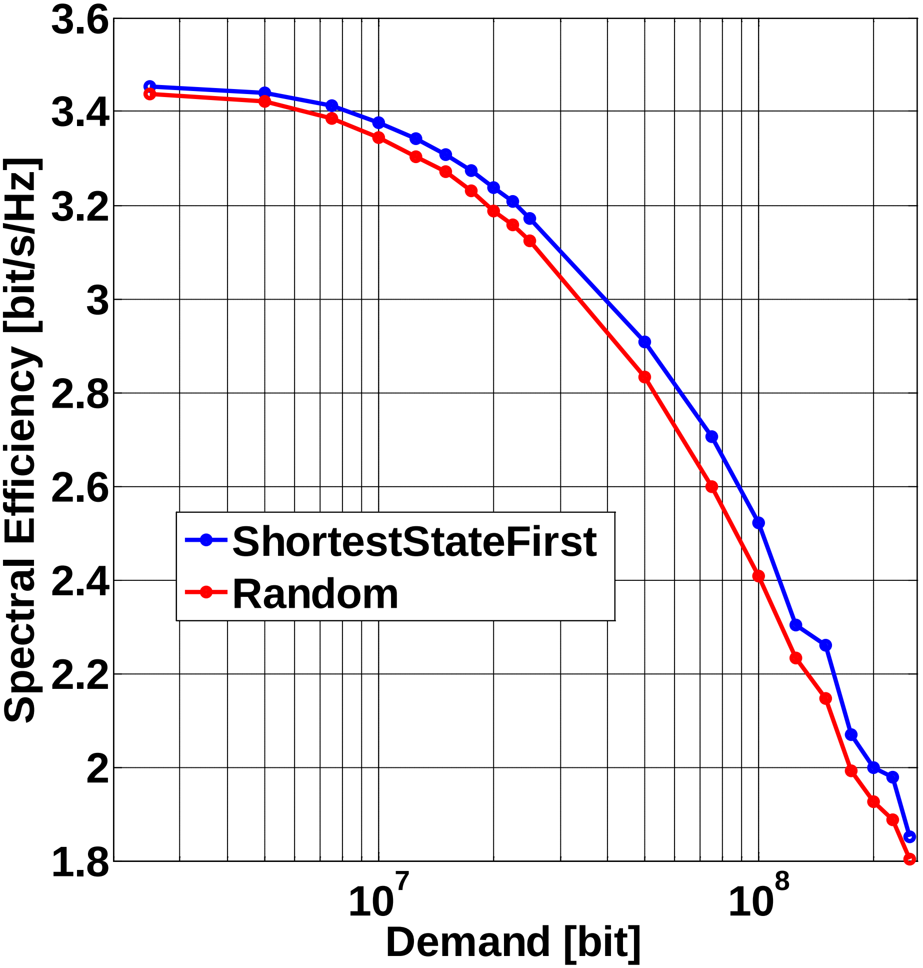
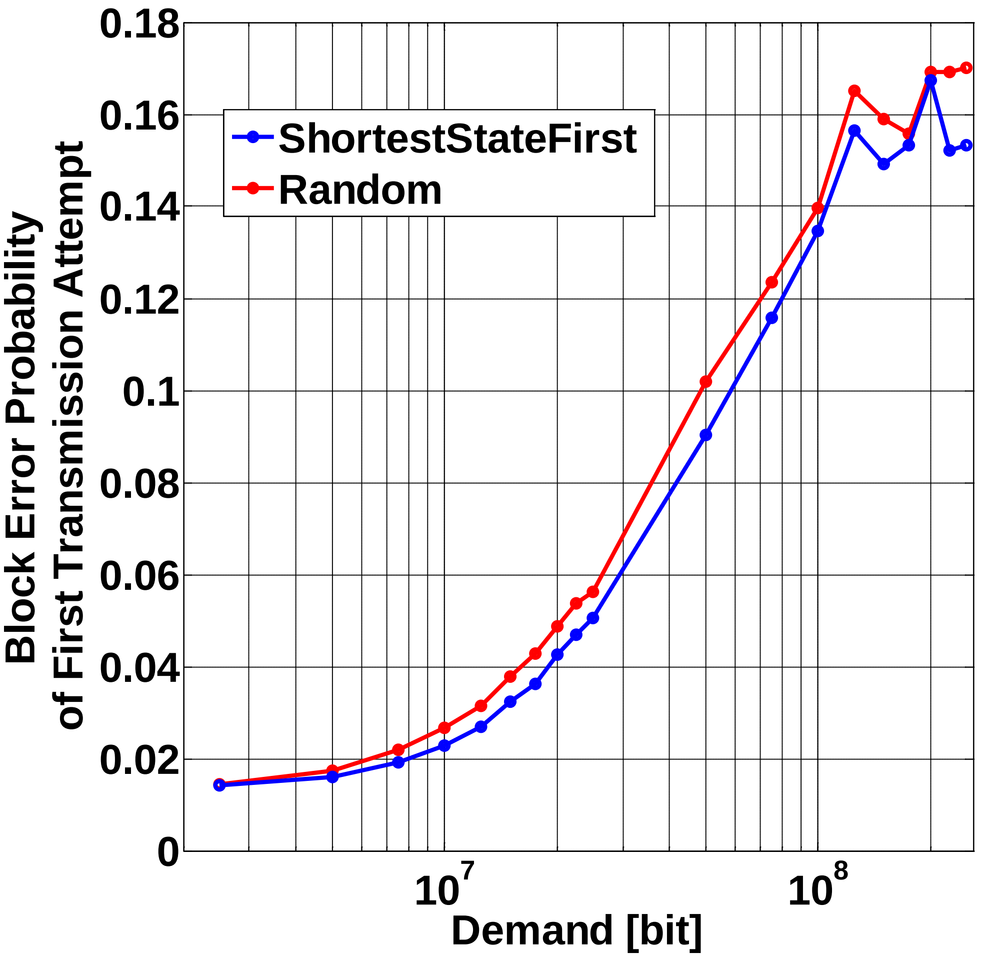


Results: With Mobility





Conclusion & Outlook

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Conclusion

- The optimal schedule obtained by Linear Programming assures high spectral efficiency
- The longer it takes to process the schedule the higher the error rate due to mobility
- Performance is increased if the schedule is processed starting with the shortest states

Outlook

- Calculate more realistic traffic demands from buffer fill levels
- Include HARQ buffers in traffic demands
- Include frequency domain
- Schedule order “Highest Relative Velocity First”
- Specify a real system using satellites for centralized scheduling

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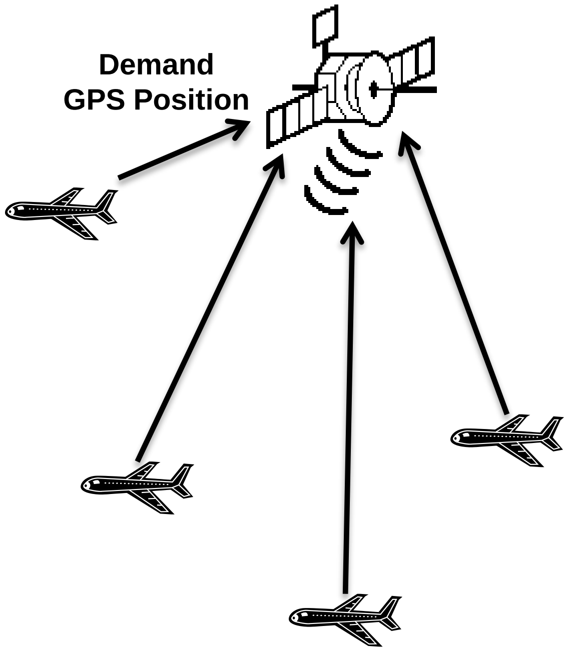

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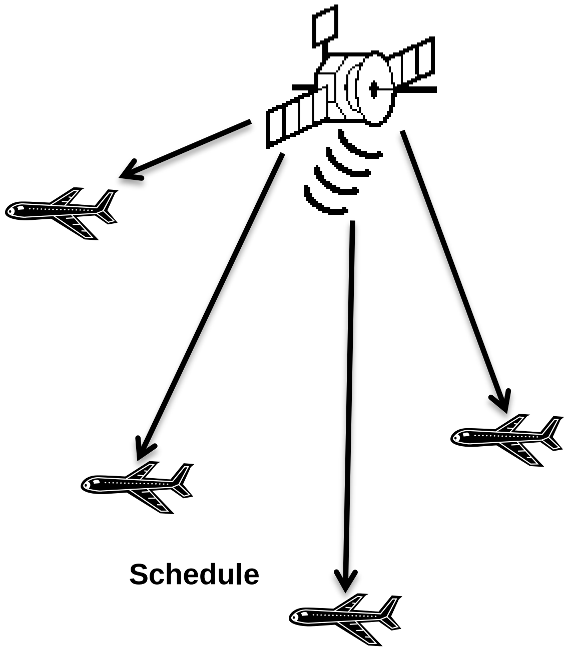

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Thank you! Questions?

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