Linear Programming for Optimal Mode-Selection for D2D Communication in LTE-Advanced

ComNets Hamburg

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Outline

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- Introduction & Motivation
- Formulation of Optimization Problem
- Scenraios
- Results
- Conclusion & Outlook

Device-to-Device Communication (D2D)

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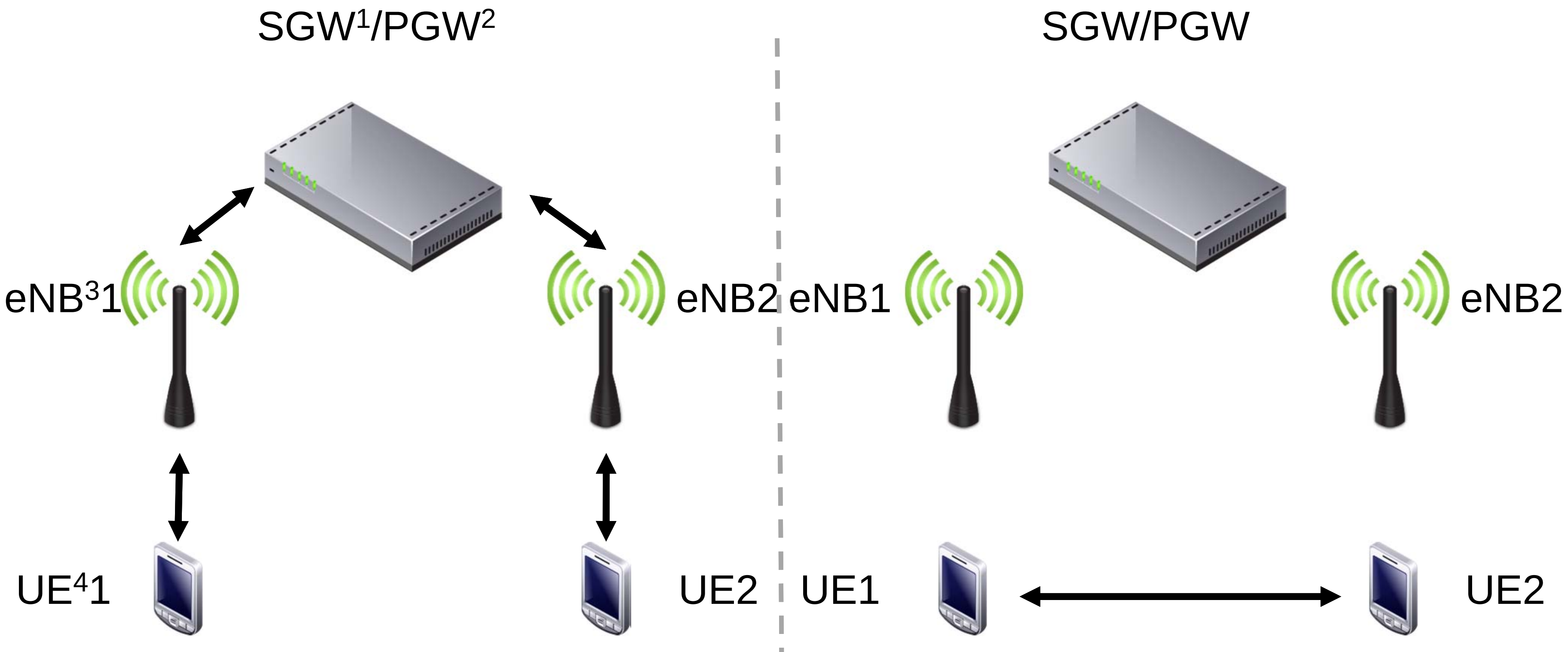
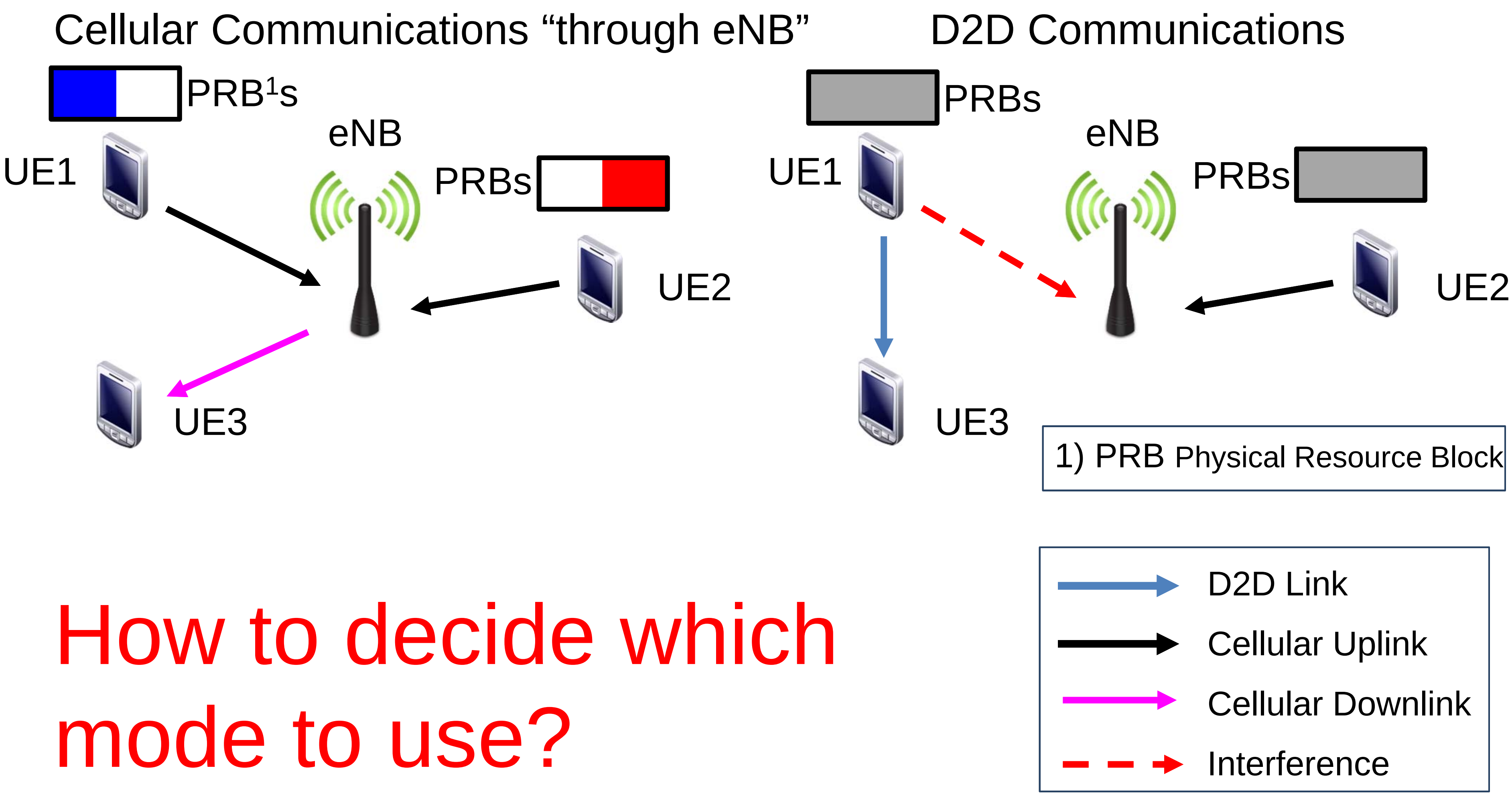


1) SGW Serving Gateway
2) PGW Packet data network Gateway
3) eNB Evolved NodeB
4) UE User Equipment

Mode Selection



How to decide which mode to use?

Motivation

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- Serve demands of mobile users
- **Increase spectral efficiency**
- Reduce communication delay
- Reusing resources
- Reduce network load
- Public safety applications & resilience in case of disaster

Schedule Optimization

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1. Generation of Feasible Network States
2. Throughput Estimation
3. Linear Programming Formulation

[1] M. Mühleisen, J. Habermann, A. Timm-Giel, *Optimal Schedule for LTE-Advanced Device-to-Device Communication in Aviation*, European Wireless 2015

Generation of Feasible Network States

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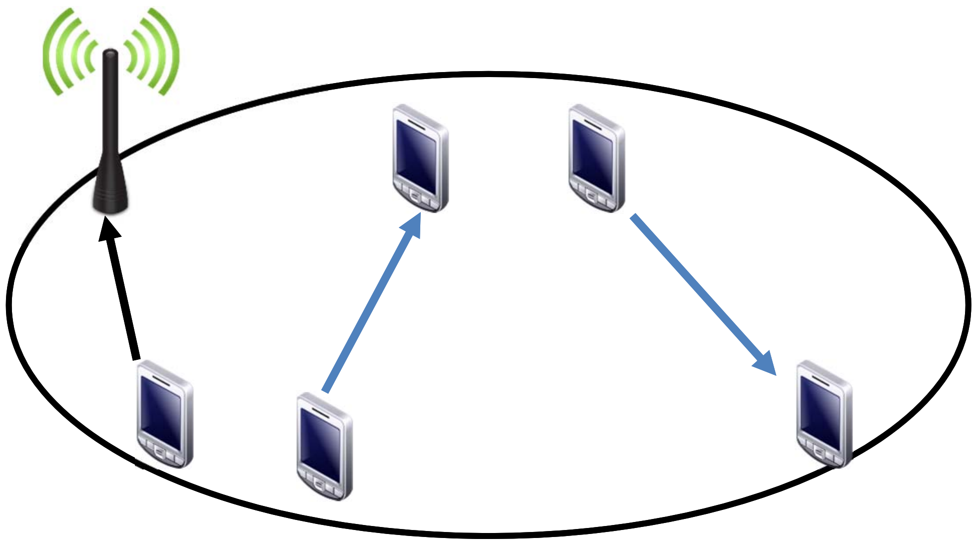
- Network State$_i$ for each active link:
  [*Source (a), Data Rate (r), Destination (b)*], $S_i \in R^{NxN}[a,b]$



Possible network states

Constraints:

- Each UE can not receive from more than one UE
- Each UE can only transmits to one UE at a time
- No UE can transmit and receive at the same time

Generation of Feasible Network States

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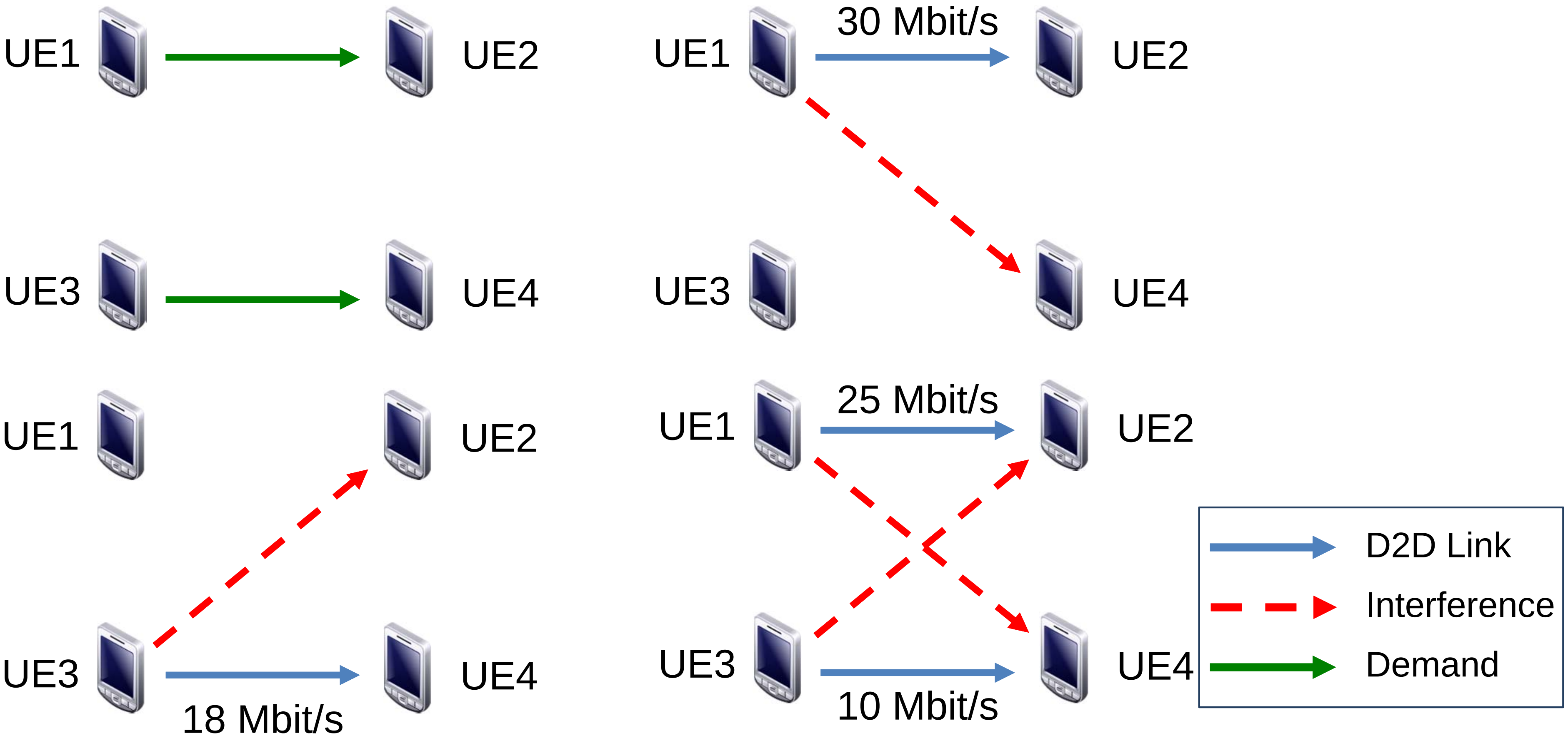
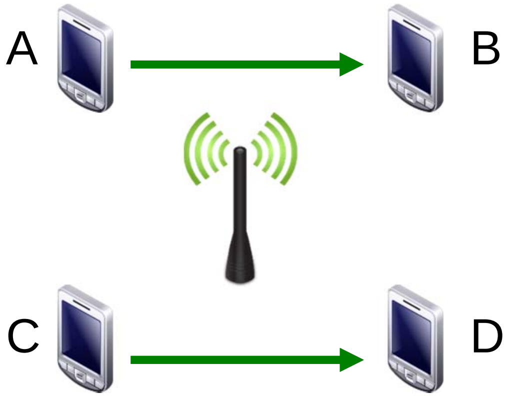


[2] S. Max, *Capacity and Efficiency of IEEE 802.11n in Wireless Mesh Operation,* PhD thesis. Communication Networks (ComNets) Research Group RWTH Aachen University, 2011

Cellular Mode Network States

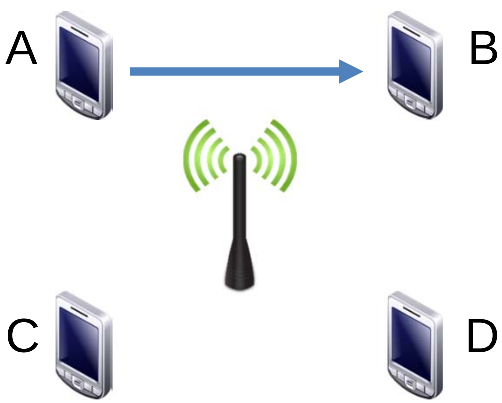


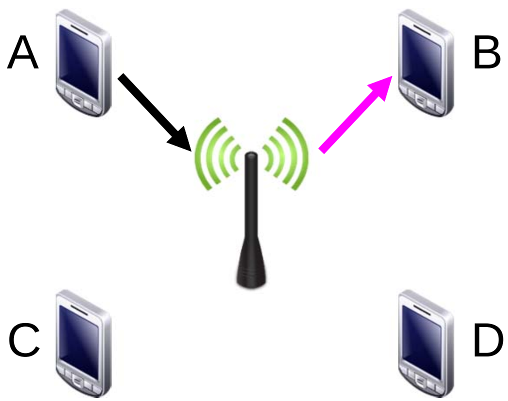
$$D = \begin{pmatrix} 0 & D_{AB} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & D_{CD} \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

Network states with 4 nodes and demands D:

- A-B
- C-D
- A-B, C-D

} *D2D Only (1)*





- A-eNB-B
- C-eNB-D
- A-eNB-B, C-D
- A-B, C-eNB-D

} *Cellular Mode (2)*

- A-eNB-B, C-eNB-D *Cellular Mode with Multiple TXs to the eNB (3)*

Cellular Mode Network States

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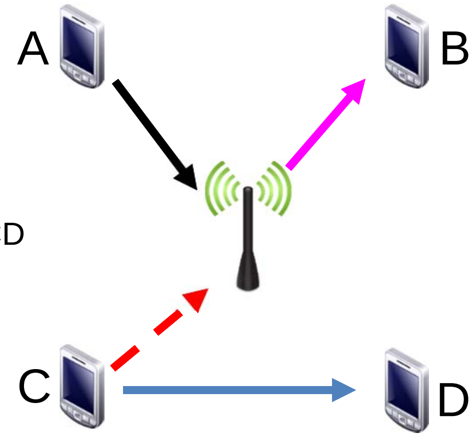
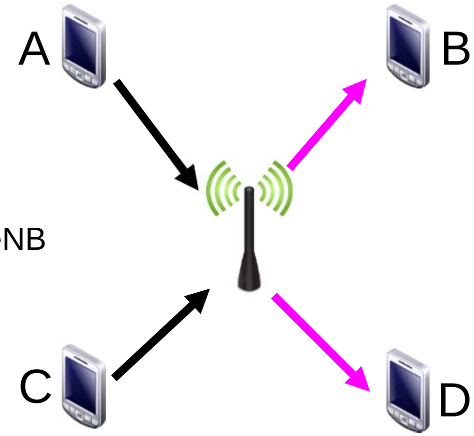


$S_{6,AeNB,CD}$

$$\left(\frac{1}{R\left(\frac{P_{TX} WBL_{AeNB}}{P_{TX} WBL_{CeNB} + P_{Noise}}, N_{PRB,Max} \right)} + \frac{1}{R\left(\frac{P_{TX} WBL_{eNBB}}{P_{Noise}}, N_{PRB,Max} \right)} \right)^{-1}$$



$S_{8,AeNB,CeNB}$

$$\left(\frac{1}{R\left(\frac{P_{TX} WBL_{AeNB}}{P_{Noise}}, \frac{N_{PRB,Max}}{2} \right)} + \frac{1}{R\left(\frac{P_{TX} WBL_{eNBB}}{P_{Noise}}, \frac{N_{PRB,Max}}{2} \right)} \right)^{-1}$$

N_{PRB}: Number of PRBs
R(SINR, N_{PRB}): data rate
WBL: Wideband loss
P_{TX}: TX Power

Linear Program Formulation

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$$S_i[a,b] = \begin{cases} r & \text{if node a can transmit rate } r \text{ [bit/s] to node b} \\ 0 & \text{if there is no transmission from node a to node b in this state S} \end{cases}$$

$$D[a,b] := \text{demand from } a \text{ to } b$$

$$\min \sum_{i=1}^{iMax} t_i \qquad \text{s.t.} \qquad \sum_{i=1}^{|S|} t_i \cdot S_i \geq D, \quad t_i \geq 0$$

Solving Round Duration

i is the network state index
S is set of feasible network state matrices $\{S_1,\ldots,S_{iMax}\}$
D is the demand matrix
t_i is transmission time for network state *i*

Simulation Environment

- **openWNS:** dynamic event driven system-level simulation platform
  - Code in C++, configuration in Python
  - Models available for WPAN, WLAN and cellular communication systems
  - Developed at ComNets RWTH Aachen

- **IMTAphy:** open source LTE/LTE-Advanced system-level simulator and IMT-A channel model implementation (openWNS module)
  - Developed at LKN TU Munich

Simulation Scenario

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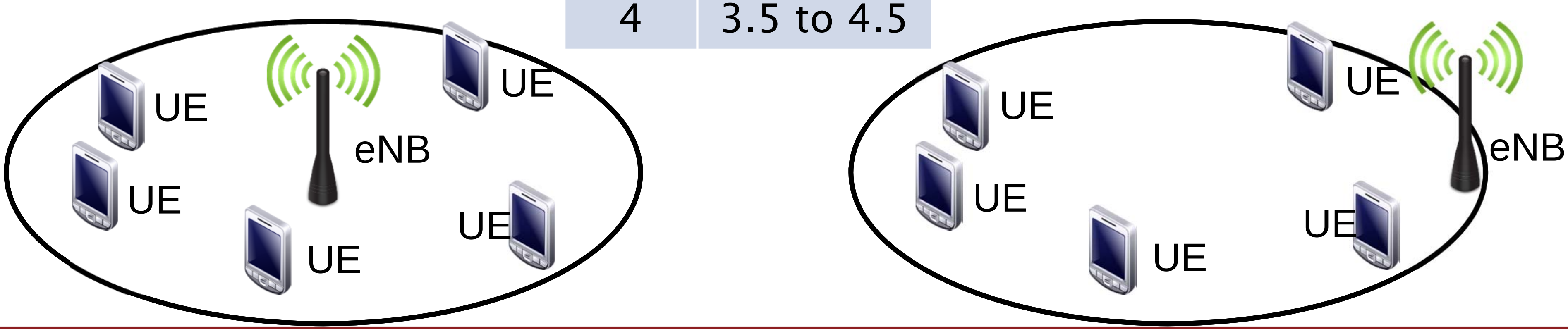
Transmission Power	Uplink Noise Power	Banwidth	Demands	Channel Model	Antenna	Cell Radius
23 dBm	-114.45 dBm	3MHz (15 PRBs)	2Mbit to nearest neighbour	Pathloss only	Omni	115 m 290 m 1000 m (UMi, UMa, RMa)

#UEs	Path Loss Exponent
3-5	2
3-5	2
4	3.5 to 4.5



Simulation Results: UMa Free Space Path Loss

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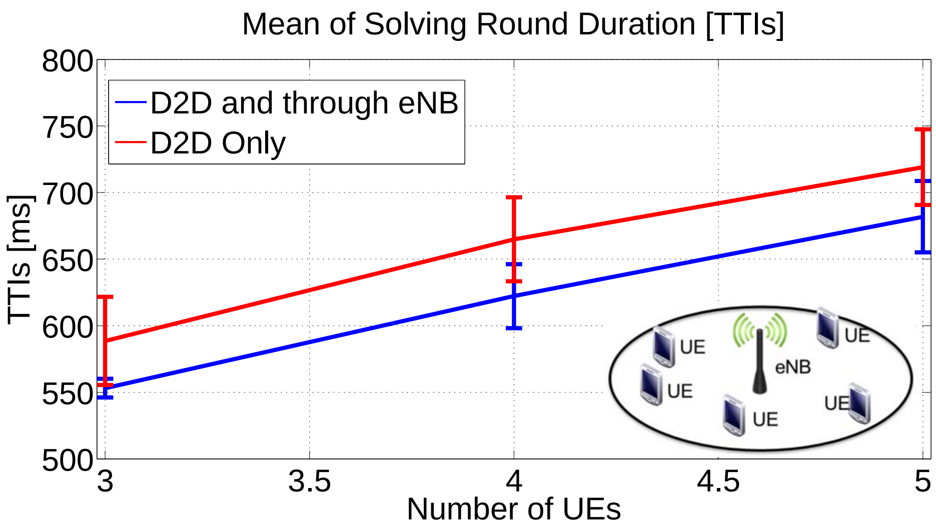
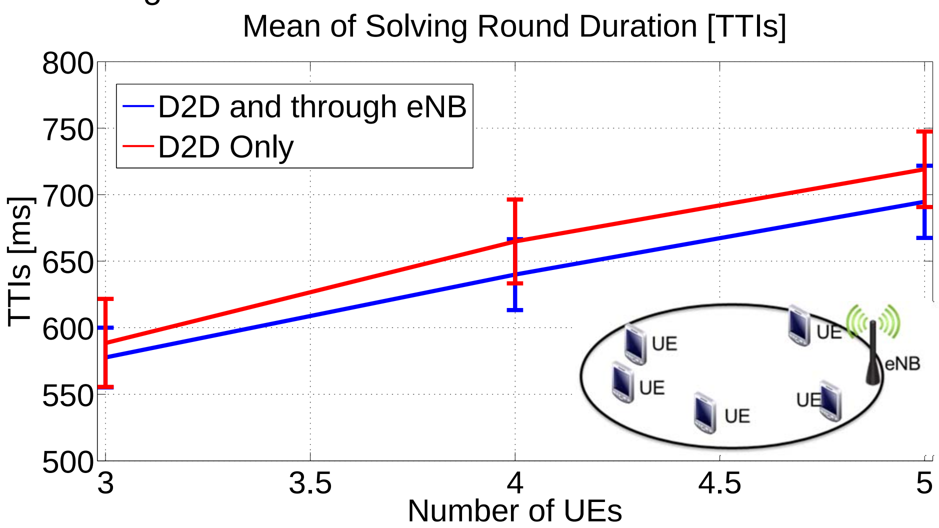
3-5 UEs
eNB in center



eNB **at edge**: users more likely communicate directly

3-5 UEs
eNB at edge



Simulation Results: UMa Free Space Path Loss

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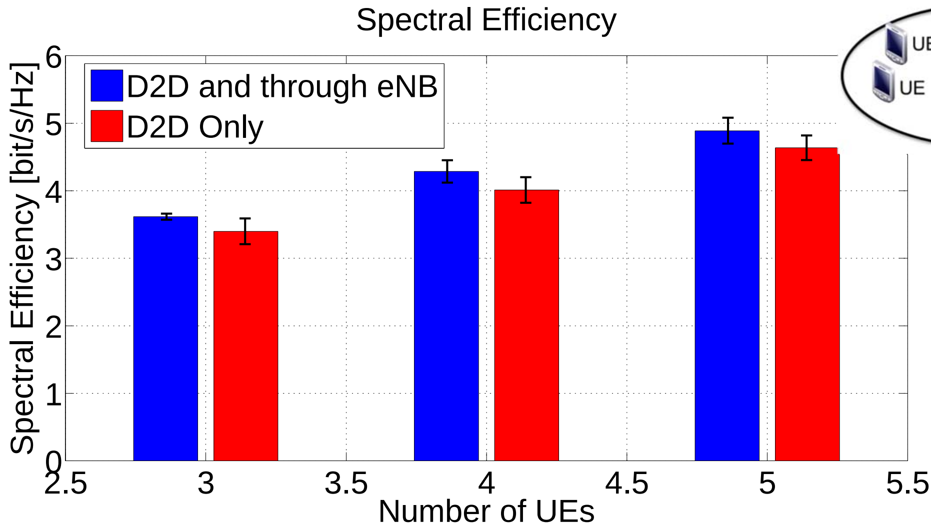
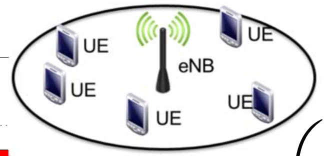
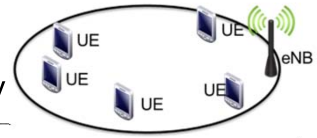
3-5 UEs
eNB in center

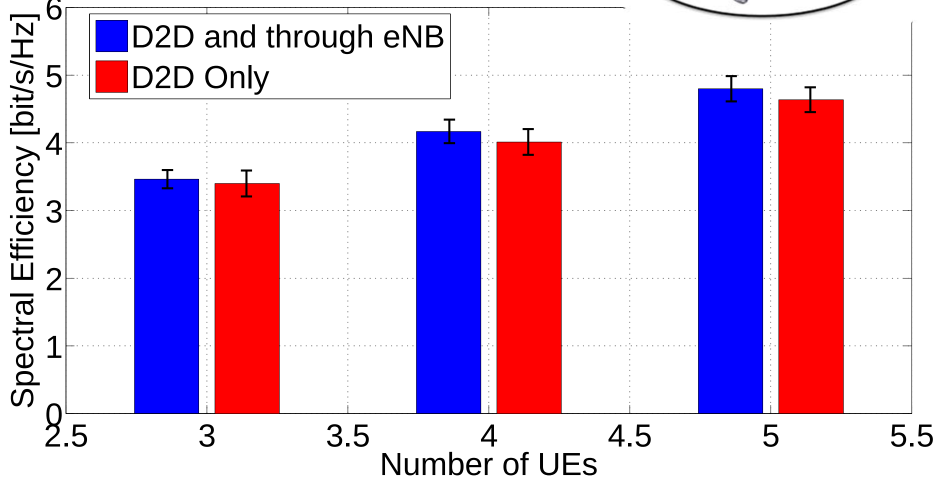




$$SE := \frac{\left(\dfrac{\#UE \cdot demandSize}{\#TTIs \cdot 0.001s}\right)}{3MHz}$$



3-5 UEs
eNB at edge



eNB **in center**: Spectral Efficiency is slightly higher if mode selection is performed

eNB **at edge**: Spectral Efficiency remains almost the same

Simulation Results: UMa & RMa Adjusted Path Loss

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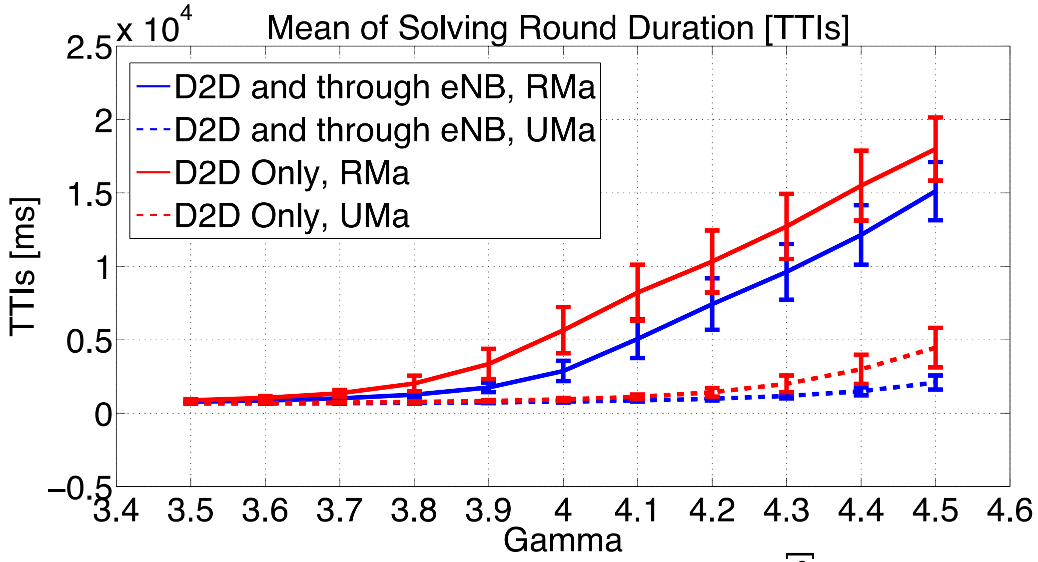
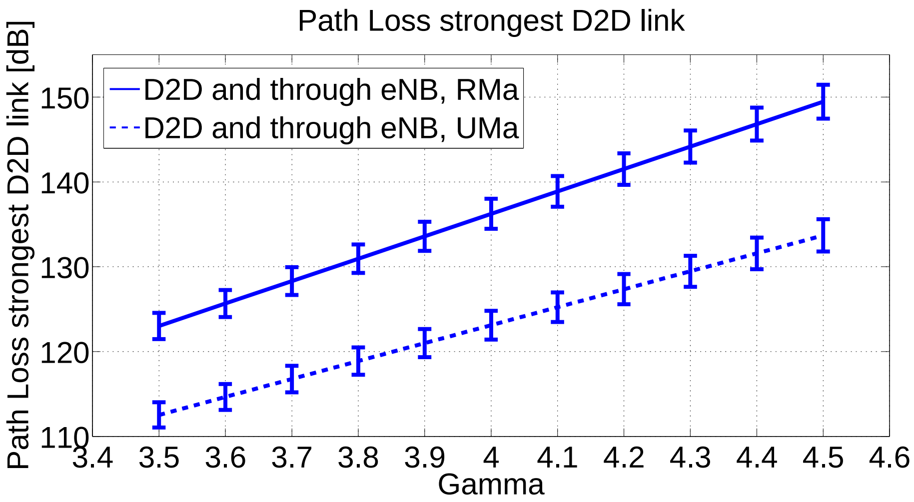
4 UEs UMa & RMa
Path Loss Exp.
Gamma (3.5 to 4.5)



SE increased in scenarios with higher path loss



Simulation Results: Downlink SINR

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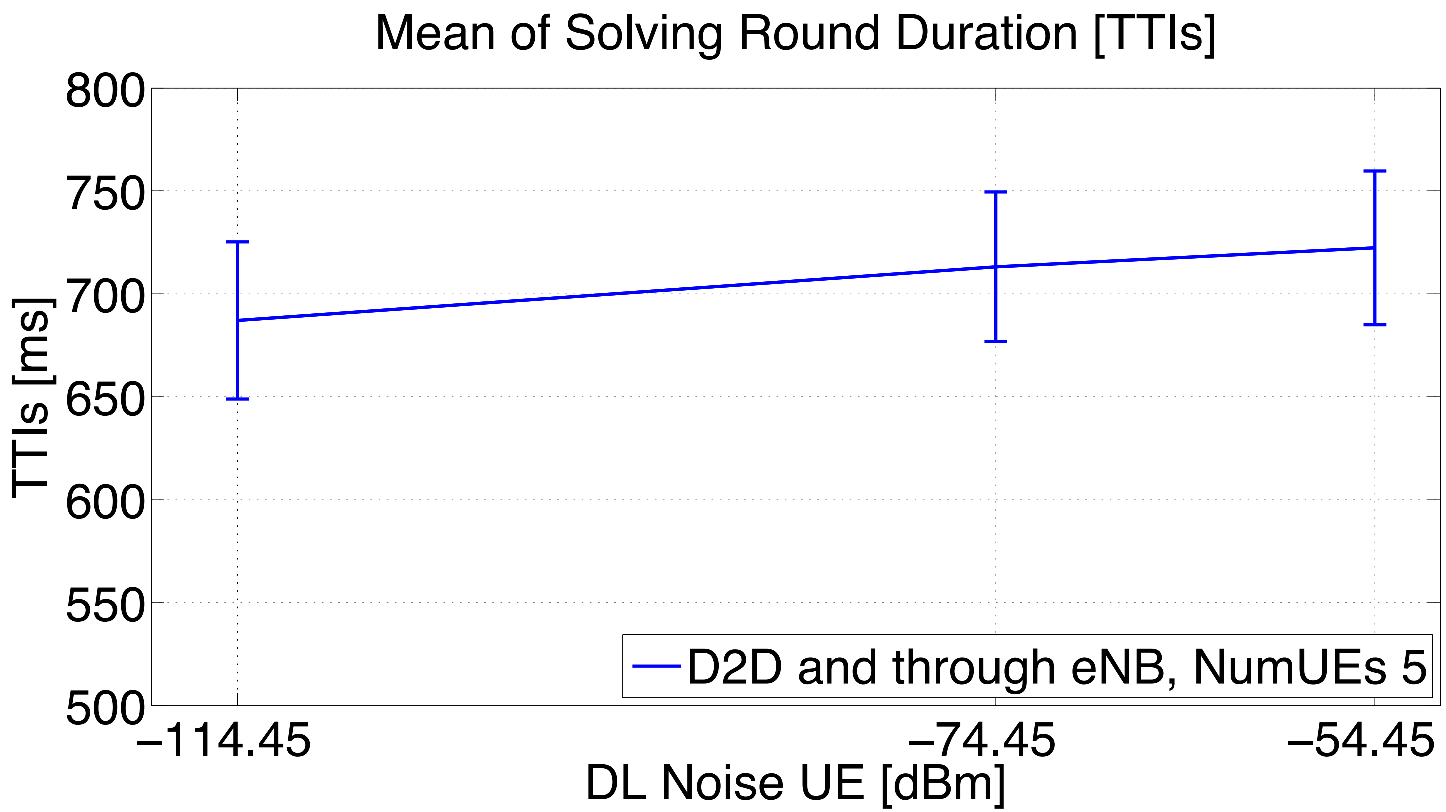

Spectral Efficiency remains almost constant if DL SINR decreases
➔ System adapts and uses more D2D

Conclusion and Outlook

Conclusion:

- Linear Problem solution optimally selects mode
- Spectral Efficiency slightly increased, depending on channel conditions

Outlook:

- More realistic channel model
- Multi cell scenario with realistic DL interference
- Heuristic to generate subset of network states
- More realistic traffic model

Thank you! Questions?

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Optimal Schedule

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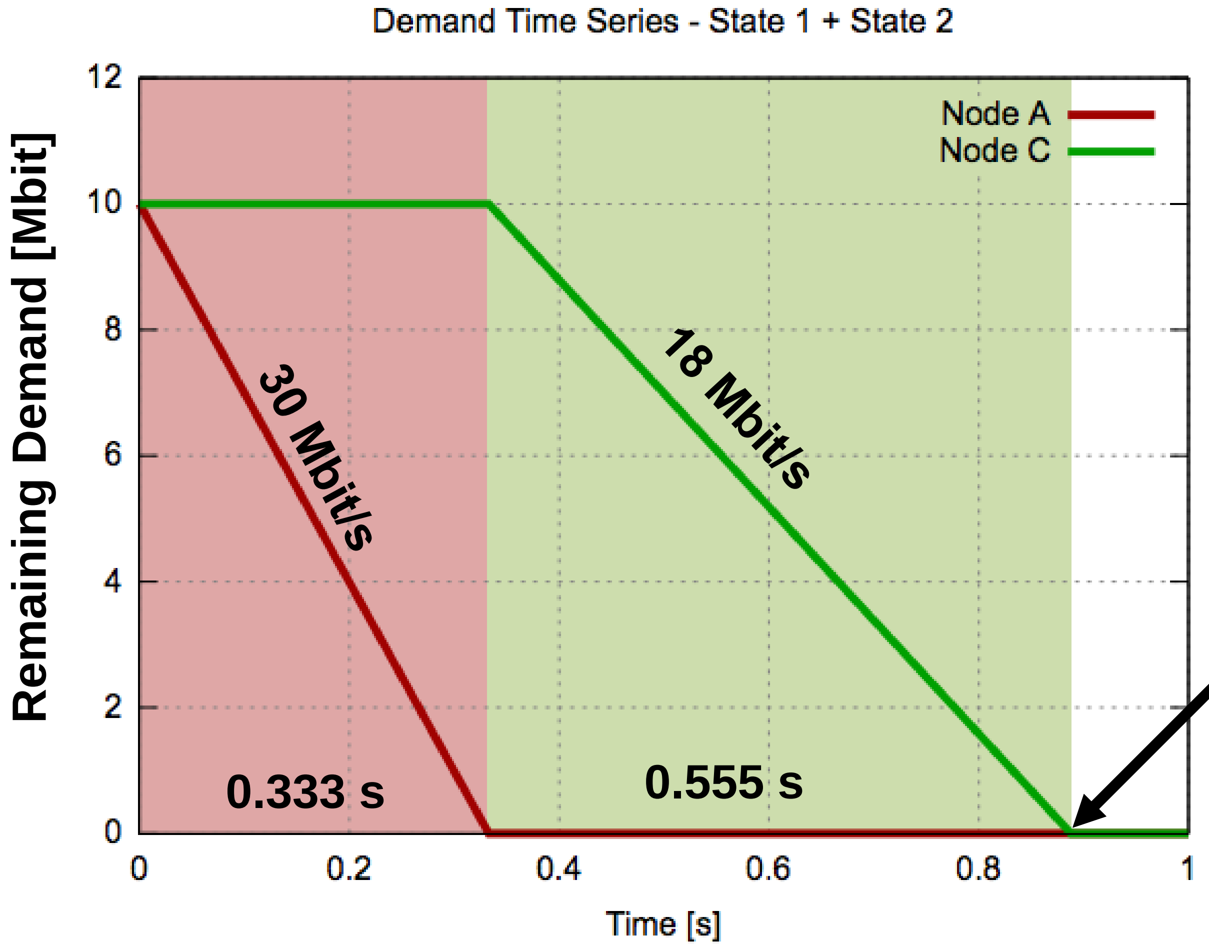
Example with four nodes and only two demands:



End of the scheduling round
(t = 0.888 s)

➔ 22.5 Mbit/s

Optimal Schedule

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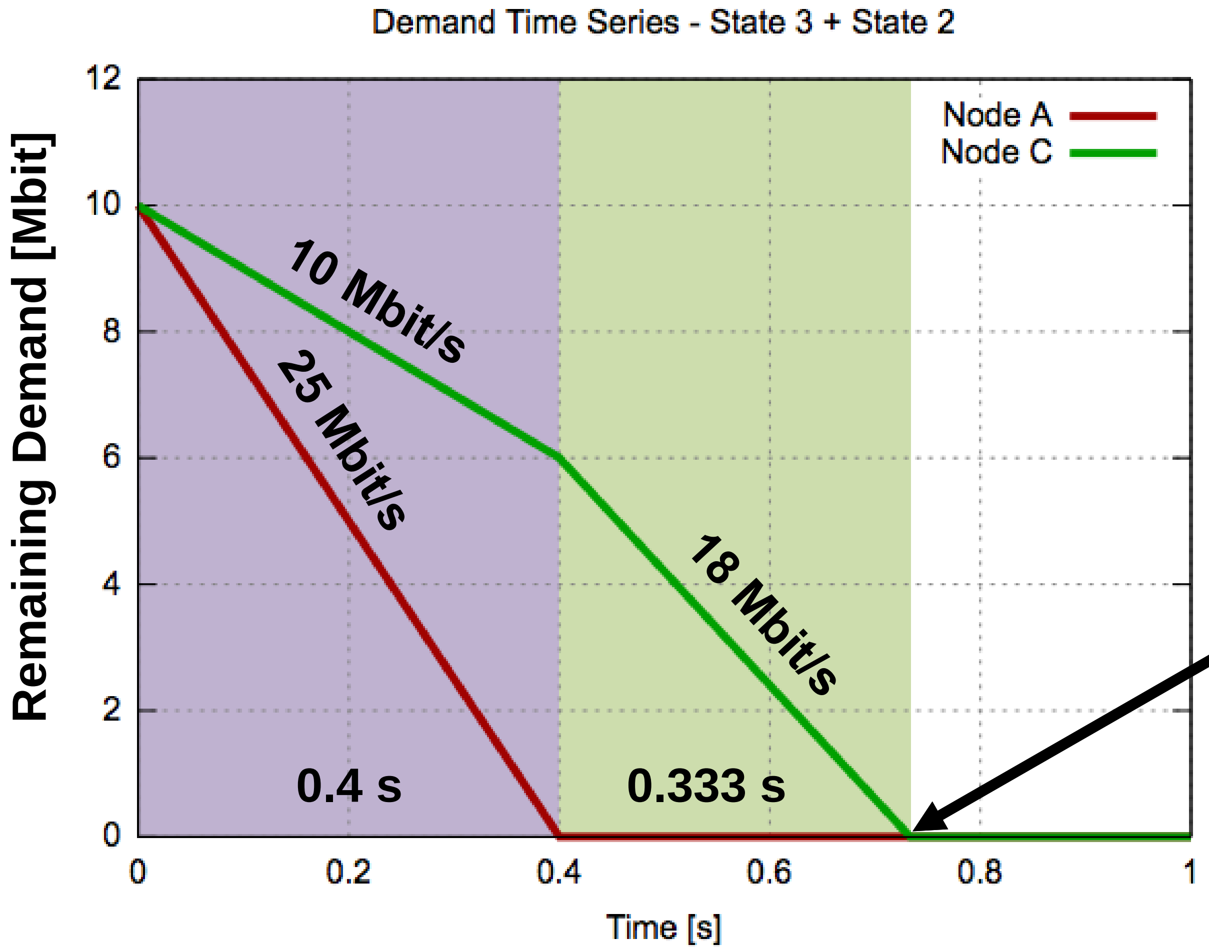
Example with four nodes and only two demands:



End of the scheduling round
(t = 0.733 s)

➔ **27.3 Mbit/s**