

Affordable Mobile Communications Experiments in High Mobility Scenarios

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Experiments in High Mobility Scenarios



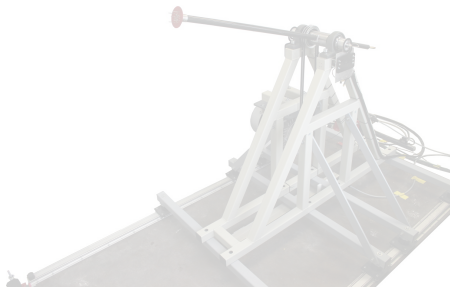
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Experiments in High Mobility Scenarios



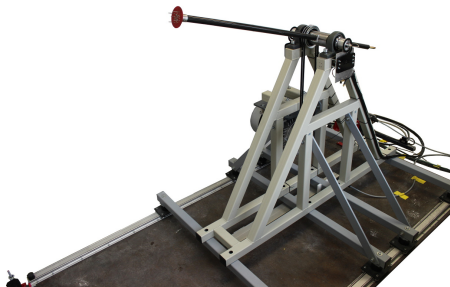
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Experiments in High Mobility Scenarios



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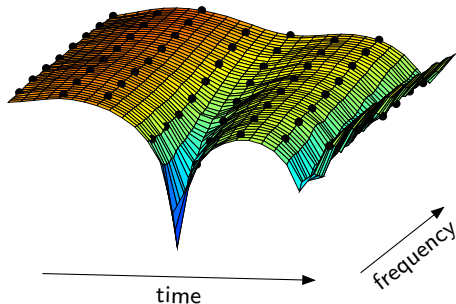


OFDM under Time-Varying Channel Conditions

channel interpolation errors

• pilot

$v \approx 220 \text{ km/h}$



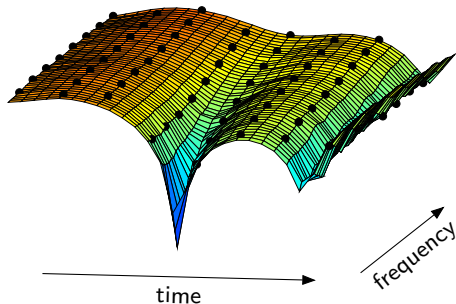
inter-carrier interference



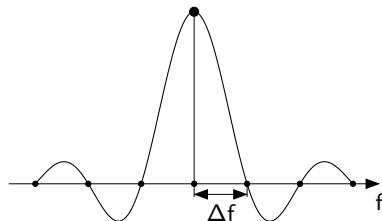
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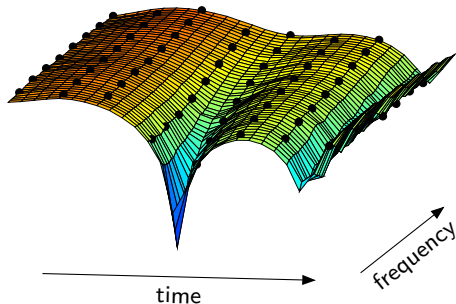
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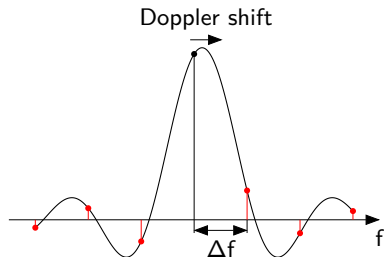
OFDM under Time-Varying Channel Conditions

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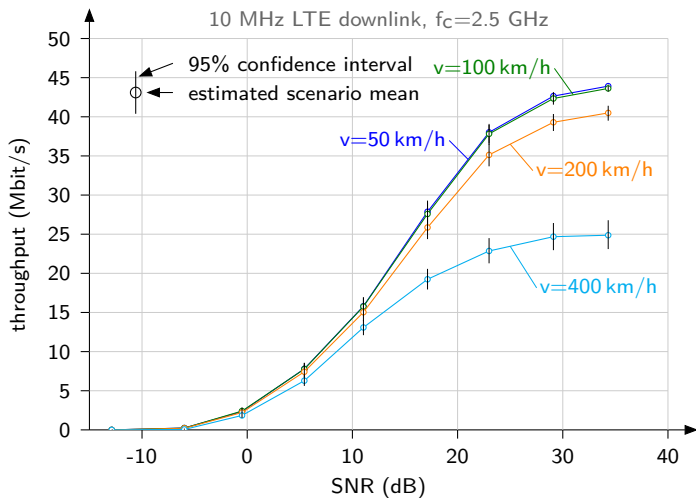
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inter-carrier interference



LTE Downlink Performance



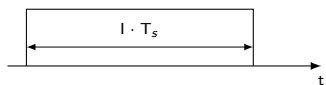
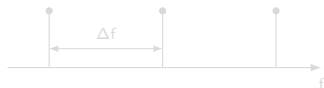
Emulation of Higher Velocities through Time Stretching



transmitted at $v = v_0$



original OFDM signal



transmitted at $v = \frac{v_0}{l}$

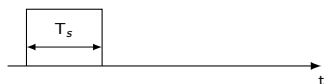


stretched OFDM signal

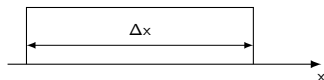


- T_s ... signal duration
- l ... stretching factor
- v ... velocity
- Δx ... spatial signal length
- Δf ... subcarrier spacing

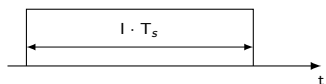
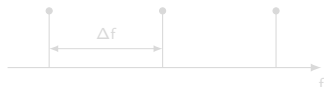
Emulation of Higher Velocities through Time Stretching



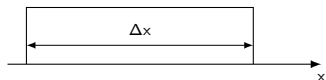
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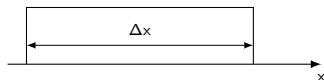


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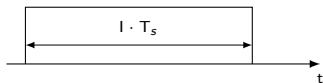
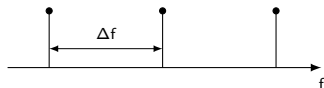
Emulation of Higher Velocities through Time Stretching



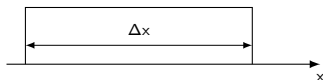
transmitted at $v = v_0$



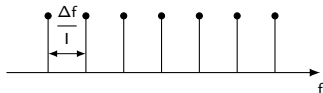
original OFDM signal



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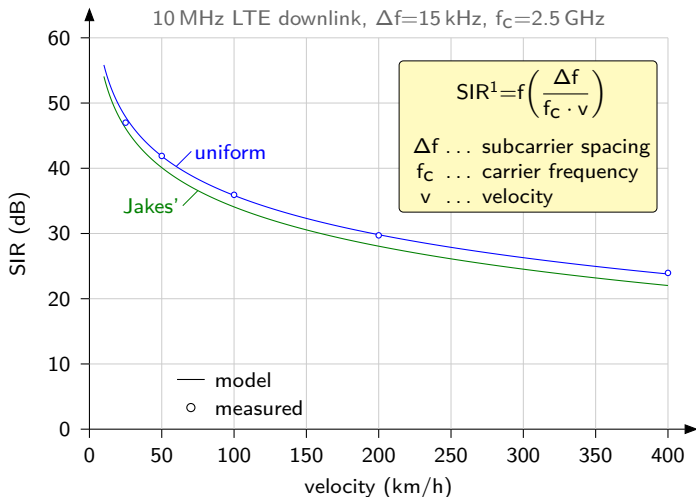


stretched OFDM signal



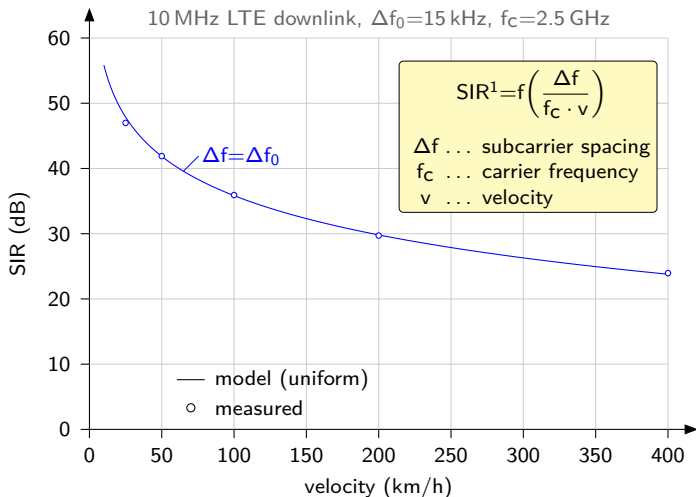
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Inter-Carrier Interference



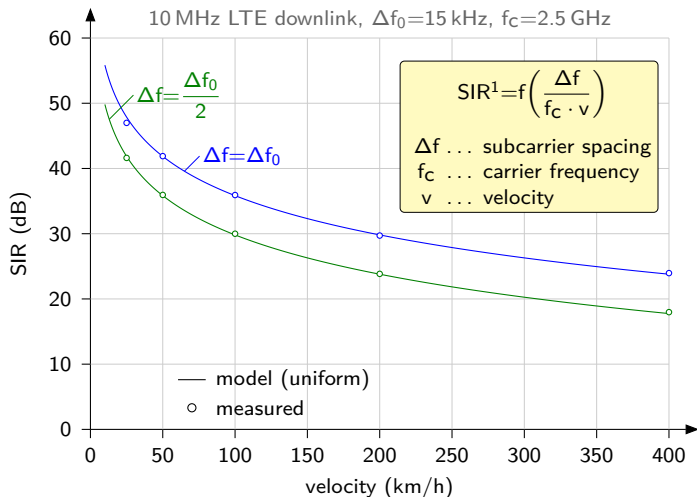
¹P. Robertson and S. Kaiser, "The effects of Doppler spreads in OFDM (A) mobile radio systems", *IEEE Vehicular Technology Conference, Fall, 1999*.

Inter-Carrier Interference



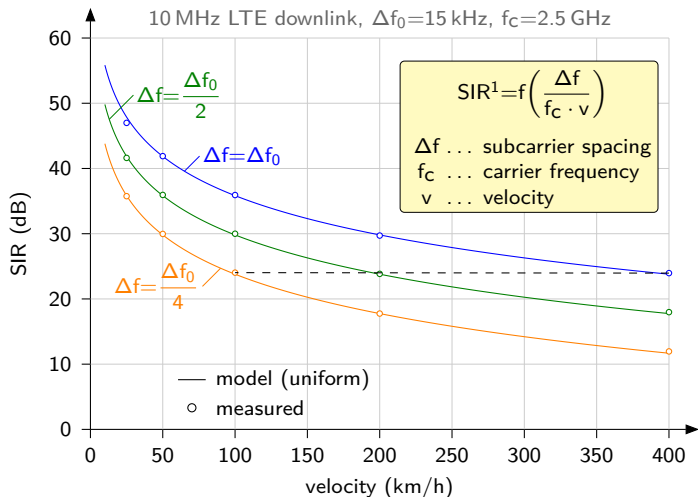
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Inter-Carrier Interference



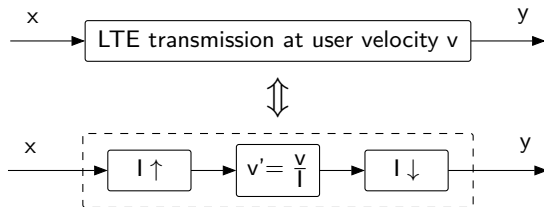
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Inter-Carrier Interference



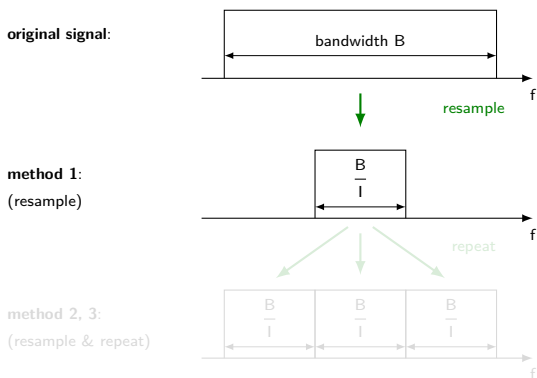
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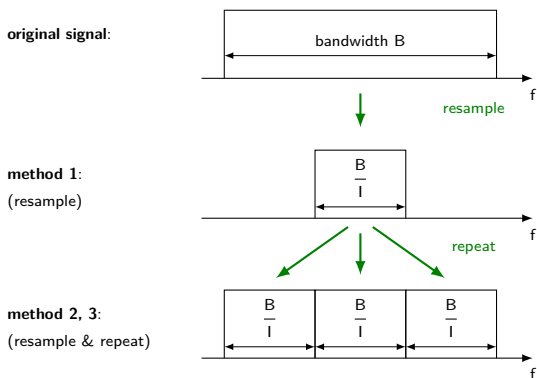
Is it that simple?

Time Stretching through Resampling²



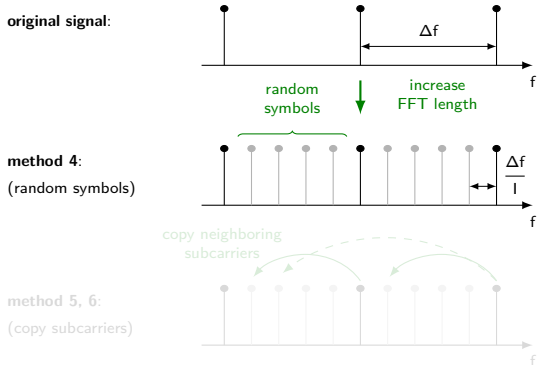
²J. Rodríguez-Piñeiro *et al.*, "Emulating Extreme Velocities of Mobile LTE Receivers in the Downlink", *Special issue JWCN*, 2015.

Time Stretching through Resampling²



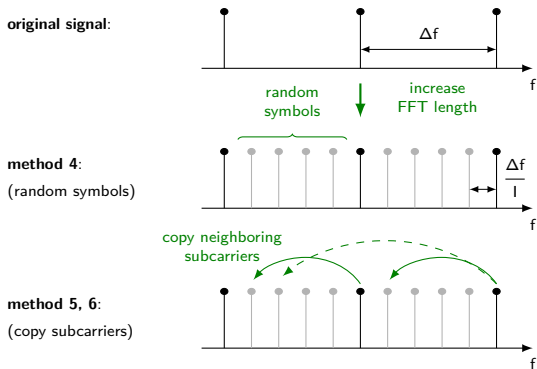
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Time Stretching by Inserting additional Subcarriers³



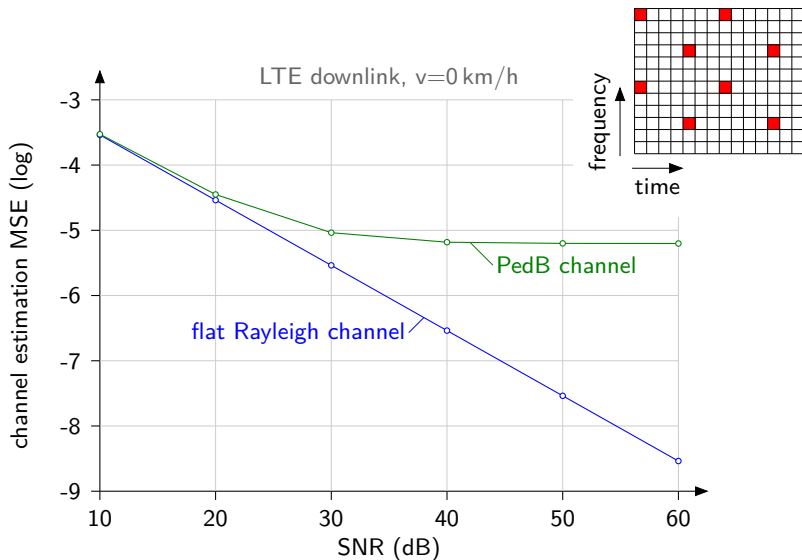
³M. Lerch *et al.*, "Methods to Perform High Velocity LTE Experiments at Low Velocities", *IEEE 83rd Vehicular Technology Conference (VTC2016-Spring)*, Nanjing, China, May 2016.

Time Stretching by Inserting additional Subcarriers³

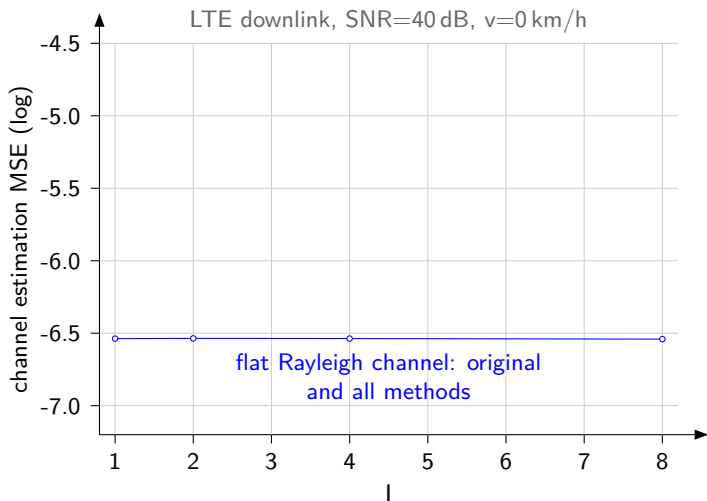


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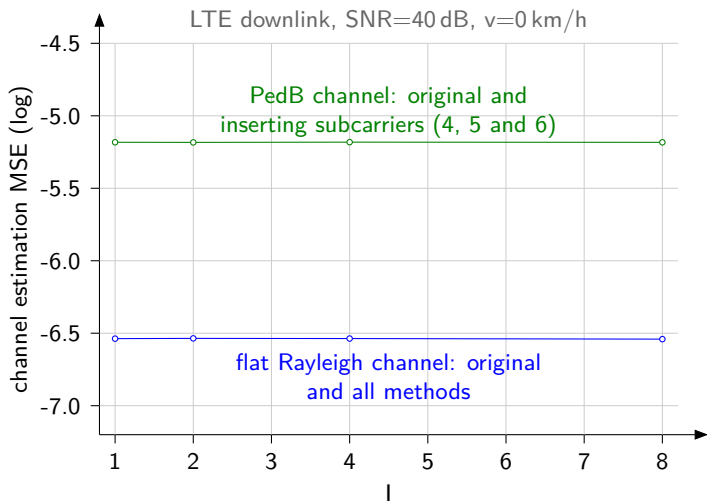
Channel Interpolation Error



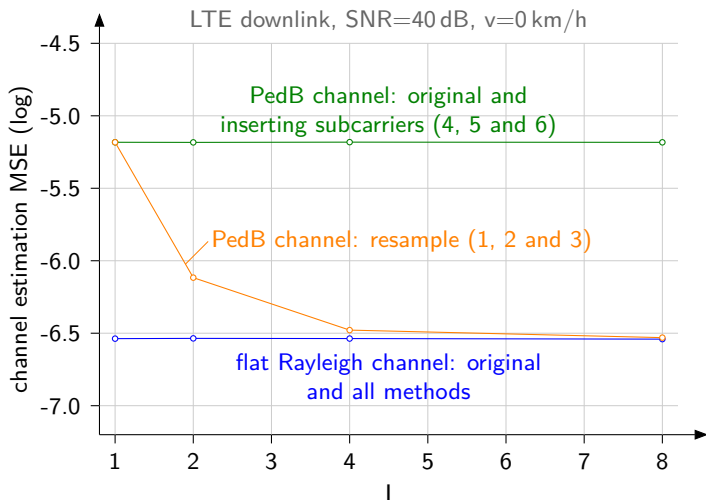
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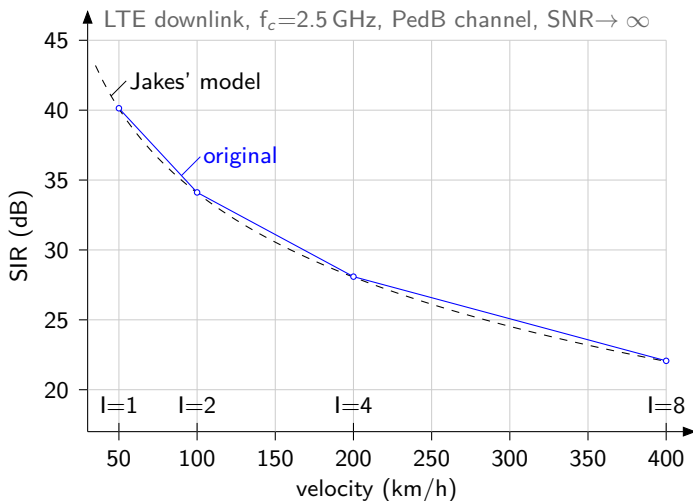
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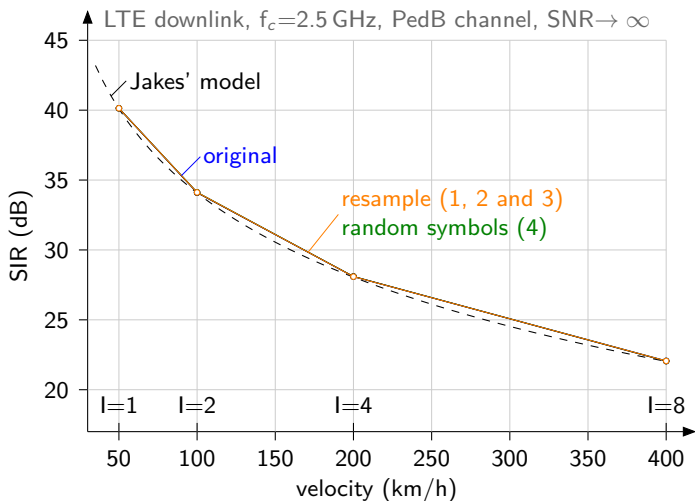
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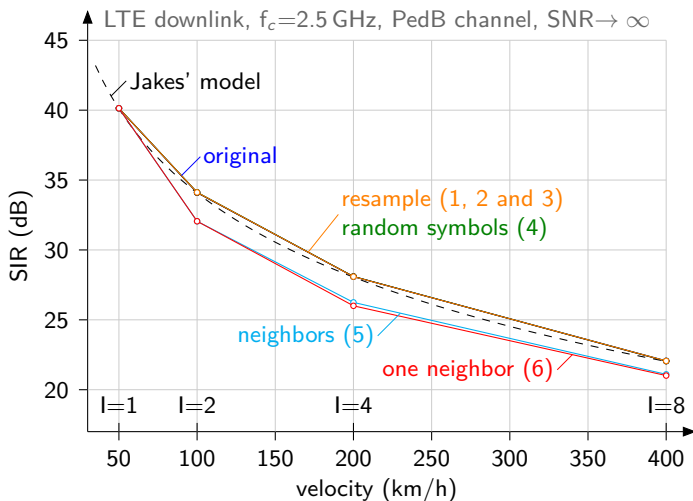
Signal-to-Interference Ratio



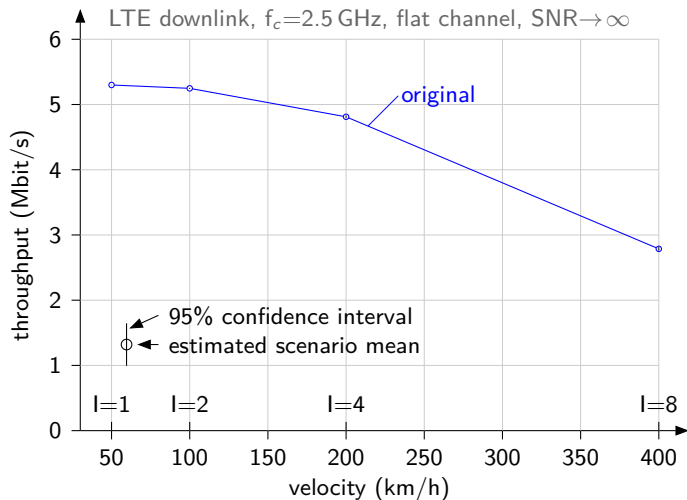
Signal-to-Interference Ratio



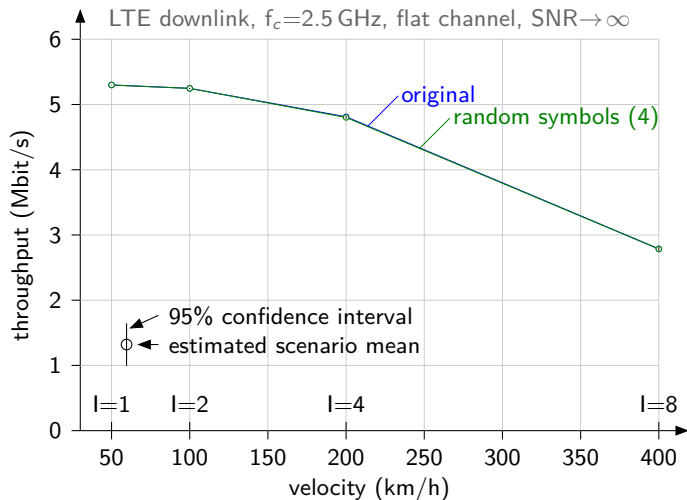
Signal-to-Interference Ratio



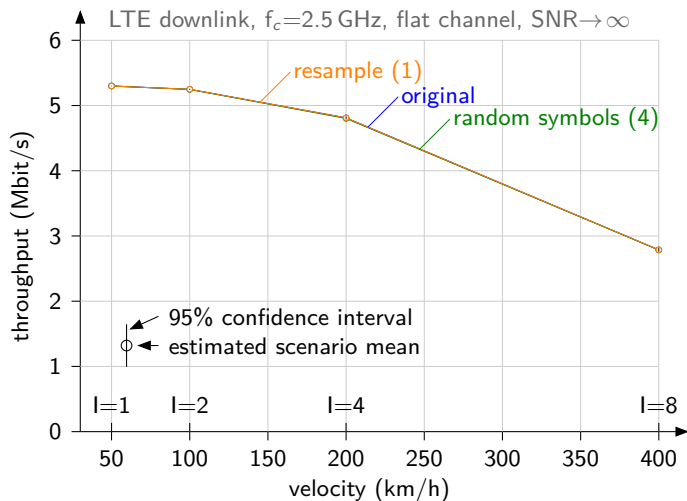
Physical Layer Throughput



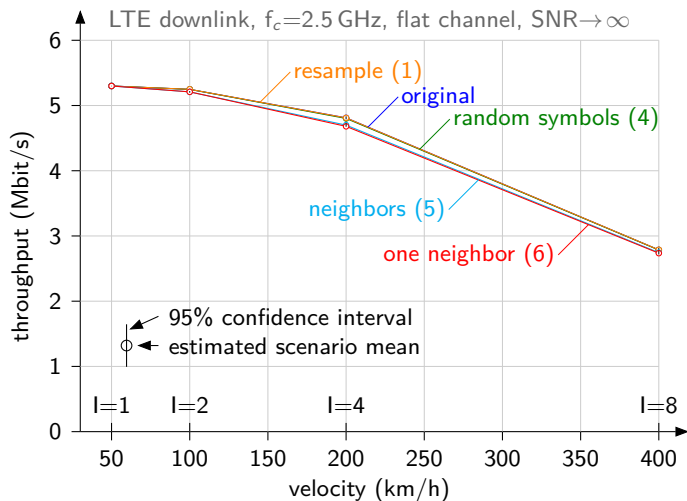
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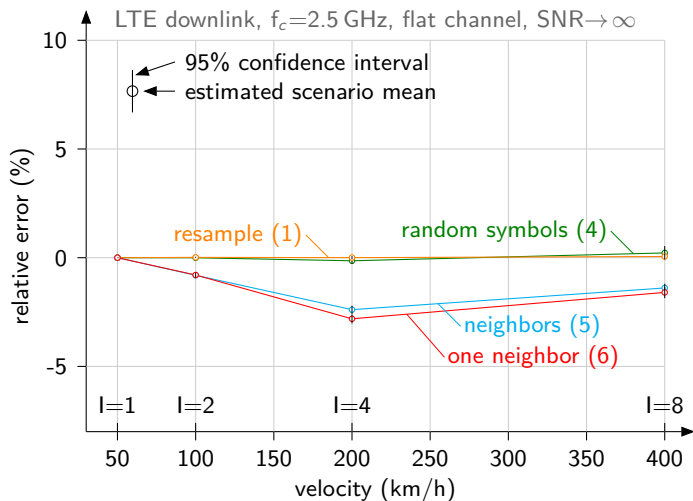
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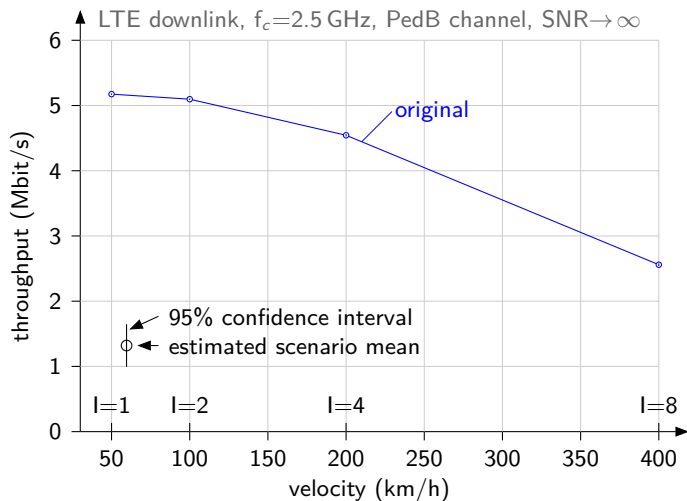
Physical Layer Throughput



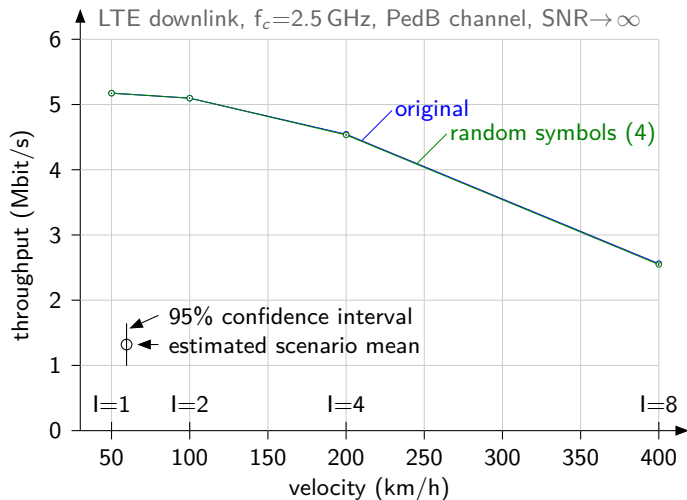
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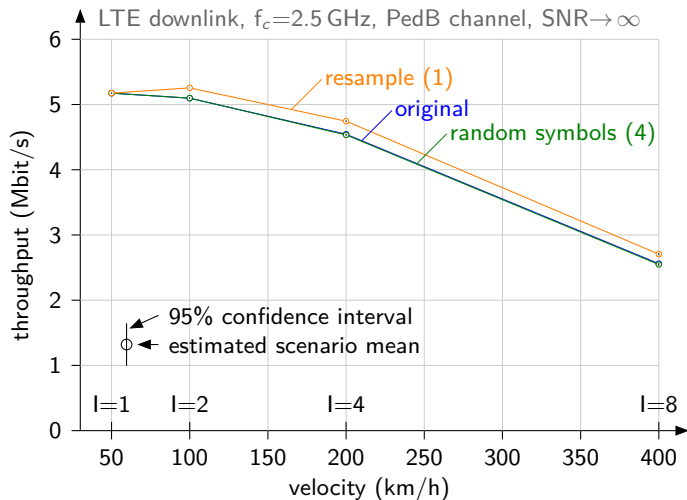
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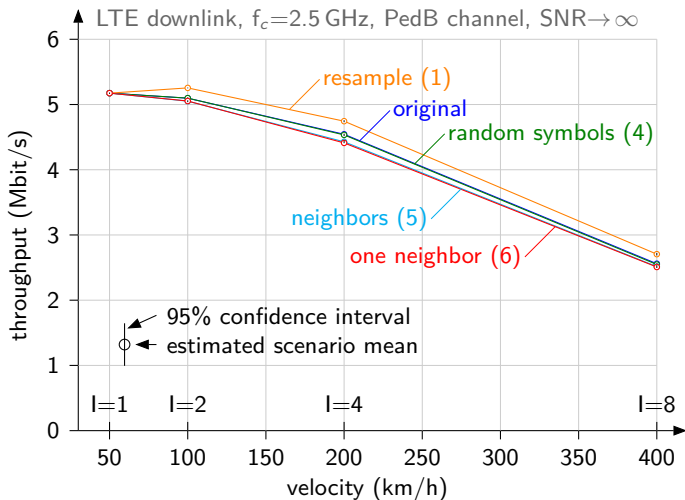
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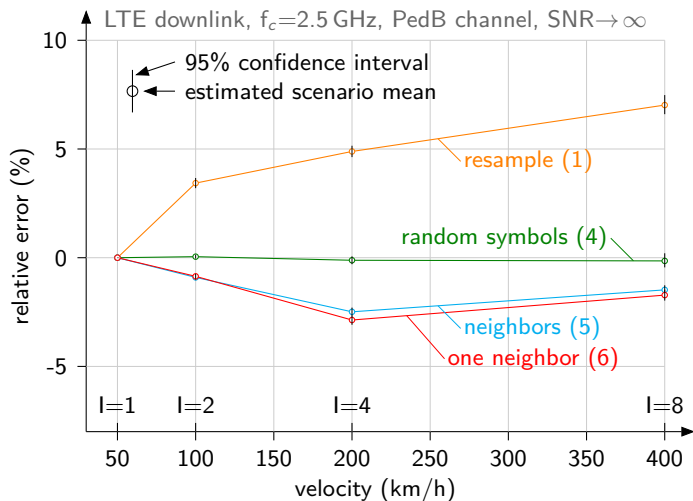
Physical Layer Throughput



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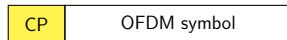
Further Aspects

- ▶ Cyclic prefix

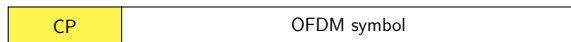
Impulse response



Original signal



Stretched signal



⇒ inter-symbol interference is not emulated correctly

- ▶ Post-FFT SNR
- ▶ Phase noise / carrier frequency offset
- ▶ Peak-to-average power ratio

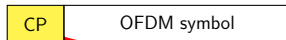
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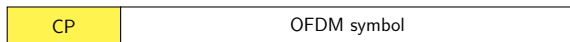
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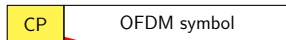
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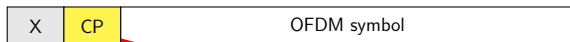
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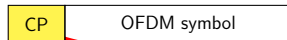
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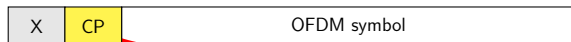
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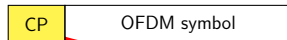
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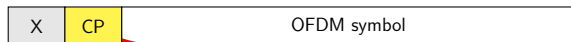
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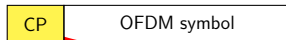
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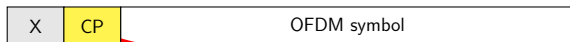
Impulse response



Original signal



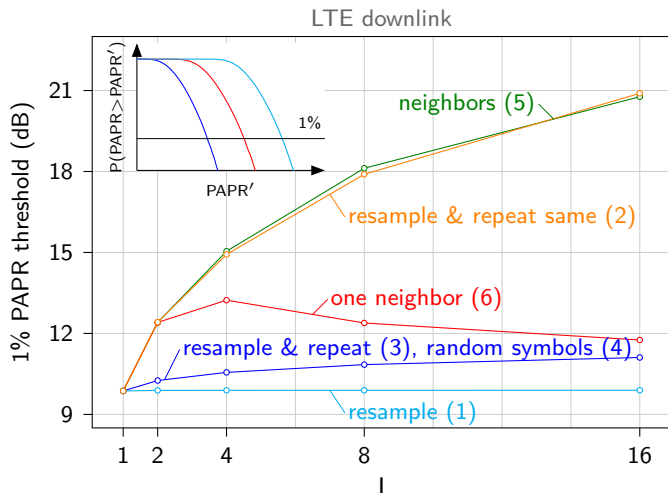
Stretched signal



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Peak-to-Average Power Ratio⁴



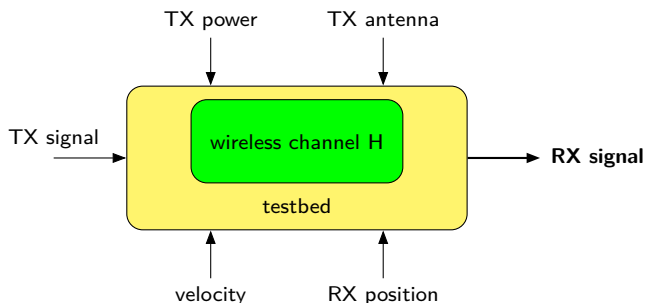
⁴T. Jiang and Y. Wu, "An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM signals", *Broadcasting, IEEE Transactions on*, vol. 54, no. 2, pp. 257-268, Jun. 2008.

Comparison of Methods to Emulate Higher Velocities⁵

method		$l \in$	channel	SNR	SIR	pilot spacing	neighboring subcarriers	PAPR	scenarios	ICI cancellation
1	resample	$\mathbb{R}_{>0}$	-	$\propto l$	+	-	+	+	σ_τ small	+
2	resample & repeat same	$\mathbb{N}_{>1}$	(+)	= const.	+	-	+	-	σ_τ small	+
3	resample & repeat	$\mathbb{N}_{>1}$	(+)	= const.	+	-	+	+	σ_τ small	+
4	insert random symbols	$\mathbb{N}_{>1}$	+	\approx const.	+	+	-	+	all	-
5	repeat neighbors	$\mathbb{N}_{>1}$	+	\approx const.	-	+	(+)	-	all	(+)
6	repeat one neighbor	$\mathbb{N}_{>1}$	+	\approx const.	-	+	(+)	(+)	all	(+)

⁵M. Lerch *et al.*, "Methods to Perform High Velocity LTE Experiments at Low Velocities", *IEEE 83rd Vehicular Technology Conference (VTC2016-Spring)*, Nanjing, China, May 2016.

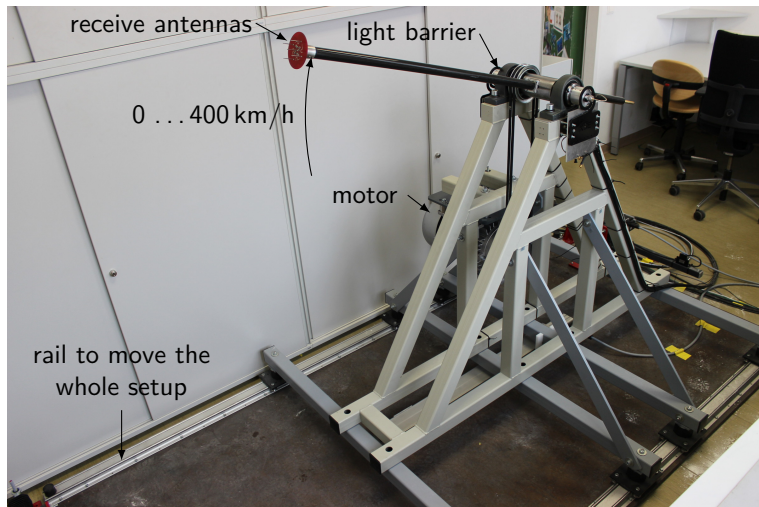
Fully Controllable Testbed Measurements⁶



- ▶ Measurements over SNR, velocity, . . .
- ▶ Comparison of different transmit signals
- ▶ . . .

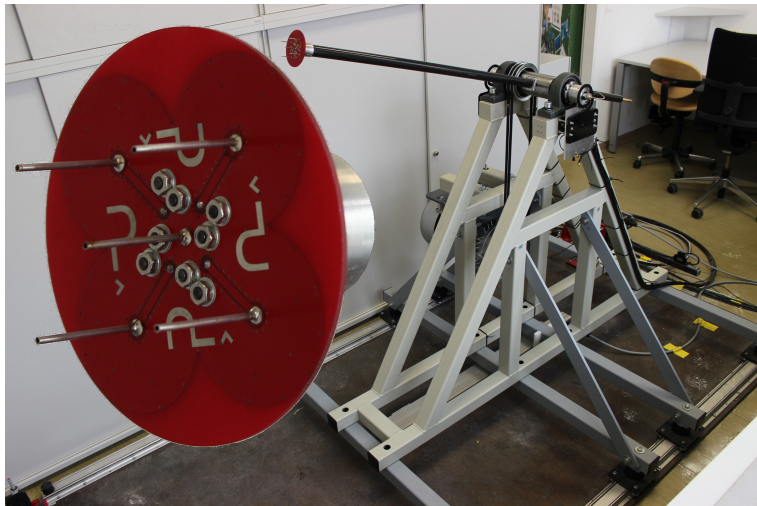
⁶M. Lerch *et al.*, "The Vienna MIMO Testbed: Evaluation of Future Mobile Communication Techniques", *Intel Technology Journal*, vol. 18, pp. 58–69, 3 2014.

Measurements at Very High Velocities⁷



⁷S. Caban *et al.*, "A Methodology for Repeatable, Off-line, Closed-loop Wireless Communication System Measurements at Very High Velocities of up to 560 km/h", *Proc. International Instrumentation and Measurement Technology Conference (I2MTC 2011)*, Binjiang, Hangzhou, China, May 2011.

Measurements at Very High Velocities⁷



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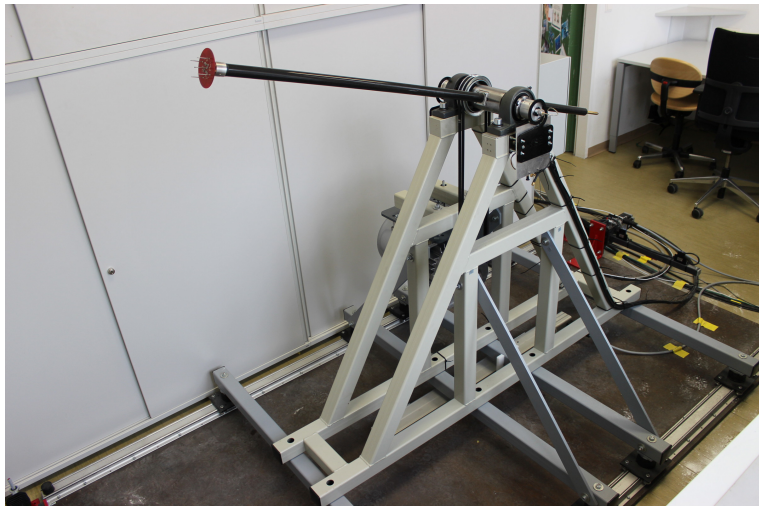
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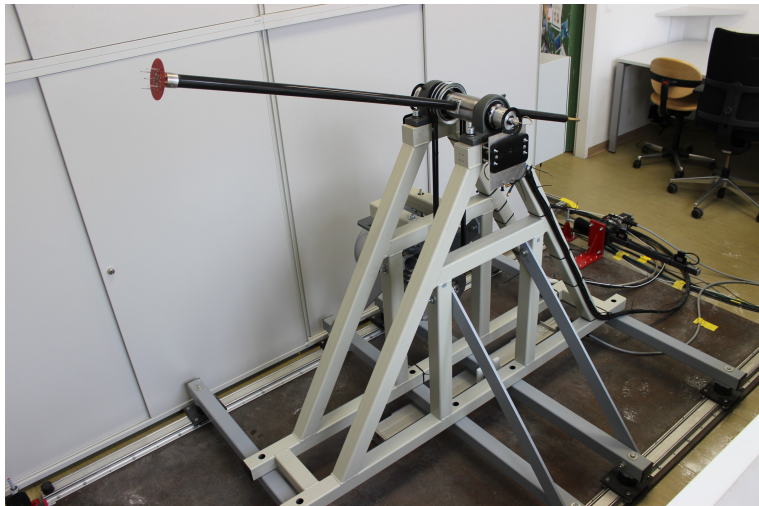
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Measurements at Very High Velocities⁷



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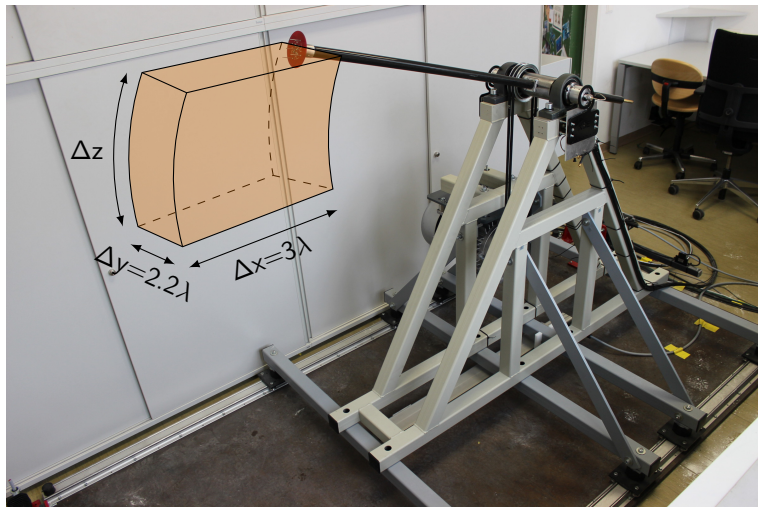
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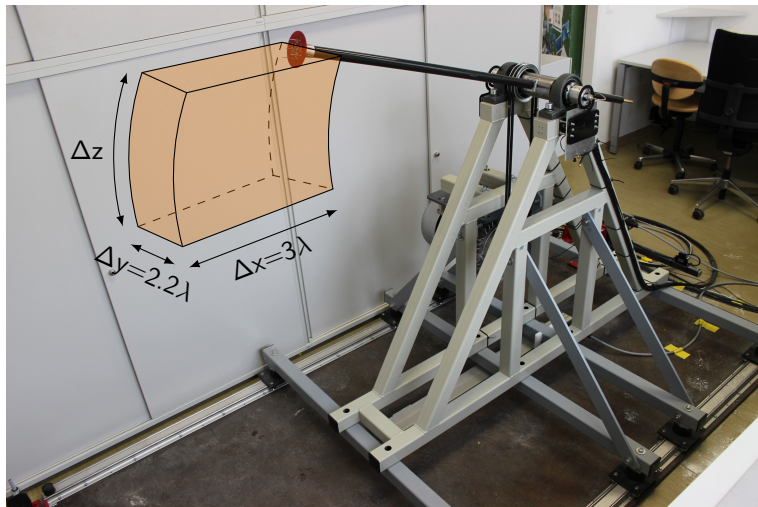
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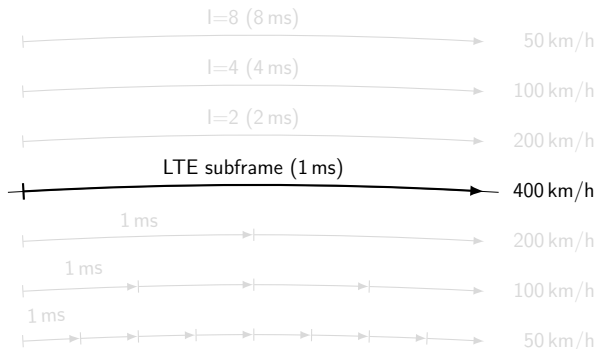
Measurements at Very High Velocities



trigger → LTE subframe (1 ms, $\Delta z \approx 11$ cm, $\Delta \alpha \approx 6^\circ$) → 400 km/h

Measurements

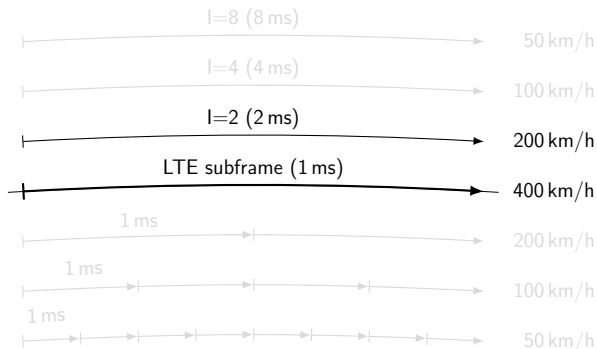
- ▶ “Validate” emulation of 400 km/h at different velocities



- ▶ Measure LTE performance at different velocities

Measurements

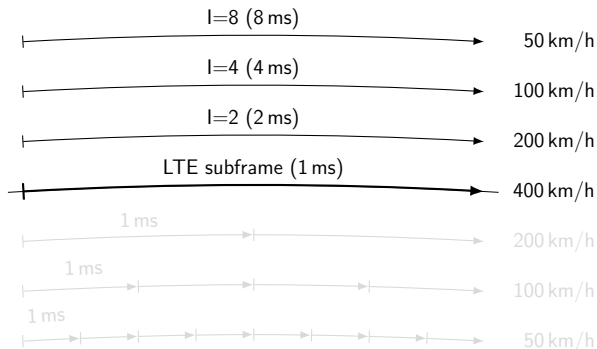
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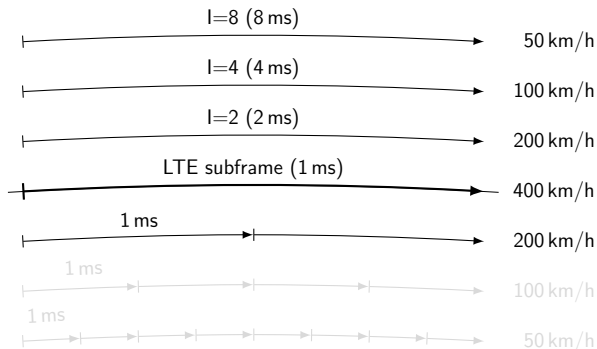
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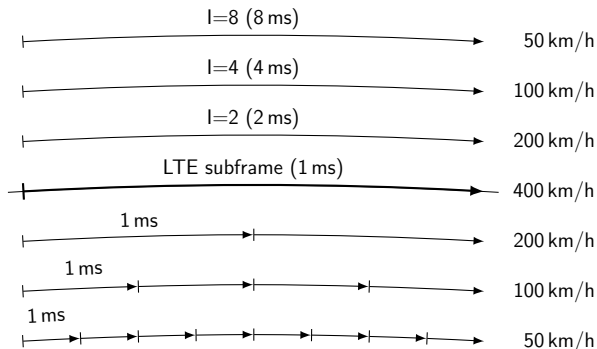
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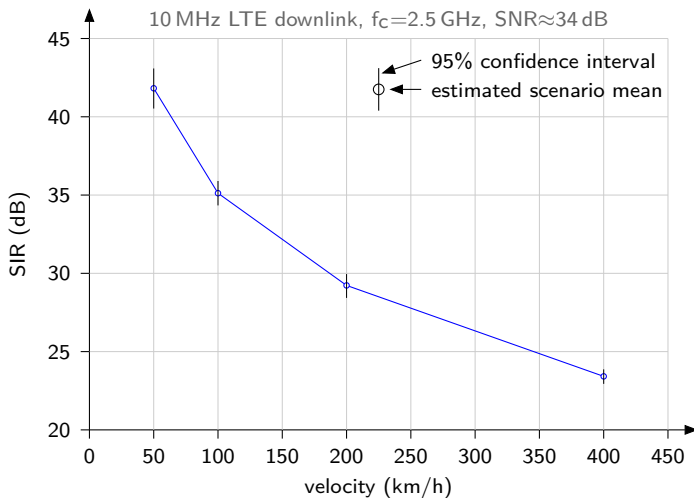
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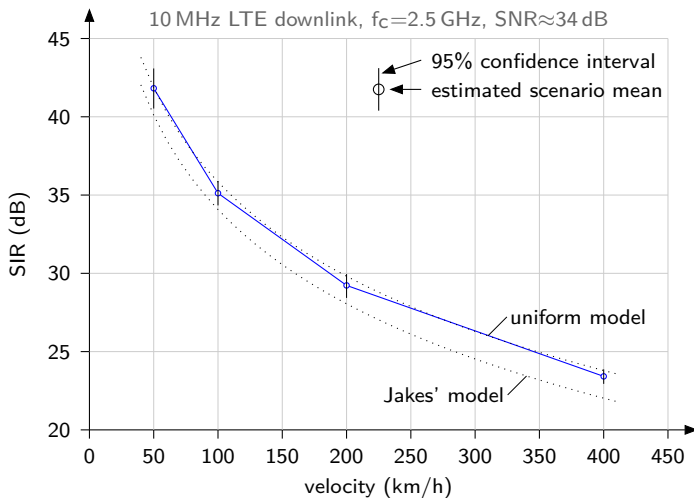


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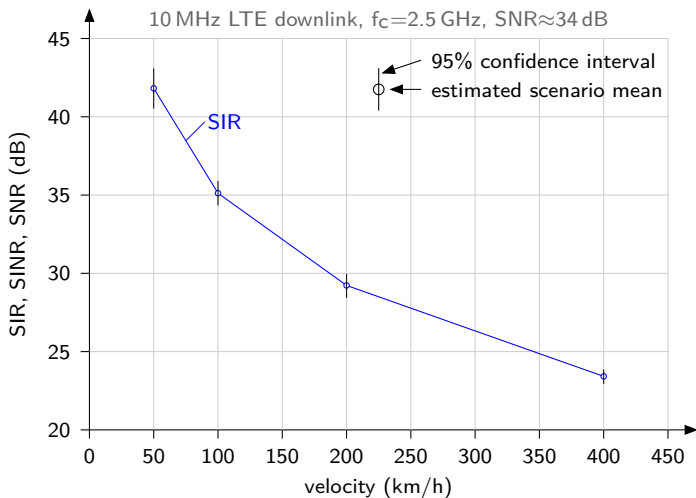
Signal-to-Interference Ratio



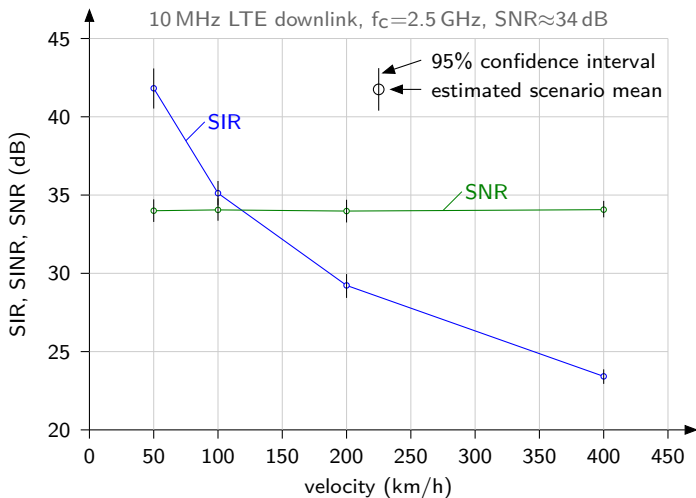
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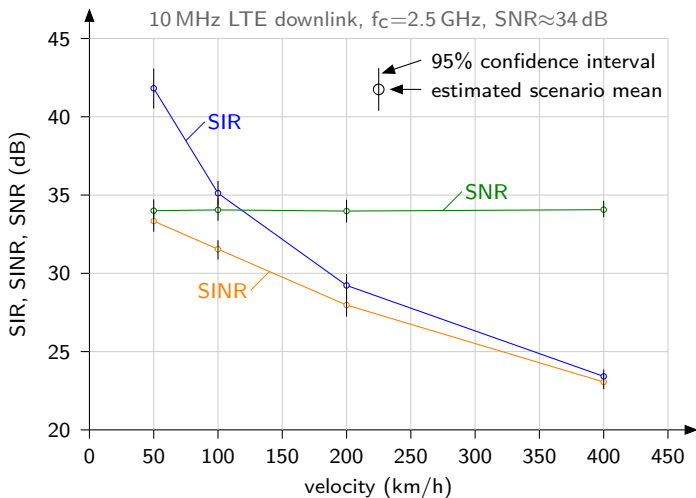
Signal-to-Interference Ratio



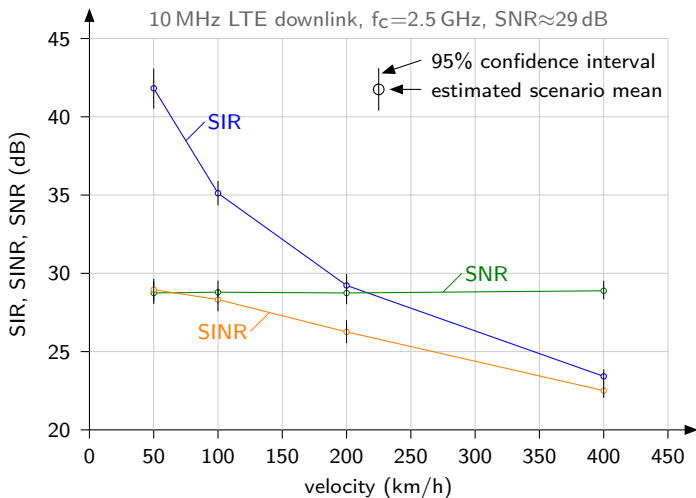
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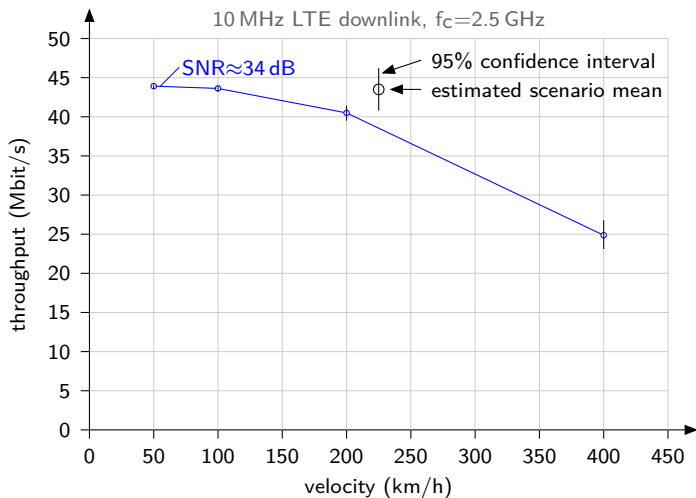
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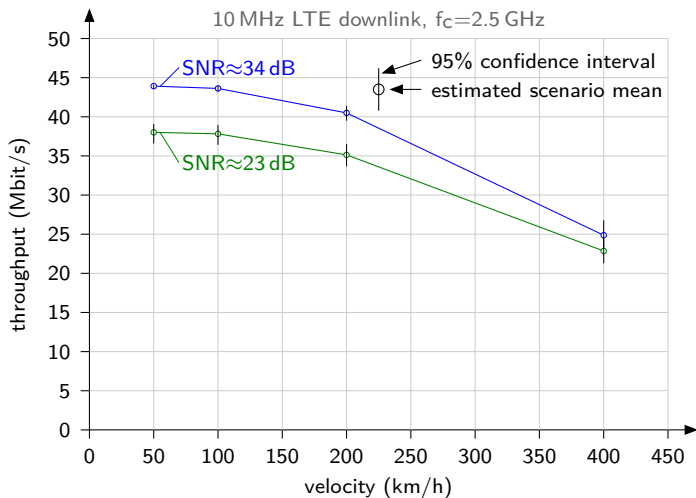
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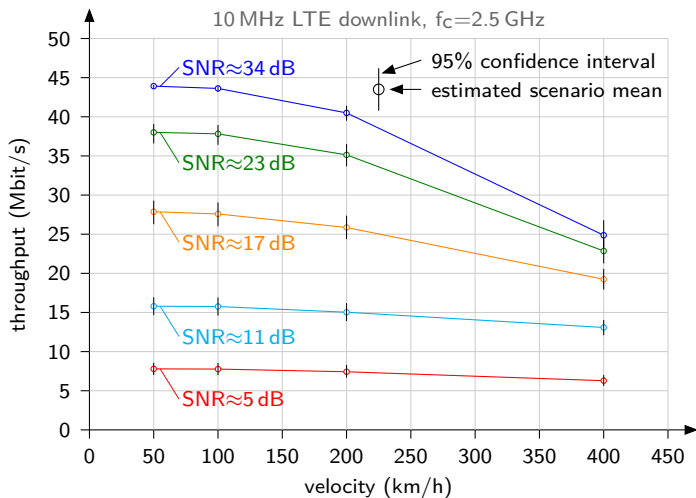
Physical Layer Throughput



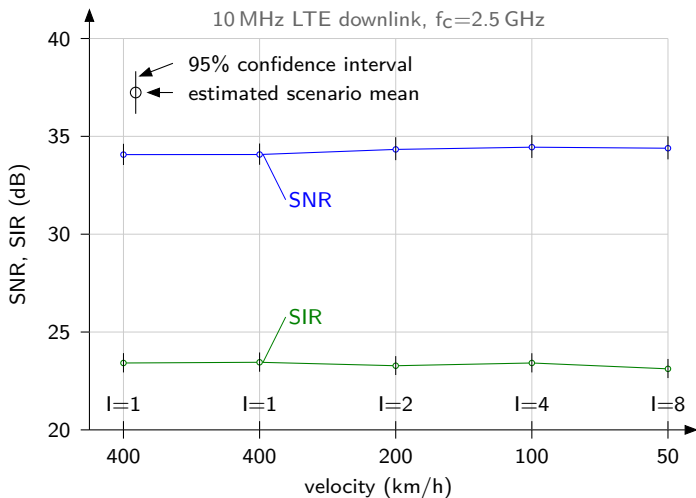
Physical Layer Throughput



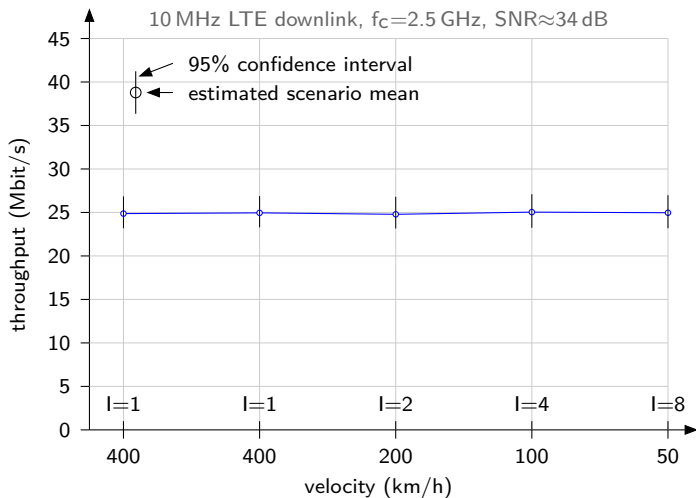
Physical Layer Throughput



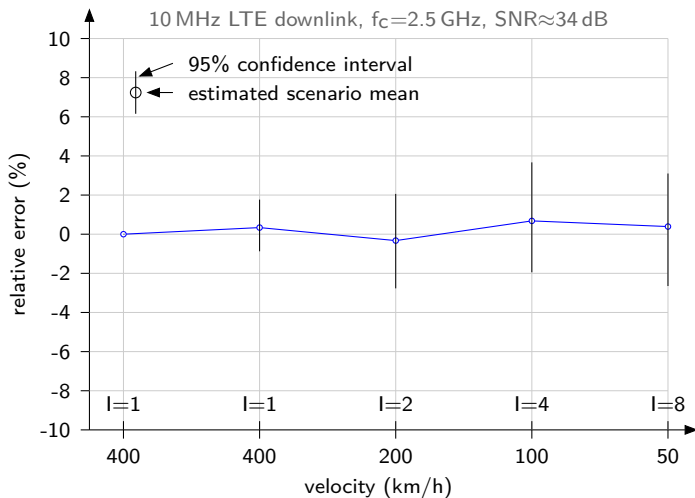
Emulation of 400 km/h



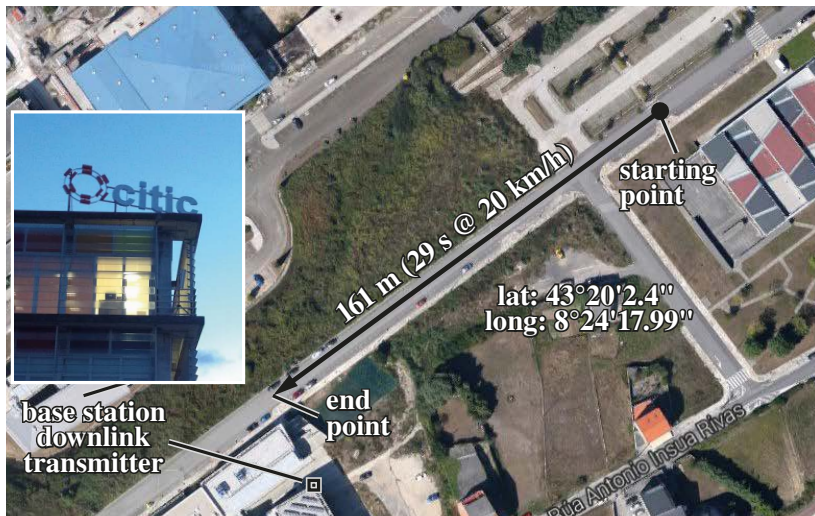
Emulation of 400 km/h



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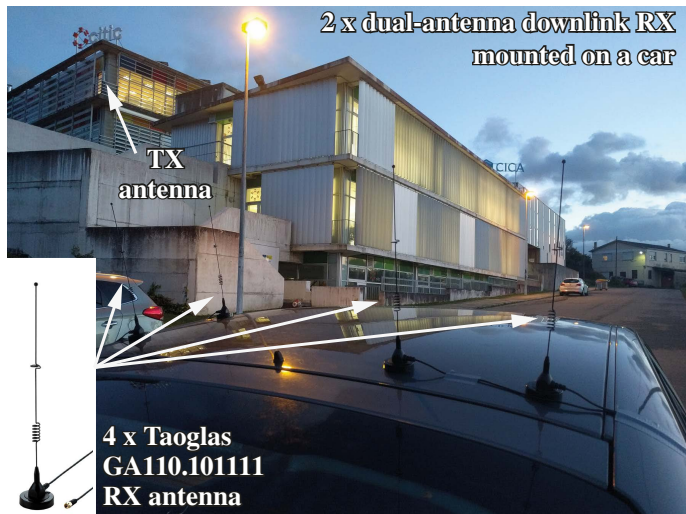


Application in Outdoor Measurements in A Coruña⁷



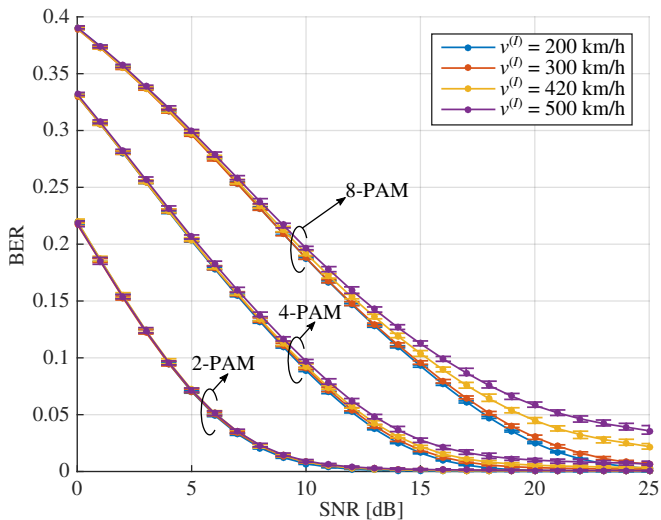
⁷J. Rodríguez-Piñeiro *et al.*, "Performance Assessment of 5G-Candidate Waveforms in High Speed Scenarios", *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2016 IEEE 27th Annual International Symposium on*, IEEE, 2016.

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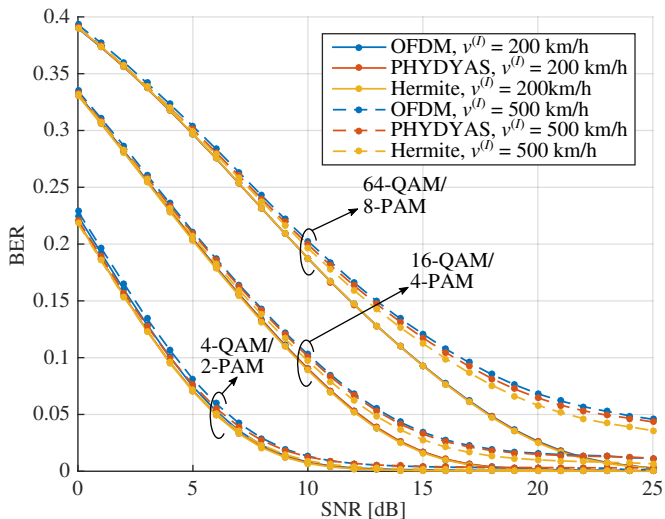


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Measurement Results (Hermite prototype filter)



Measurement Results



Conclusions

- ▶ Fully controllable experiments at high velocities are feasible
- ▶ High velocity experiments can be emulated at lower velocities
 - ▶ Different methods for different scenarios and different kinds of experiments

but ...

- ▶ A lab is not a “high mobility scenario”
- ▶ A campus is not a “high speed train scenario”

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Affordable Mobile Communications Experiments in High Mobility Scenarios

Martin Lerch

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