Technische Universität Braunschweig

Institut für Nachrichtentechnik

Propagation and Channel Modelling – Impact by 40 years of COST Actions

Keynote, Lisbon 22 January 2024

Thomas Kürner
Institut für Nachrichtentechnik (IfN)
Technische Universität Braunschweig

Agenda

- My Personal History in COST
- The specific Role of Lisbon for this Series of COST Actions
- The Era of Channel Delay Profiles
- The Era of Path Loss Prediction Models
- The Era of Spatial Channel Models
- Collaboration in COST
  - Short-Term Scientific Missions
  - Sharing of Data - early Days of Research Data Management
- Outlook

- *A huge number of colleagues have significantly contributed to the success of propagation and channel characterisation in these 40 years. Some of them – but by far not all – are mentioned in this presentation.*
- *My apologies to all I could not mention!*

My Personal History in COST

- *“ I have had the privilege to participate in COST since June 1991, when I attended my first COST 231 meeting in Lund as a young Ph. D. student. Since then I enjoyed the special spirit of COST meetings. Participating in COST has been relevant to be part of the evolution of wireless standards and build up my technical expertise. But even more important, it has been essential to help creating my surtainable professional network in the wireless community”.*

  https://interactca20120.org/anniversary-testimonials/

- Since 1991 I have represented three different entities

Ph. D. Student
1991-1994

Industry
1994-2003

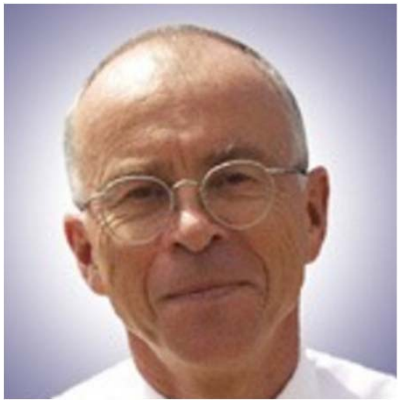
Professor
Since 2003

- From 1997 to 2000, I have been the Chair of COST 259 WG Network Aspects

The specific Role of Lisbon for this series of COST Actions

- The whole COST 259 Action (and with this probably all subsequent COST Actions) was at stake!
- At the September 1997 in Lisbon COST 259 did not have an active chair nor a vice-chair nor a budget for 1998!
- The meeting was opened by the the three WG chairs as the only legal officers of the action!

Stephen K. Barton



Ernst Bonek

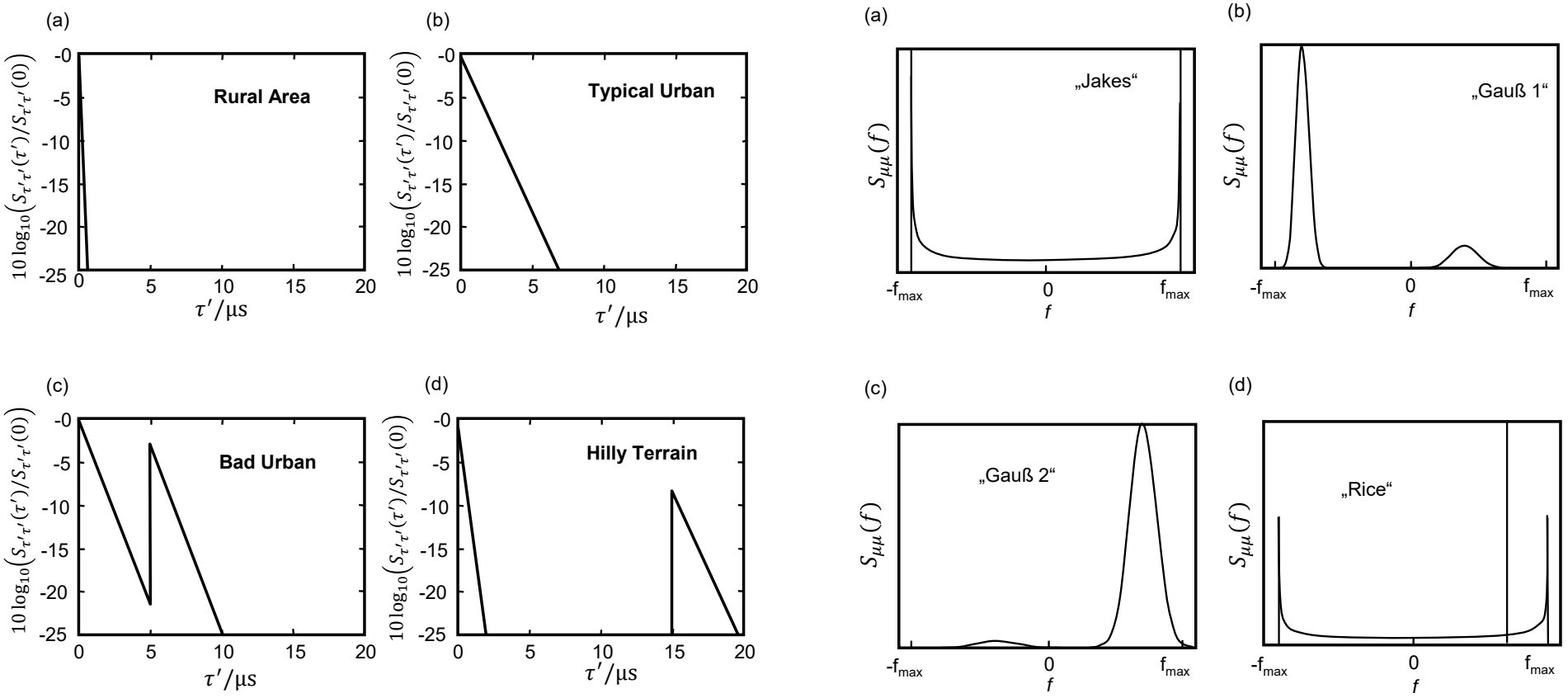
Thomas Kürner

Luis Correia

The Era of Channel Delay Profiles

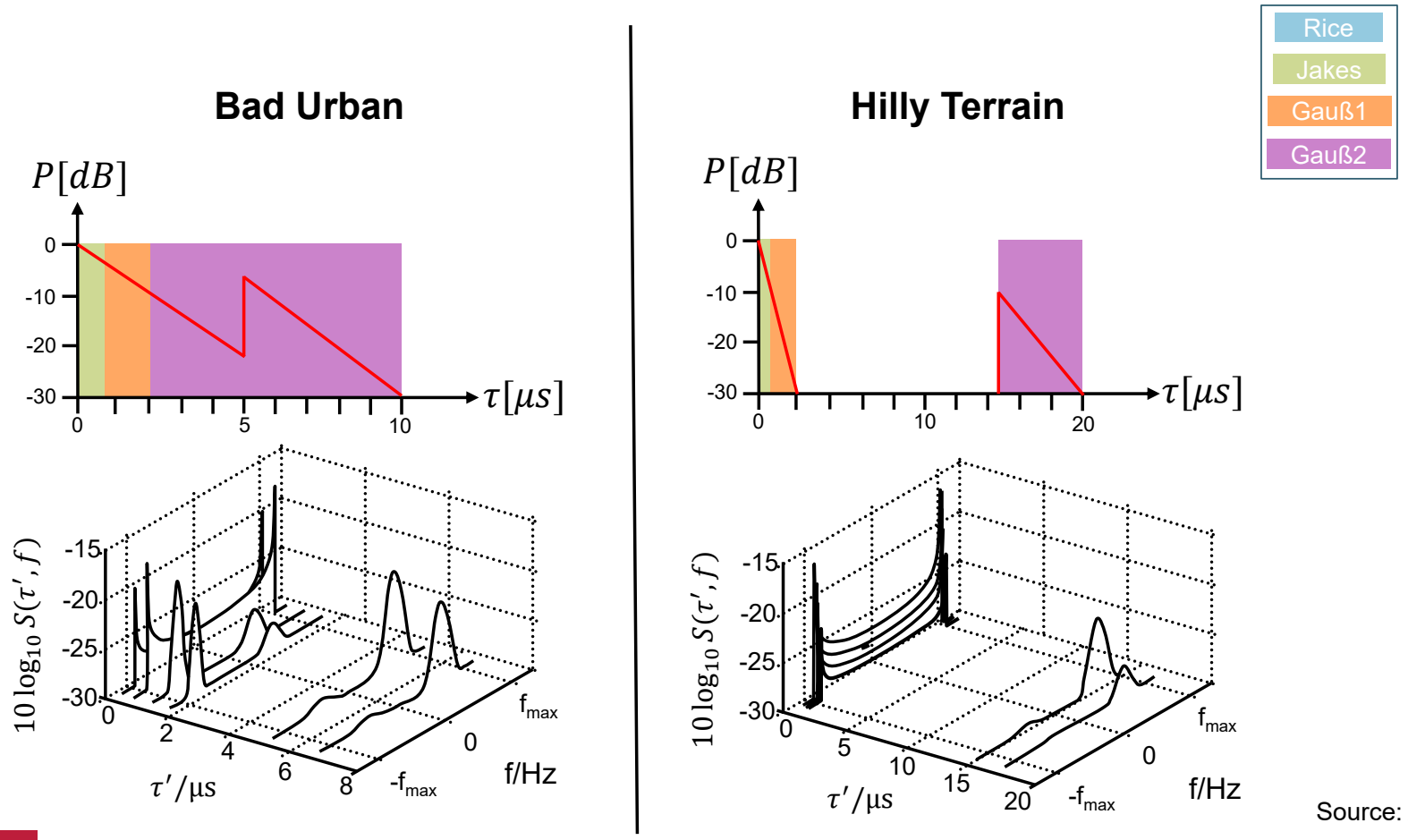
- COST 207 / COST 231

COST 207 has defined Power Delay Profiles and 4 Doppler Spectra



Source: M. Pätzold, *Mobilfunkkanäle – Modellierung, Analyse und Simulation*, Vieweg 1999

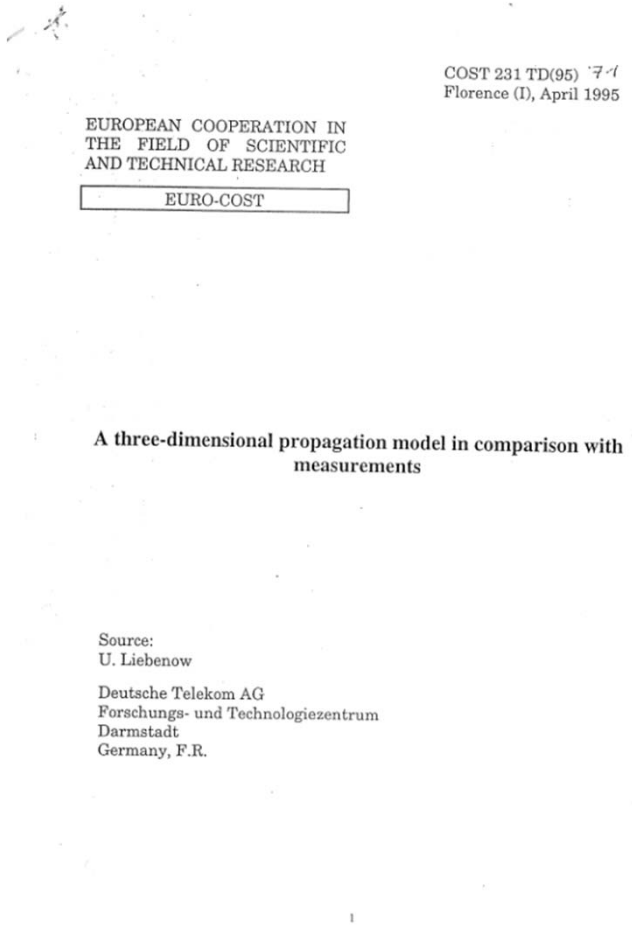
For the Implementation in Channel Simulators COST 207 has defined 4,6 and 12-Path Models combining Power Delay Profiles and Doppler Spectra



Source: Andy Molisch

Impact of COST 207 Model

- The COST 207 Profiles have been used to standardize GSM allowing multi path signals with up to ~16 µs of delay
- Until today the profiles have been used also for the standardardisation of of other wireless technologies, e.g. DVB-T2.
- With the deployment of the first GSM networks in the early 90s, research focussed on the question, delays > 16 µs would occur in the real network.
- This has triggered extensive activities in channel sounding and 3D propagation channel modelling in COST 231.



COST 231 TD(95) 74
Florence (I), April 1995

EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH

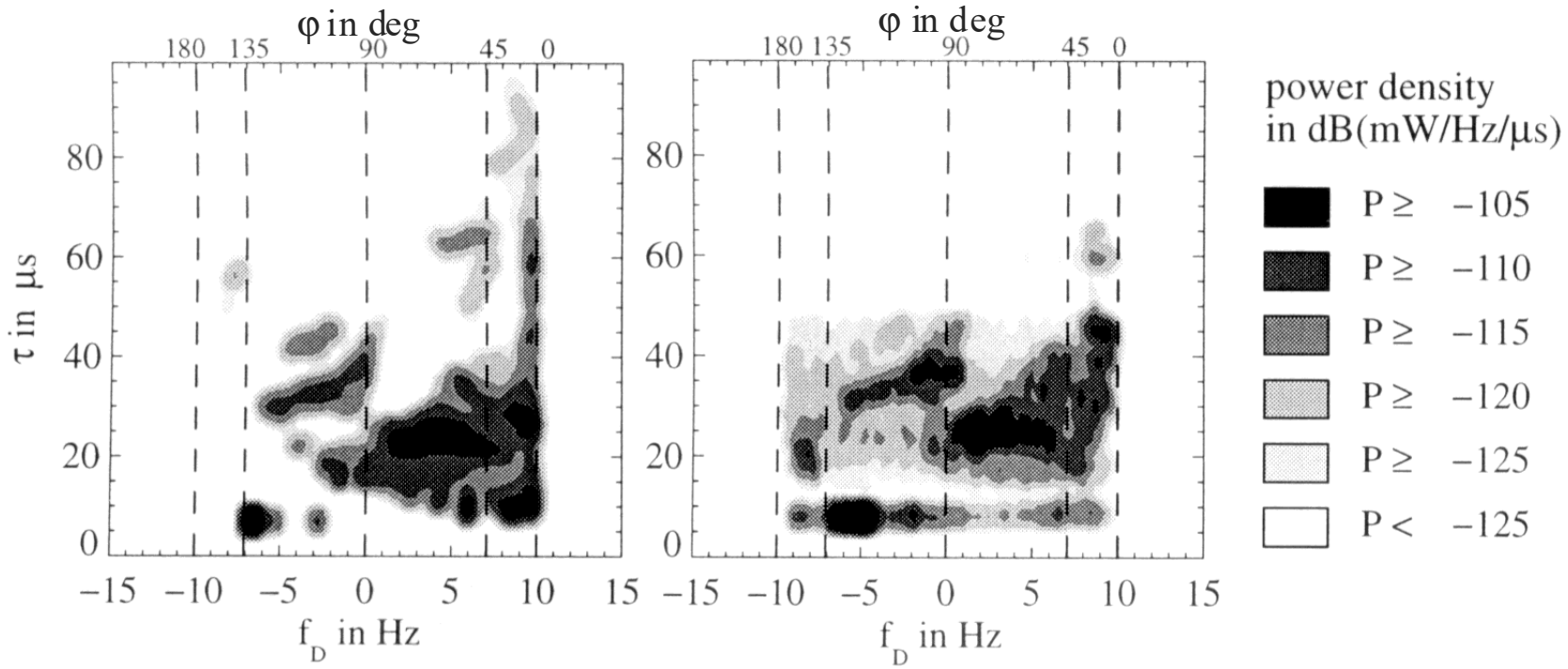
EURO-COST

A three-dimensional propagation model in comparison with measurements

Source:
U. Liebenow

Deutsche Telekom AG
Forschungs- und Technologiezentrum
Darmstadt
Germany, F.R.

Exemplary Comparison of Prediction with Measurement

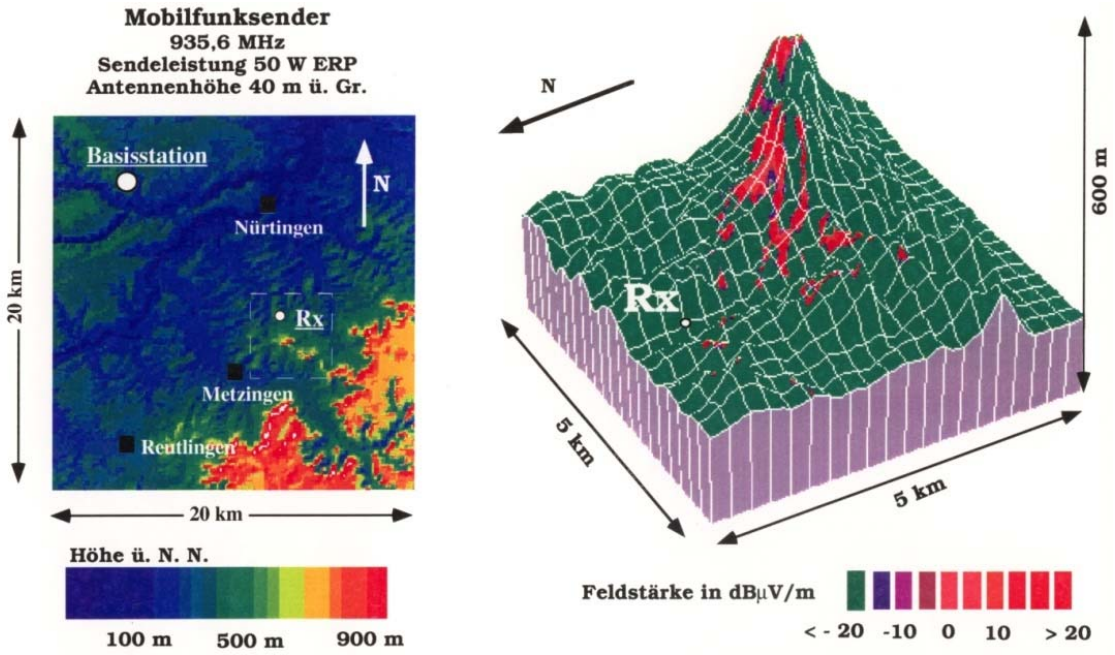


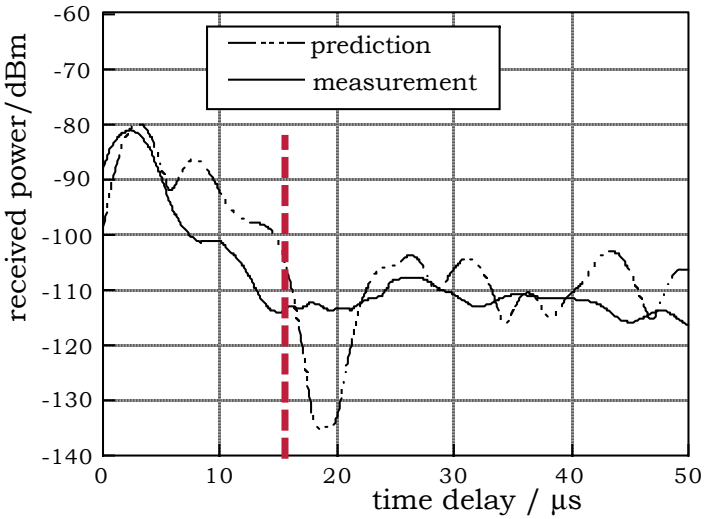
Prediction by 3D Model

Channel Sounder Measurement

Source: U. Liebenow COST 231 TD (95) 71

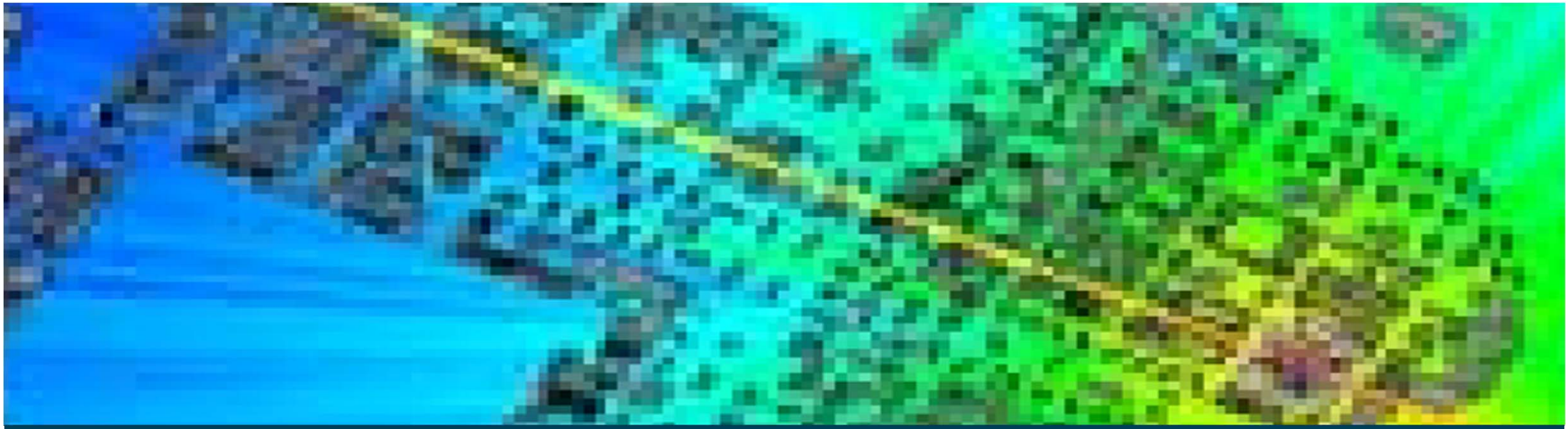
Exemplary Situation with a deployed GSM900 Base Station in medium mountaineous Area





Power Delay Profile

Source: T. Kürner, D. J. Cichon and W. Wiesbeck, "Evaluation and verification of the VHF/UHF propagation channel based on a 3-D-wave propagation model," in *IEEE Transactions on Antennas and Propagation*, vol. 44, no. 3, pp. 393-404, March 1996.

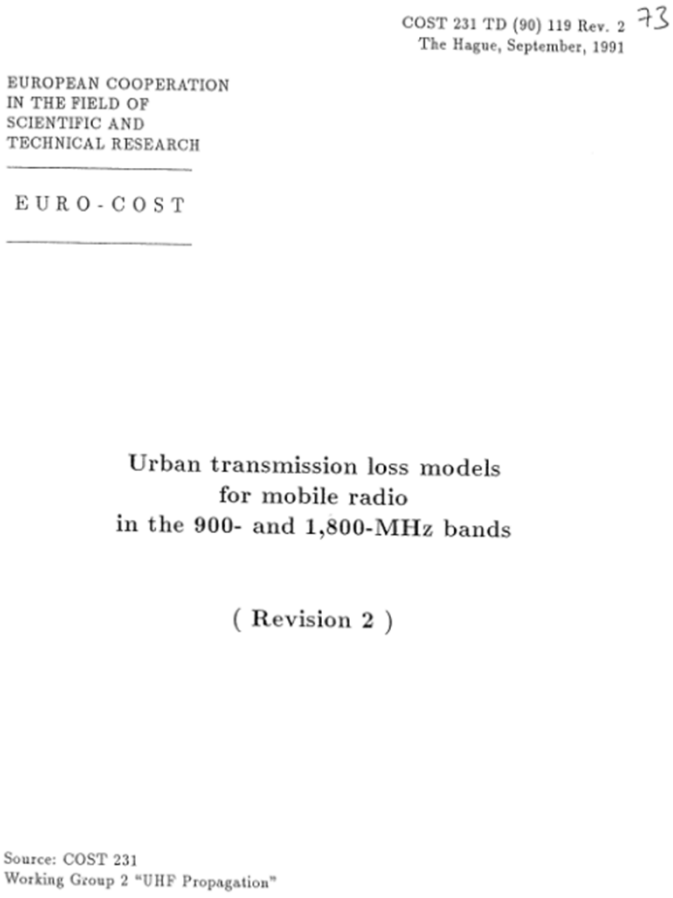


The Era of Path Loss Prediction Models

- COST 231

COST 231-Hata and COST 231-Walfisch-Ikegami Models

- The deployment of GSM networks at 900 MHz and 1800 MHz has triggered the deployment of path loss prediction models
- COST 231 has significantly contributed mainly by enhancing and developing two models:
  - COST 231 Hata Model as an extension of the Okumura-Hata Model to the 1800 MHz frequency range
  - COST 231 Walfsich-Ikegami Model taking into account information form 3D building data in urban and suburban areas



COST 231 TD (90) 119 Rev. 2 73
The Hague, September, 1991

EUROPEAN COOPERATION
IN THE FIELD OF
SCIENTIFIC AND
TECHNICAL RESEARCH

EURO-COST

Urban transmission loss models
for mobile radio
in the 900- and 1,800-MHz bands

(Revision 2)

Source: COST 231
Working Group 2 "UHF Propagation"

COST 231 Hata Model

COST 231 has extended Hata´s model to the frequency band 1500 ≤ f(MHz) ≤ 2000 by analysing Okumura´s propagation curves in the upper frequency band. This combination is called "COST-Hata-Model" [51]:

$$L_b = 46.3 + 33.9 \log \frac{f}{MHz} - 13.82 \log \frac{h_{Base}}{m} - a(h_{Mobile})$$

$$+ (44.9 - 6.55 \log \frac{h_{Base}}{m}) \log \frac{d}{km} + C_m \qquad (4.4.3)$$

where $a(h_{Mobile})$ is defined in equation (4.4.2) and

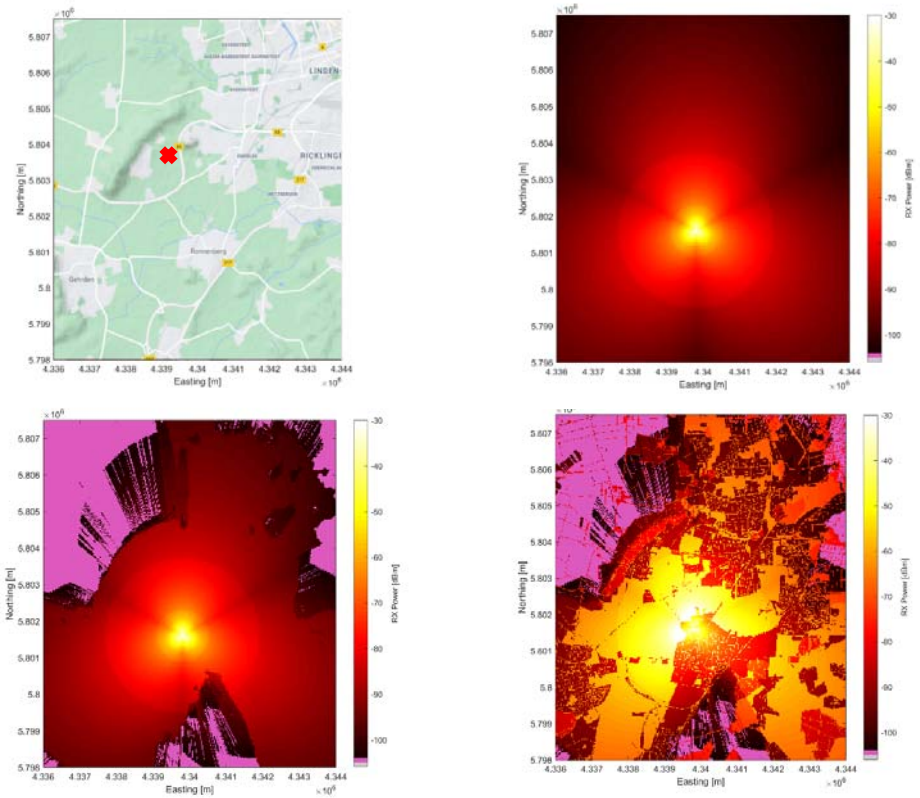
$$C_m = \begin{cases} 0 \text{ dB} & \text{for medium sized city and suburban} \\ & \text{centres with medium tree density} \\ 3 \text{ dB} & \text{for metropolitan centres} \end{cases} \qquad (4.4.4)$$

The COST-Hata-Model is restricted to the following range of parameters:

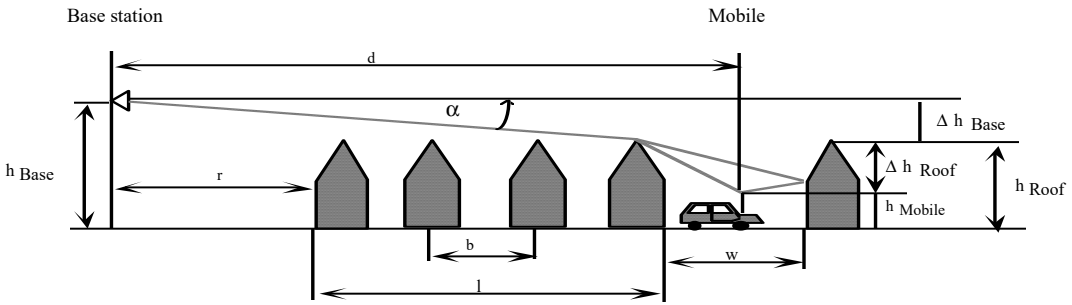
f:	1500 ... 2000 MHz
h_{Base}:	30 ... 200 m
h_{Mobile}:	1 ... 10 m
d:	1 ... 20 km

Source: COST 231 Final Report

COST 231 Hata combined with Knife Edge model and clutter loss at 900 MHz

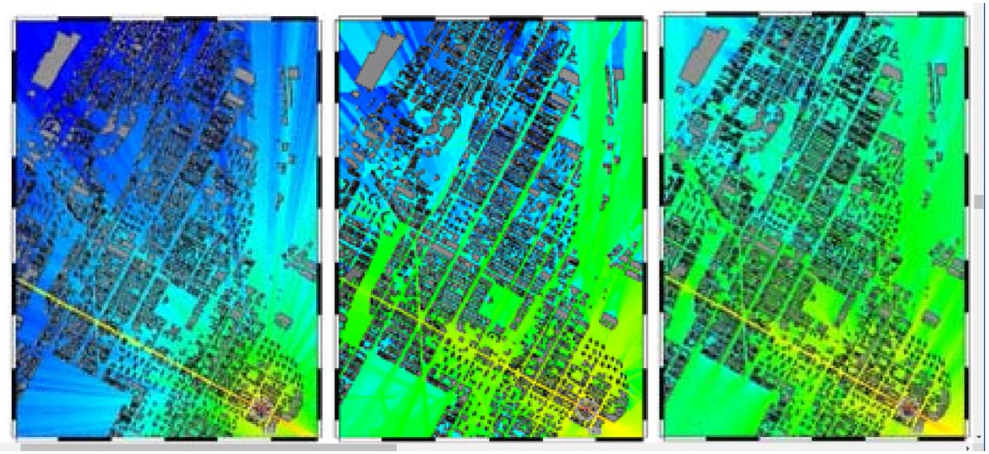


COST 231 Walfisch-Ikegami Model



Source: COST 231 Final Report

- COST 231 combined
  - the *Multiple Screen Diffraction* Model by Walfsich and Bertoni with
  - the *Rooftop-to-Street Diffraction* Model by Ikegami
- Generated a simple set of equations
- Validated the model by measurements

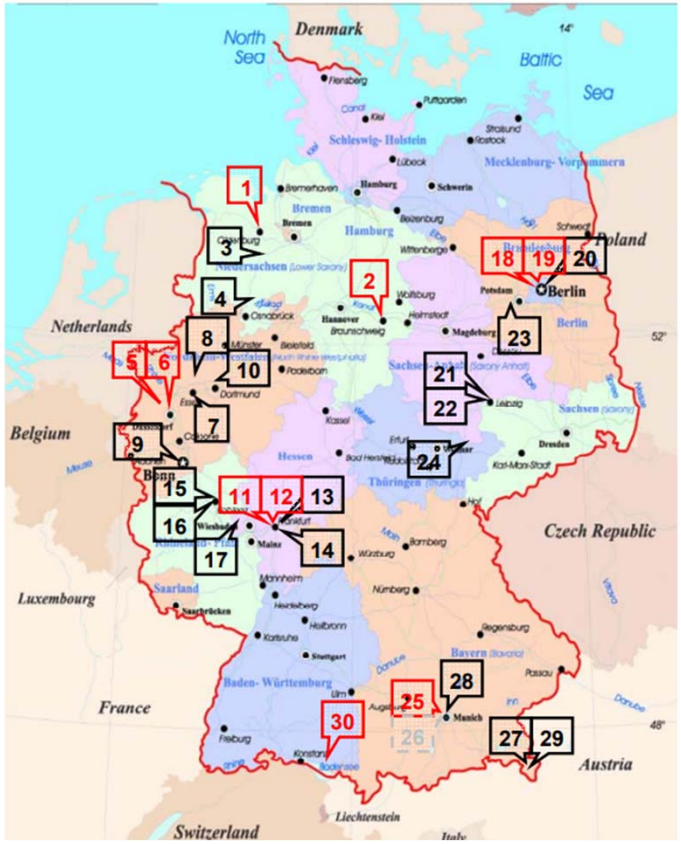


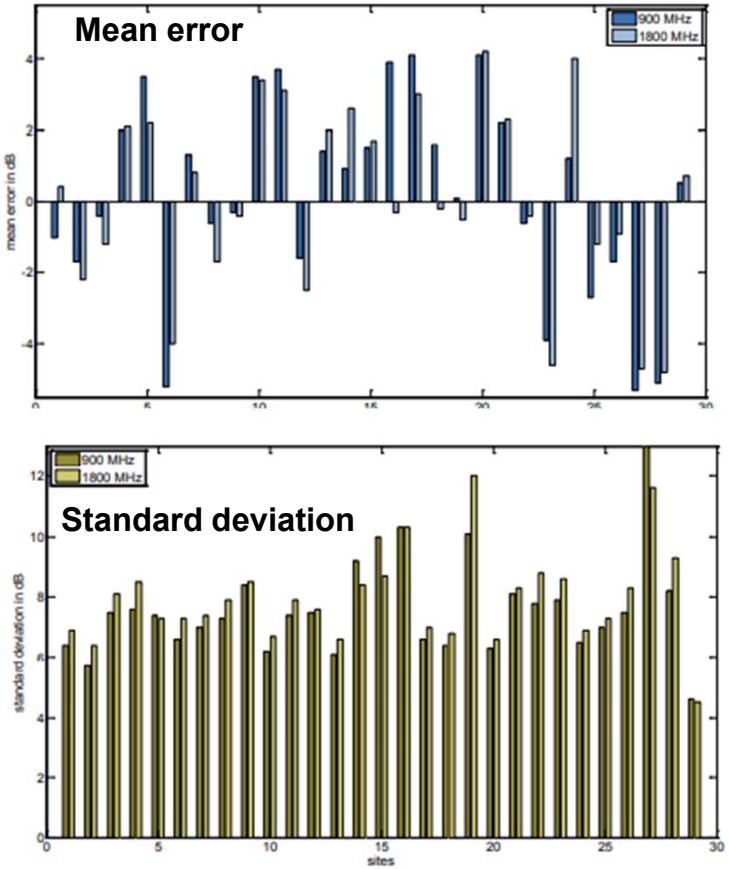
COST 231 WI | Ray Tracing | Dominant Path Model

Source: R. Wahl, P. Wert, G. Wölfle, P. Wildbolz, F. Landstorfer, Dominant Path Prediction Model for Urban Scenarios, Conference: IST Mobile and Wireless Communications Summit, June 2005

Impact: Both Models have been used for Radio Planning of real Networks

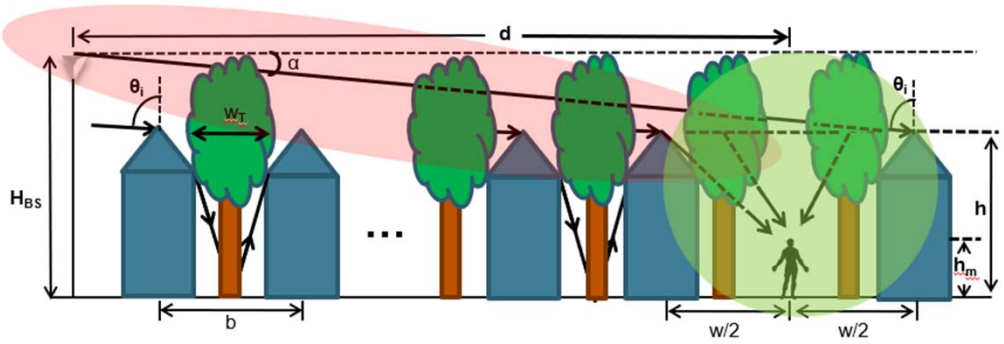
- Example:
- Both models have been major components of the hybrid propagation model developd and used by the cellulra operator E-Plus in Germany



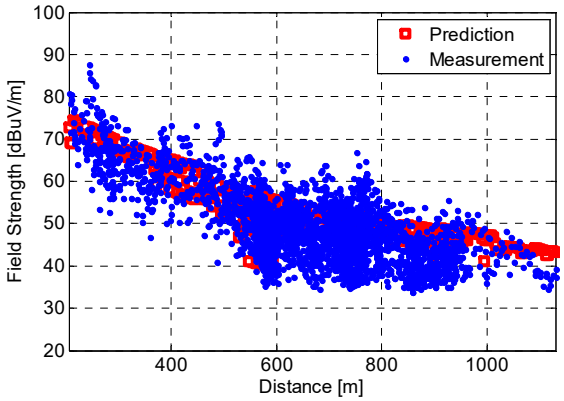


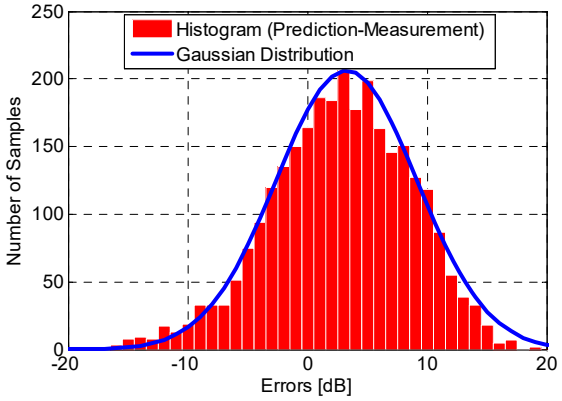
T. Kürner and M. Neuland, "Application of Bertoni's work to propagation models used for the planning of real 2G and 3G cellular networks," *2009 3rd European Conference on Antennas and Propagation*, 2009, pp. 1686-1690.

Later the model has been extended to include the Influence of Vegetation



K. L. Chee, S. A. Torrico and T. Kürner, "Radiowave Propagation Prediction in Vegetated Residential Environments," in *IEEE Transactions on Vehicular Technology*, vol. 62, no. 2, pp. 486-499, Feb. 2013, doi: 10.1109/TVT.2012.2226764.





K. L. Chee *et al*., "Propagation prediction and measurement in vegetated moderately built-up areas," *2012 6th European Conference on Antennas and Propagation (EUCAP)*, Prague, Czech Republic, 2012, pp. 3361-3365, doi: 10.1109/EuCAP.2012.6206643.

The Era of Spatial Channel Models

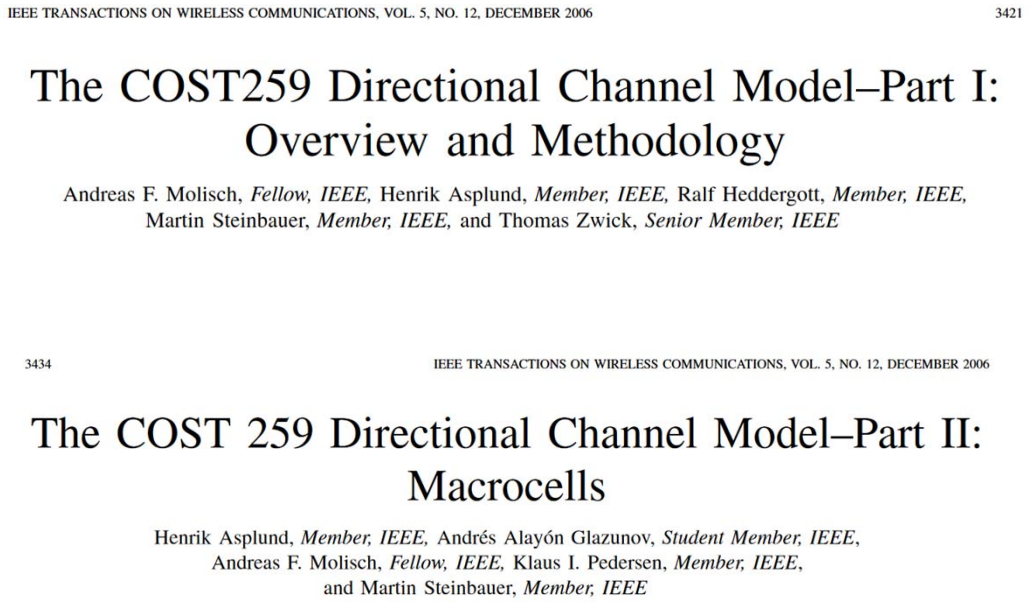
- COST 259 / COST 273 / COST 2100 / COST IRACON

COST 259 Directional Channel Model

- With the increasing use a smart antennas spatial channel models have been required taking into account the angle the angle of arrival of the multi path signals,

- COST 259 has succesfully developed such a model
- The model is specified for 13 different environments covering macro- micro- and pico cells.

- Layered approach:
  - External (fixed) paramters
  - Large-scale parameters
  - Small-scale parameters



IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 5, NO. 12, DECEMBER 2006 3421

The COST259 Directional Channel Model–Part I: Overview and Methodology

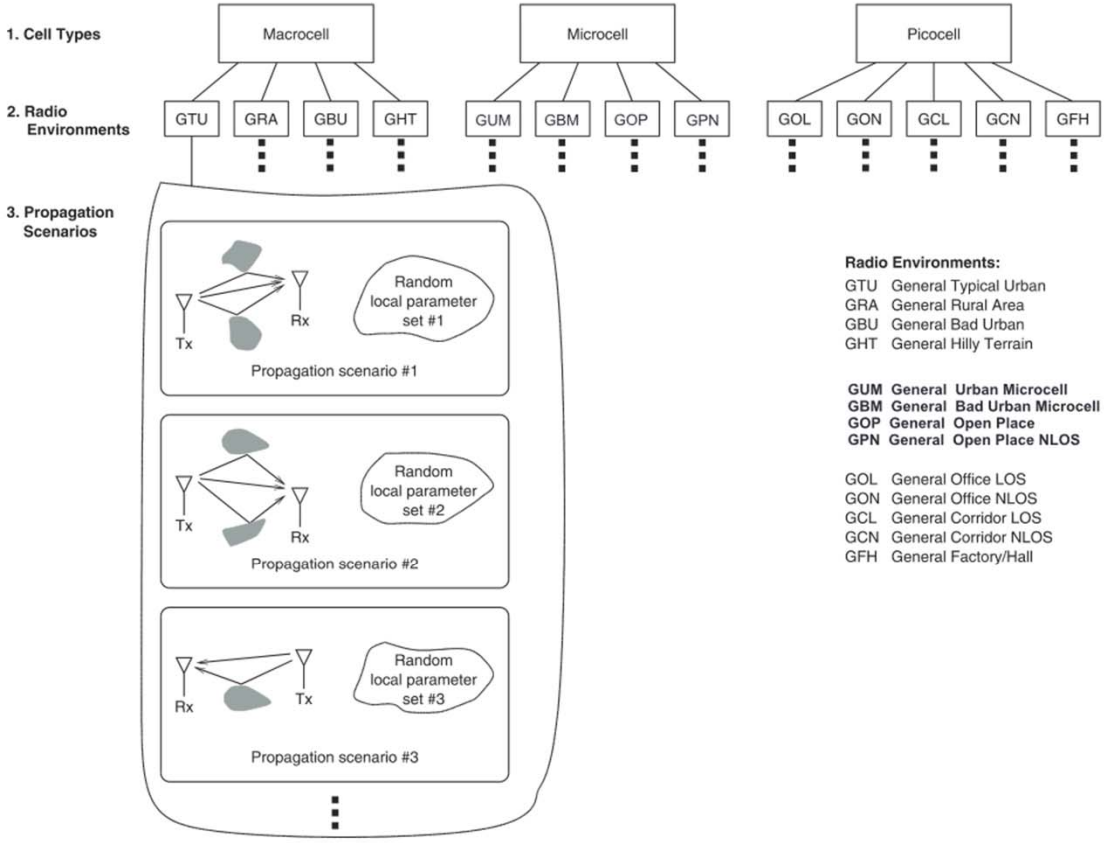
Andreas F. Molisch, *Fellow, IEEE,* Henrik Asplund, *Member, IEEE,* Ralf Heddergott, *Member, IEEE,* Martin Steinbauer, *Member, IEEE,* and Thomas Zwick, *Senior Member, IEEE*

3434 IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 5, NO. 12, DECEMBER 2006

The COST 259 Directional Channel Model–Part II: Macrocells

Henrik Asplund, *Member, IEEE,* Andrés Alayón Glazunov, *Student Member, IEEE,* Andreas F. Molisch, *Fellow, IEEE,* Klaus I. Pedersen, *Member, IEEE,* and Martin Steinbauer, *Member, IEEE*

Structure and some Results of the COST 259 Model

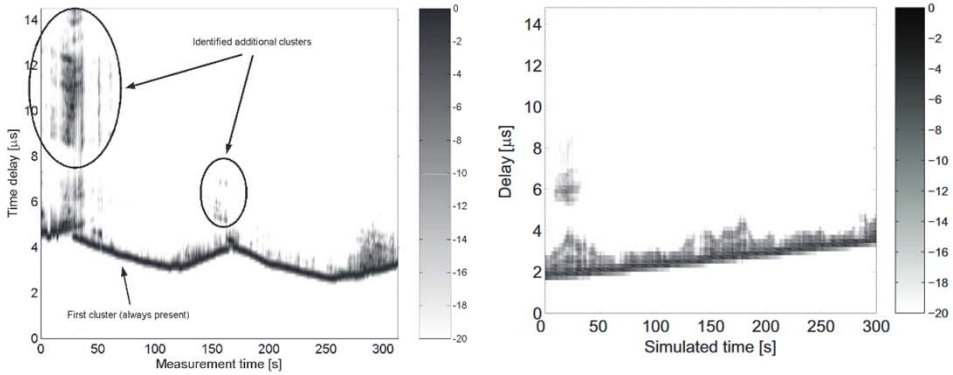


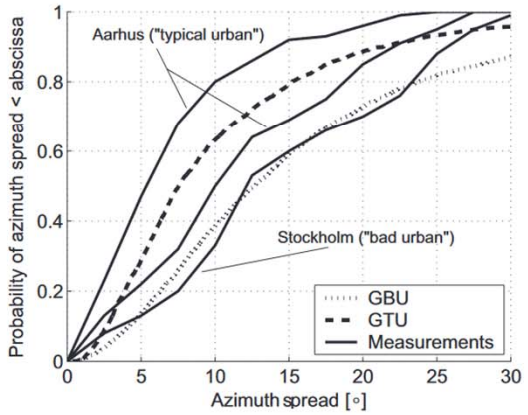
Radio Environments:

GTU General Typical Urban
GRA General Rural Area
GBU General Bad Urban
GHT General Hilly Terrain

GUM General Urban Microcell
GBM General Bad Urban Microcell
GOP General Open Place
GPN General Open Place NLOS

GOL General Office LOS
GON General Office NLOS
GCL General Corridor LOS
GCN General Corridor NLOS
GFH General Factory/Hall





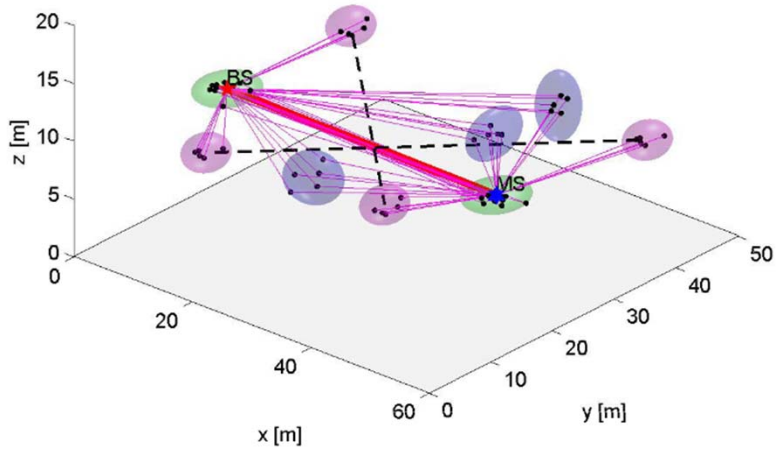
COST 273 MIMO Channel Model

- The COST 273 MIMO channel model is a geometry-based stochastic channel model aiming at link- and/or system-level simulations.
- The model itself has a generic structure, i.e. the core of the model is the same for all kinds of environments.
- Hence, the distinction between the environments is solely done by the model parameters.

2008 IEEE 10th International Symposium on Spread Spectrum Techniques and Applications, Bologna, Italy, 2008

The COST 273 MIMO Channel Model: Three Kinds of Clusters

Nicolai Czink[1], Claude Oestges[2]
[1]Forschungszentrum Telekommunikation Wien (ftw.), Vienna, Austria
[2]Microwave Laboratory, Université catholique de Louvain (UCL), Belgium
czink@ftw.at

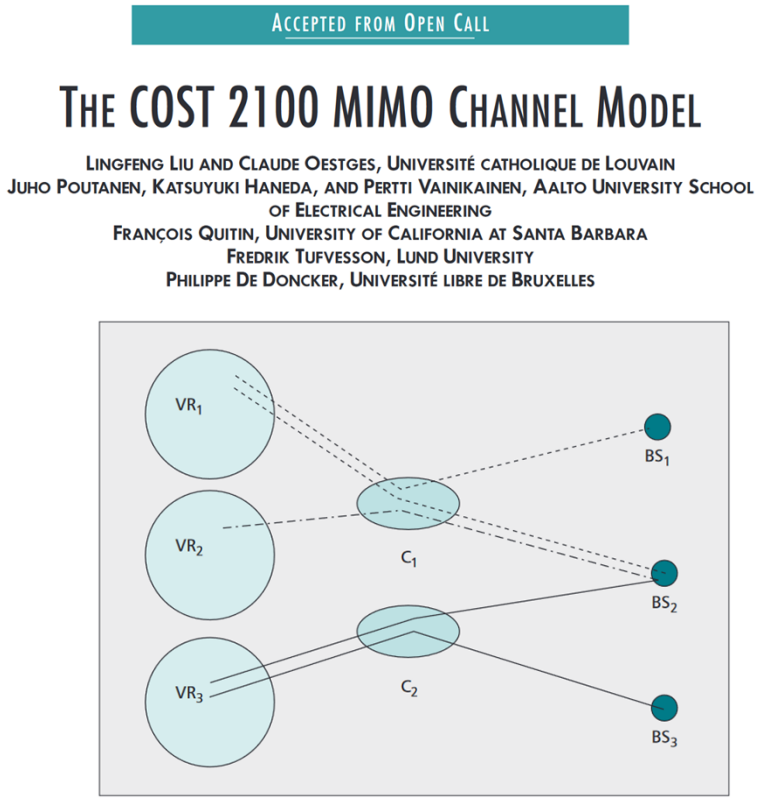


Different kinds of clusters in the COST 273 MIMO channel model: local clusters (green colour), single-interaction clusters (blue colour), multiple-interaction clusters (red colour)

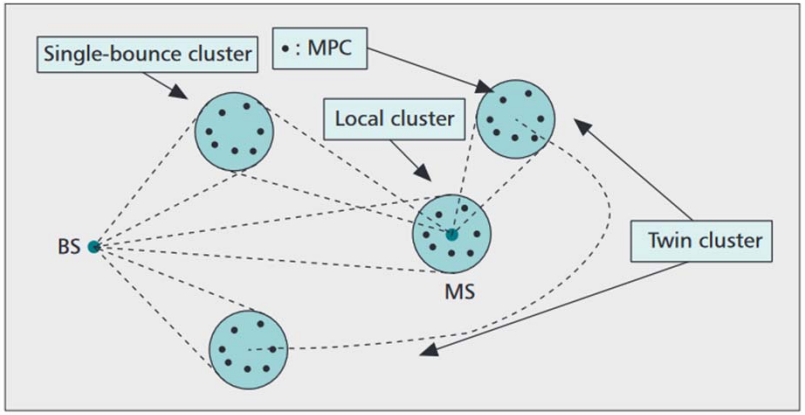
COST 2100 MIMO Channel Model

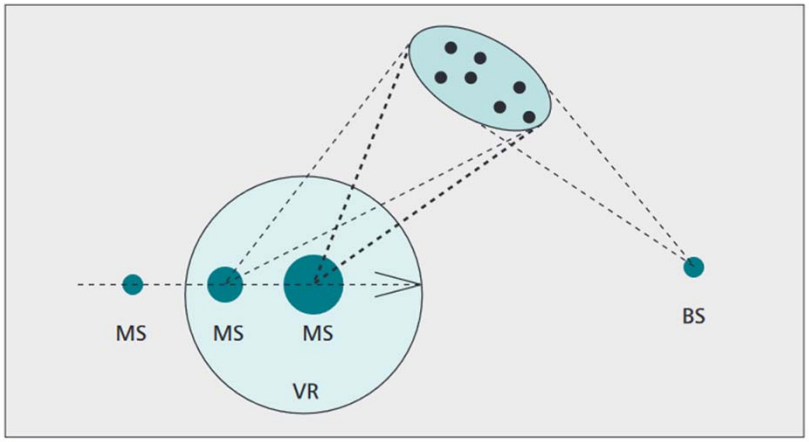
- The COST 2100 MIMO channel model is a GSCM that was built on the framework of the earlier COST 259 and 273 models.
- The COST 259 channel model was the first GSCM considering multi-antenna base stations
- Full MIMO systems were later targeted by the COST 273 model.
- The COST 2100 channel model extends the COST 273 model to cover MIMO systems at large, including multi-user, multicellular, and cooperative aspects without requiring a fundamental shift in the original modeling philosophy.

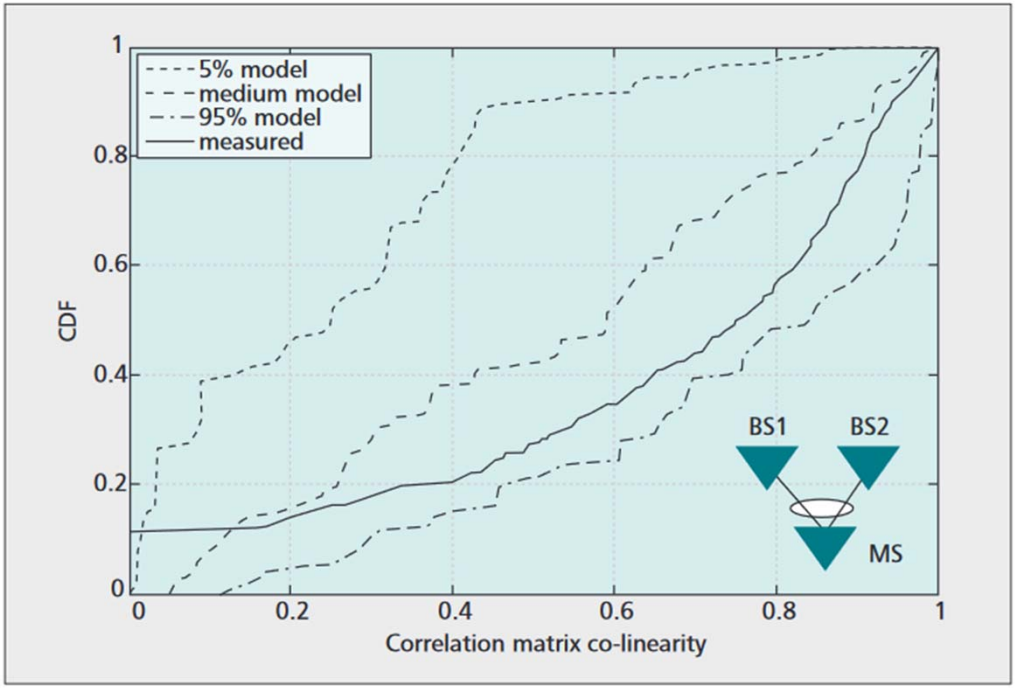
IEEE Wireless communications, December 2012



Concepts and some Results







COST IRACON GBSCM V2V Channel Model

- Vehicle-to-Vehicle Communication requires more features wrt channel modeling
  - the carrier frequencies (5-6 GHz) are significantly higher compared to the early cellular systems
  - Antennas at both ends of the link are at low heights
- COST IRACON has has developed a GBSCM based on a measurment campaign carried out at Berlin.

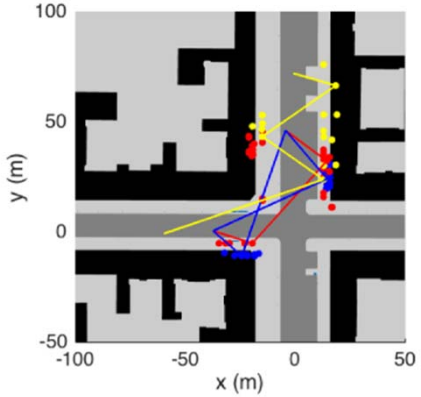
IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 69, NO. 3, MARCH 2020 2365

The COST IRACON Geometry-Based Stochastic Channel Model for Vehicle-to-Vehicle Communication in Intersections

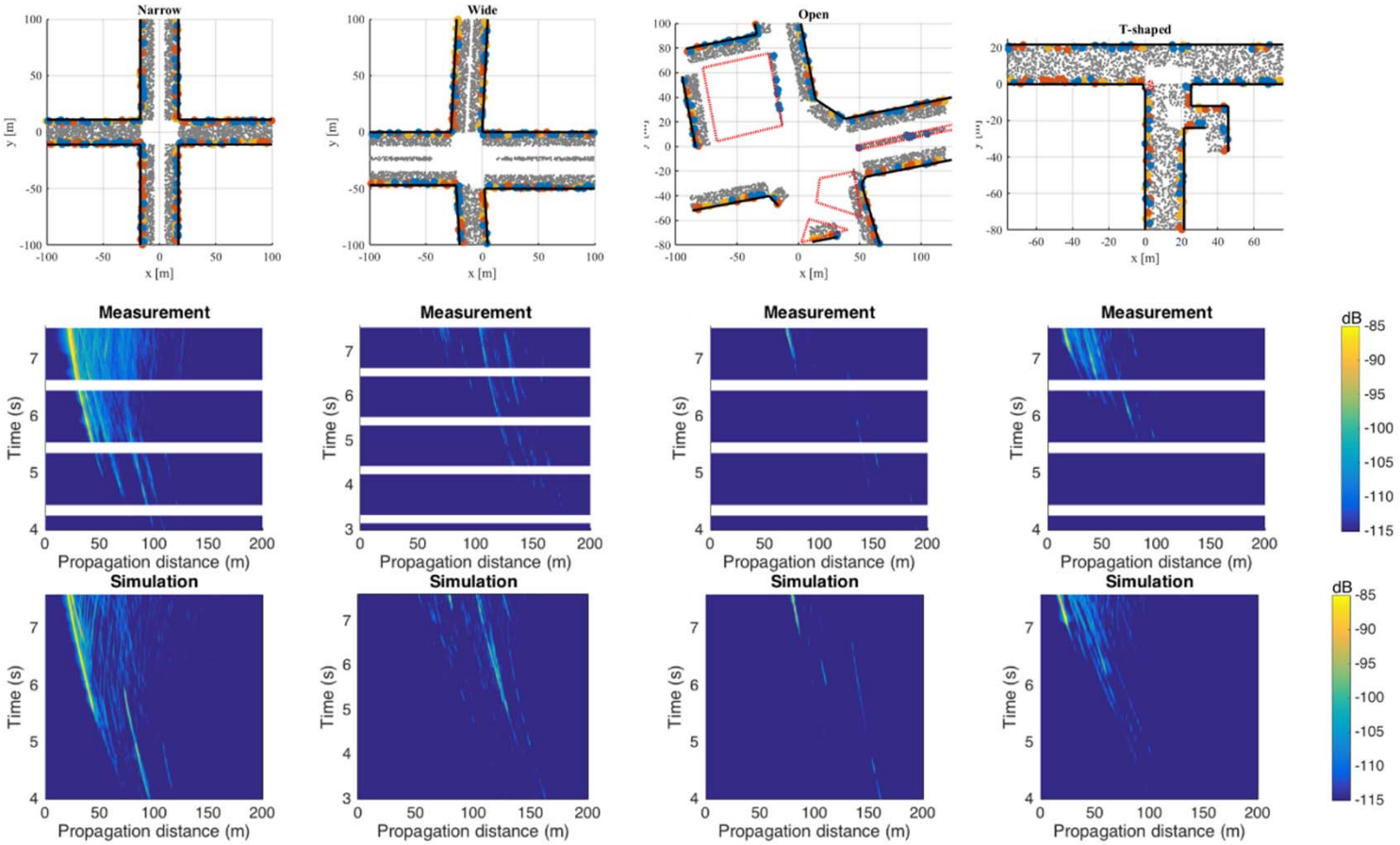
Carl Gustafson, Kim Mahler, David Bolin, and Fredrik Tufvesson

Fig. 1. Aerial photos of the four different intersections where measurements took place. Form left to right: the narrow, wide, open and T-shaped intersections. Trajectories of the Tx and Rx car for a single measurement run are also shown in each image.

Modeling Approach and some Results…

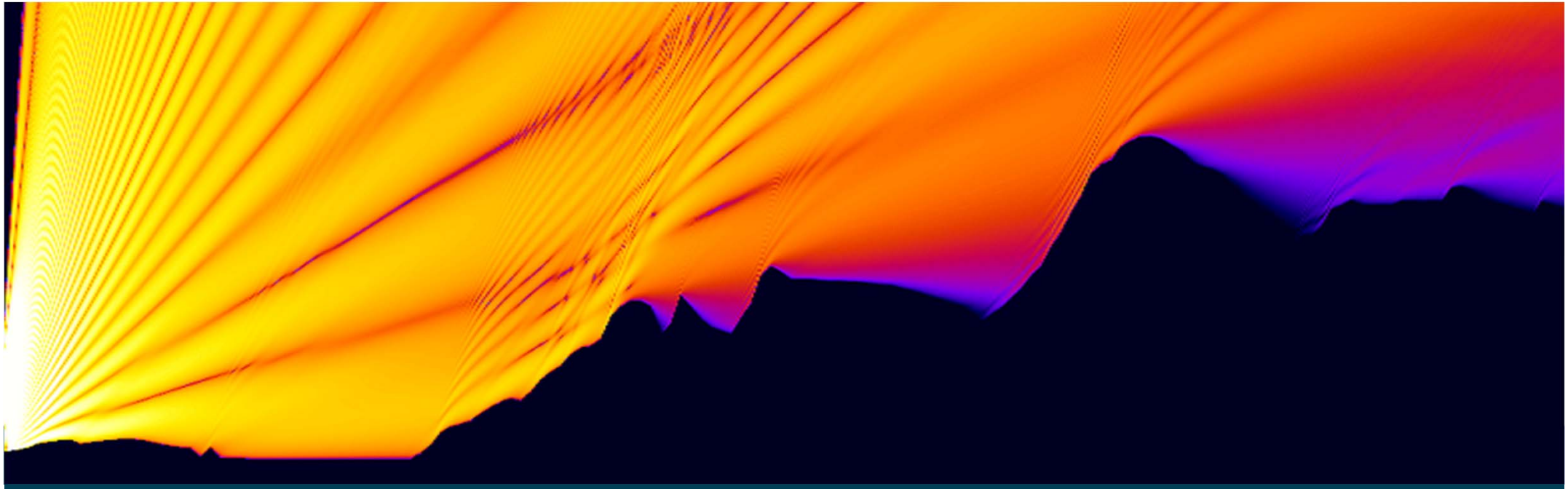


- Identified locations for scattering interactions along building facades.
- Depicted are first-, second and third order interactions, shown as blue, red and yellow dots, respectively.



Technische Universität Braunschweig

Institut für Nachrichtentechnik



Collaboration in COST

There are various Types of Collaboration in COST

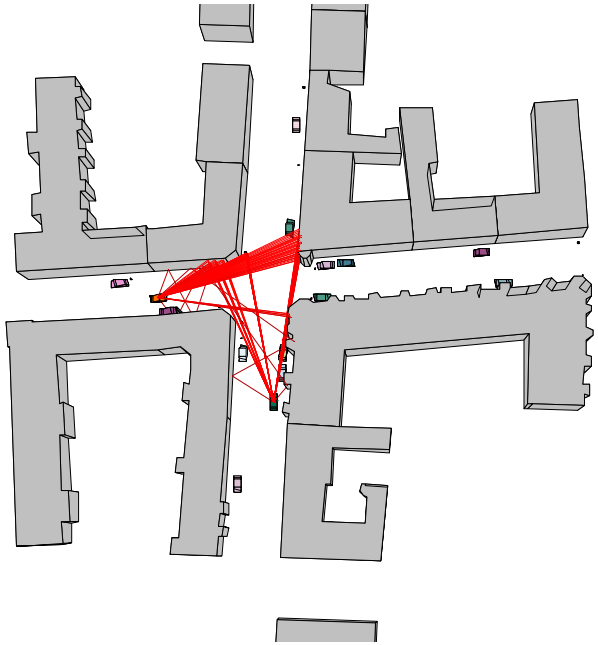
- One possibility to collaborate in COST are Short-Term Scientific Missions (STSM)
  - In an STSM typically Ph. D. students spend a few weeks with another partner.
  - Sometimes a reciprocal visit happens as well.
  - This enables intense collaboration and typcially yield in a joint publication.
  - In the following one example is shown from a reciprocal STSM between Lund University and TU Braunschweig

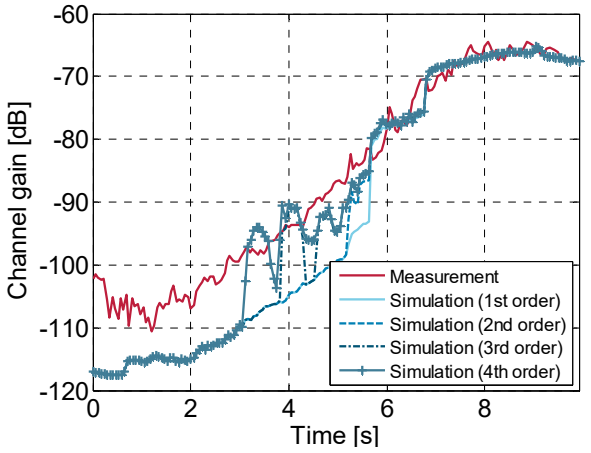
- Another way of collaboration is the sharing of (measurement or simulation) data
  - This enables for example the comparison of the performance of models with the same ground truth
  - Partners, that have only measurement data or simulation data have the possibility to validate their results
  - In the following three examples will be given:
    - Aalborg terrain profiles and measurements.
    - Munich 3D building data and measurements
    - COSt 259 Frequency planning benchmark data set.

STSM and validating V2V Ray Tracing @TUBS with CS Measurements @Lund University performed together with colleagues @TU Vienna

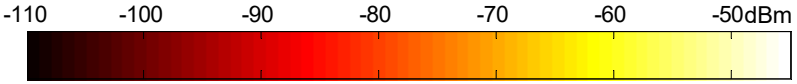
Simulation and Measurement-Based Vehicle-to-Vehicle Channel Characterization: Accuracy and Constraint Analysis

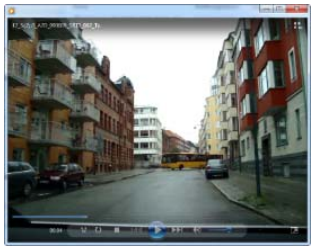
Taimoor Abbas, *Member, IEEE*, Jörg Nuckelt, Thomas Kürner, *Senior Member, IEEE*, Thomas Zemen, *Senior Member, IEEE*, Christoph F. Mecklenbräuker, *Senior Member, IEEE*, and Fredrik Tufvesson, *Senior Member, IEEE*

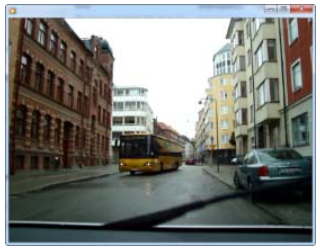


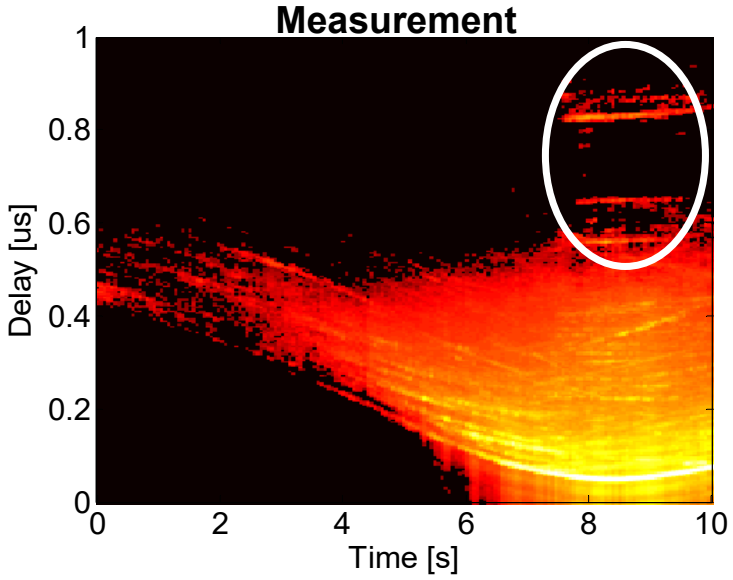


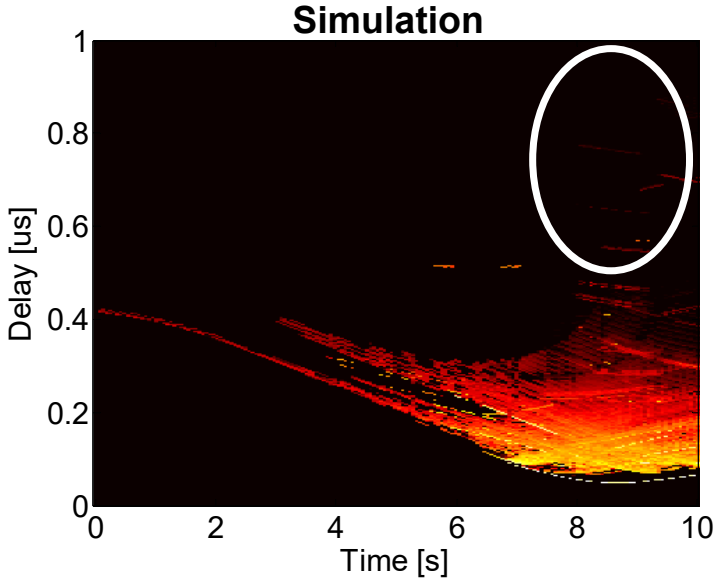
Analysis of the time-variant Power Delay Profiles with an Ellipse Model to identify missing Scatterers in the RT Model

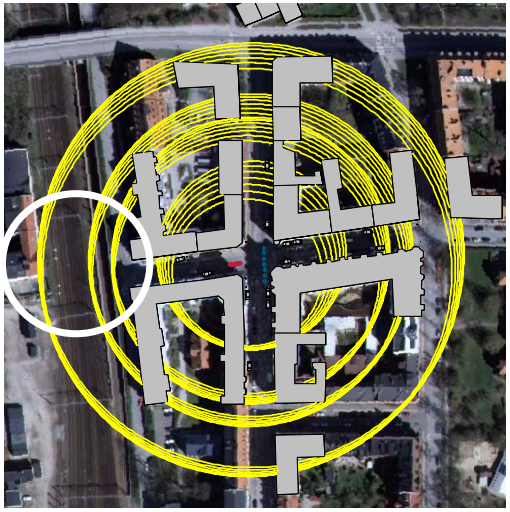




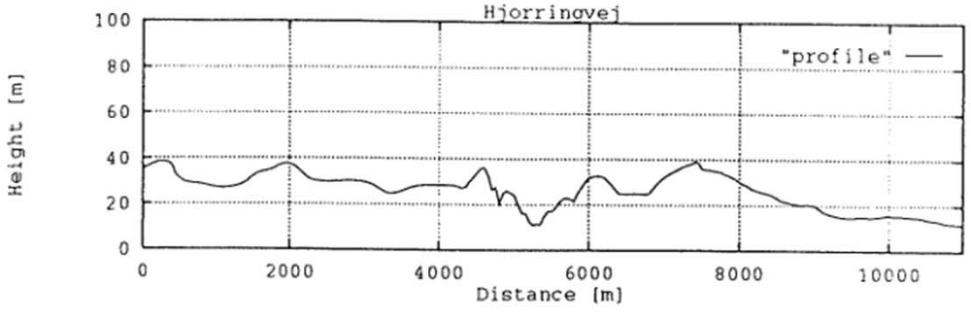






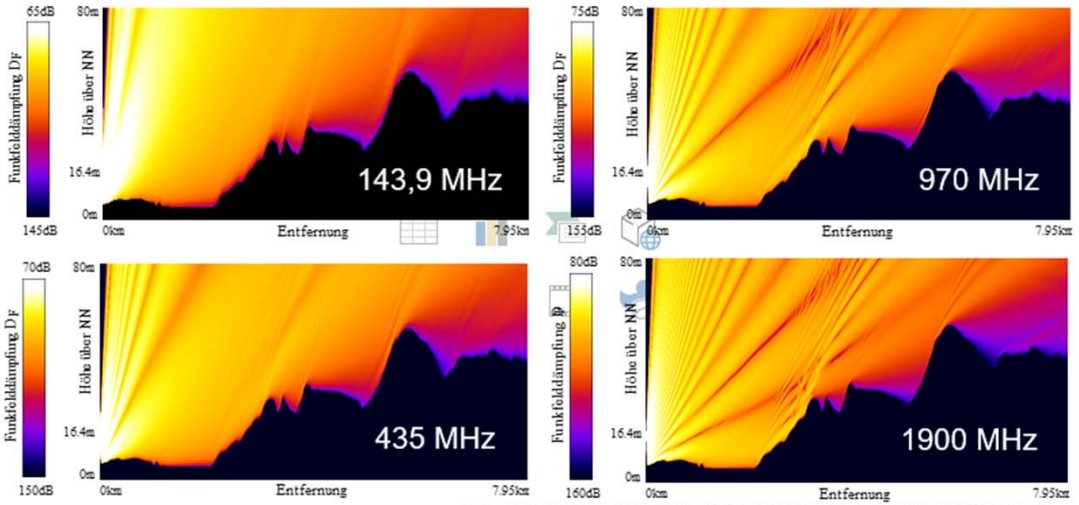


Comparing Path Loss Models along the Aalborg Terrain Profiles



In this paper a brief, preliminary discussion is given of a comparison between four different methods of varying complexity and accuracy. The methods are also compared with experimental results obtained in Denmark near Aalborg. The testing was blind in the sense that the results of the experiments were not made available to the testing groups in Israel, Germany, and Sweden until after they had submitted the results of their computations. The four different methods are

Source: COST 231 TD(93) 06



Quelle: N. Geng, W. Wiesbeck, Planungsmethoden für die Mobilkommunikation

- Aalborg University did measurements along five different terrain profiles at 4 different frequencies.
- Measurements have been provided to the research groups after they privided the predictions based on the terrain profils

Source: Wikipedia

Results have been presented at the COST 231 Meeting in Barcelona in January 1993

INSTITUTE FOR ELECTRONIC SYSTEMS
AALBORG UNIVERSITY
DEPARTMENT OF COMMUNICATION TECHNOLOGY
FREDRIK BAJERS VEJ 7 ■ DK-9220 AALBORG Ø ■ DENMARK

Phone +45 98 15 85 22
Telex 69790 aub dk
Telefax +45 98 15 67 40

To: Mr. Thomas Kürner
Universität Karlsruhe
Inst. Hochfrequenztechnik/Elektronik
Kaiserstrasse 12
D-7500 Karlsruhe

AALBORG 6.1.93 OUR REF. J. NO.

Path loss prediction test.

Dear Thomas Kürner

Thank you for participating in this path loss prediction test. Enclosed you will find plots of the 5 terrain profiles and the comparison of the measurements and the path loss predictions preformed by the four participants.

The four participants are:

Thomas Kürner (UTD)
Jan-Erik Berg (Knife-Edge)
Sherman Marcus (IFDG)
Jan Hviid & Jørn Toftgård (IE)

For each profile and frequency the standard deviation and the mean have been derived.

With your permission we would like to present the results at the COST meeting in Barcelona 19-1-1993.

Sincerely

Jan Hviid and Jørn Toftgård
Phone +45 98 15 85 22 ext.4902

EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH

COST 231 TD(93)-06
Barcelona january 1993

EURO-COST

Comparison between Different Path Loss Prediction Models

Jørgen Bach Andersen
Jan T. Hviid
Jørn Toftgård

Aalborg University
DK-9220 Aalborg
DENMARK

Prof. Jørgen Bach Andersen

(* 13 November 1935 - † 30 November 2021)

Chair COST 231 WG 2 UHF Propagation

Some Results….

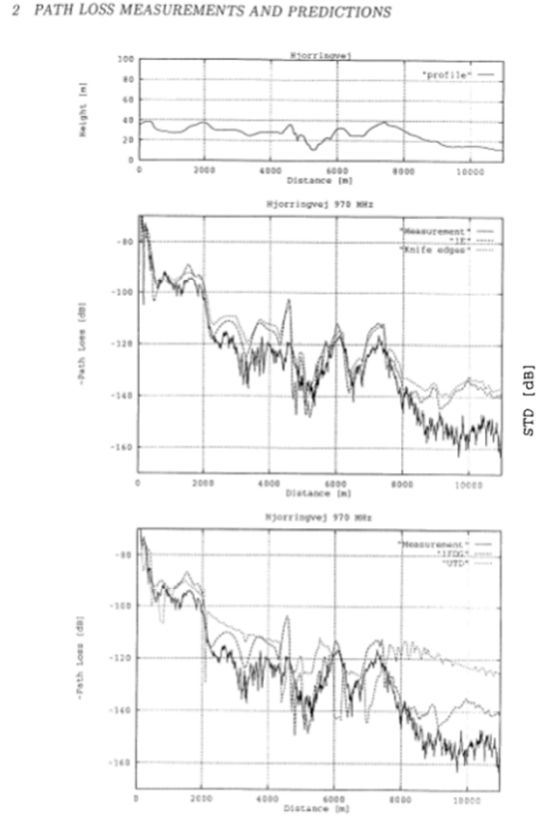


Figure 3: Illustration of the terrain profile "Hjørringvej" and the four path loss predictions at 970 MHz compared the measurements.

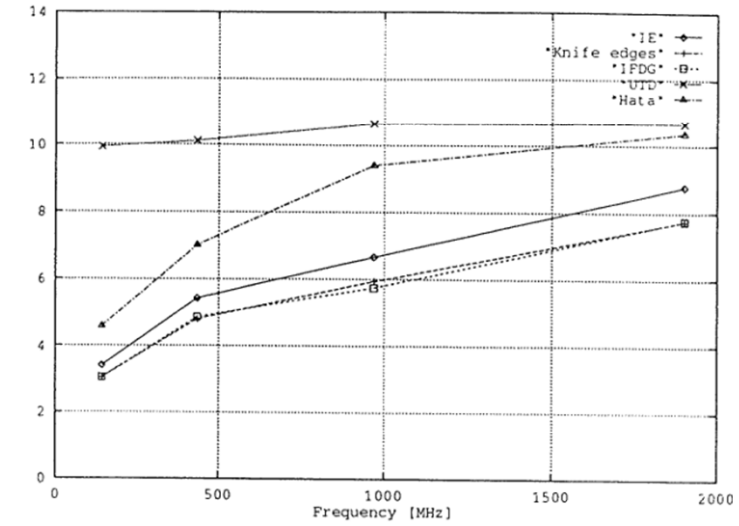


Figure 5: Illustration of the STD versus the frequency,

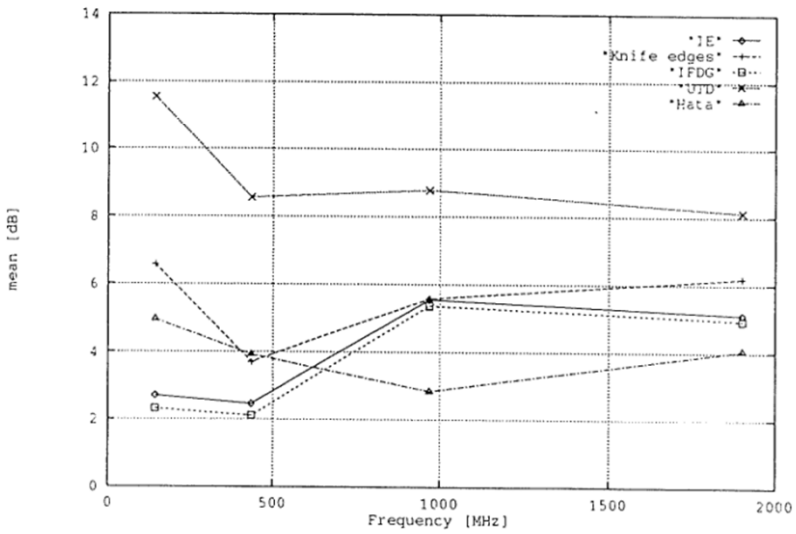
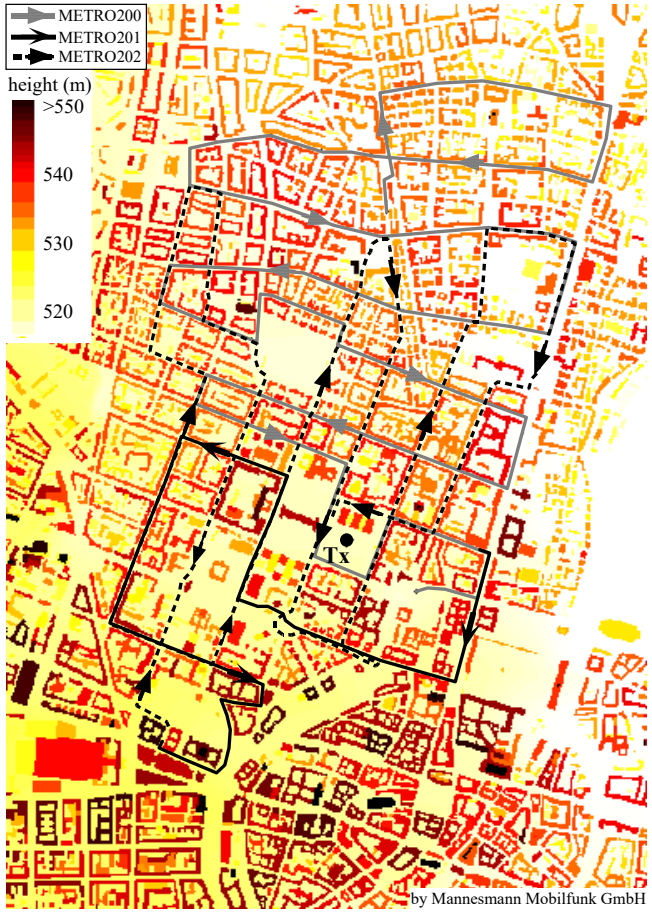


Figure 6: Illustration of the numerical mean error versus the frequency,

COST 231 Munich 3D Building Data and Measurements



- Mannesmann Mobilfunk (now Vodafone Germany) provided 3D building data in Munich together with measurements from 3 sites
- Similar to the procedure with the Aalborg data a blind test has been performed.
- This data set is still used up to day.

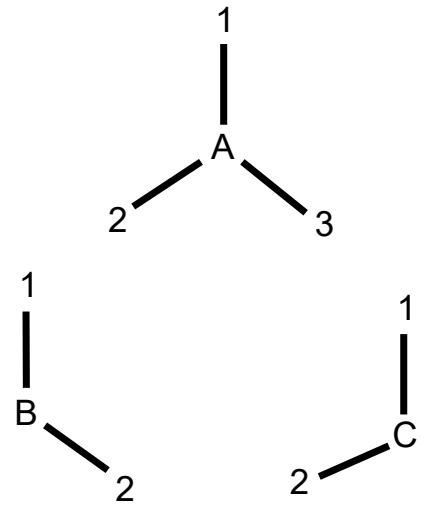
Prediction model	METRO200 (970 points)		METRO201 (355 points)		METRO202 (1031 points)		average
	STD (dB)	mean (dB)	STD (dB)	mean (dB)	STD (dB)	mean (dB)	**STD (dB)**
Ericsson	6.7	0.3	7.1	2.3	7.5	1.4	**7.1**
CNET	6.9	-2.1	9.5	-3.6	5.6	-0.2	**7.3**
PTT (RT)	14.6 [1)]	-6.1 [1)]	15.5 [2)]	-6.7 [2)]	12.3 [3)]	-1.1 [3)]	**14.1**
PTT (TLM)	13.8	0.8	21.7	6.7	12.9	6.5	**16.1**
COST-WI [4)]	7.7	10.8	5.9	15.4	7.3	16.3	**7.0**
Uni.-Valencia [5)]	8.7	0.2	7.0	-6.6	10.3	-7.4	**8.7**
CSELT	10.4	21.8	12.3	16.1	13.3	20.6	**12.0**
PTT (MCOR)	7.0	-3.3	6.2	-0.1	7.6	-1.1	**6.9**
Villa Griffone Lab	6.3	-1.7	10.9	-6.3	6.8	-5.5	**8.0**
Uni.-Karlsruhe	8.5 [6)]	-4.3 [6)]	9.1	2.4	8.6 [6)]	-1.0 [6)]	**8.7**

[1)]calculations at 425 points only; [2)]calculations at 264 points only; [3)]calculations at 774 points only; [4)]assumed terrain parameters: building height: 20m, street width: 13m, building separation: 26m; [5)]no 3D effects are considered; [6)]2D-vertical propagation plane only;

Source:COST 231 Final Report

COST 259 Frequency Planning Benchmark Scenarios

- Frequency planning algorithms to solve the frequency planning problems in real GSM network planning.
- Results achieved by different research groups have been published each of them usimg ist one scenario data.
- In order to solve the problem COST 259 established a sub-working Group (SWG 3.1) to create and publish benchmark scenarios
- 32 real-world planning scenarios are available contributed from threeindustrial partners:
  - E-Plus Mobilfunk GmbH, Siemens AG, and Swisscom Ltd.
- The scenarios together with several contributed frequency plans are made available at https://fap.zib.de/problems/COST259/ (still alive today!)



TINY network for data format explanation

Cell	A1	A2		A3		B1		B2	C1	C2	
# of TRX	0	0	1	2	0	1	0	1	0	0	0	1
Channel Number	9	11	7	16	5	14	14	5	9	8	17	12

Solution for the TINY network

„Communications for the Millenium", Proceedings of COST252/259 Joint Workshop, University of Bradford, April 21-22, pp. 87-92

Radio Planning Algorithms for Interference Reduction in Cellular Networks

Andreas Eisenblätter,[1] Thomas Kürner,[2] Reiner Fauß[2]

[1]Konrad-Zuse-Zentrum für Informationstechnik, Berlin, Germany
[2]E-Plus Mobilfunk GmbH, Düsseldorf, Germany
eisenblaetter@zib.de; Reiner.Fauss@eplus.de

Final Results have been presented at the final COST 259 Meeting in Bergen In April 2000

EUROPEAN COOPERATION IN

THE FIELD OF SCIENTIFIC

AND TECHNICAL RESEARCH

EURO-COST

COST 259 TD (00) 44

Bergen, Norway, April 27-28, 2000

SOURCE: ZIB, E-Plus (Germany)

Benchmarking Frequency Allocation Strategies

Andreas Eisenblätter, Thomas Kürner

Some Results…

Download

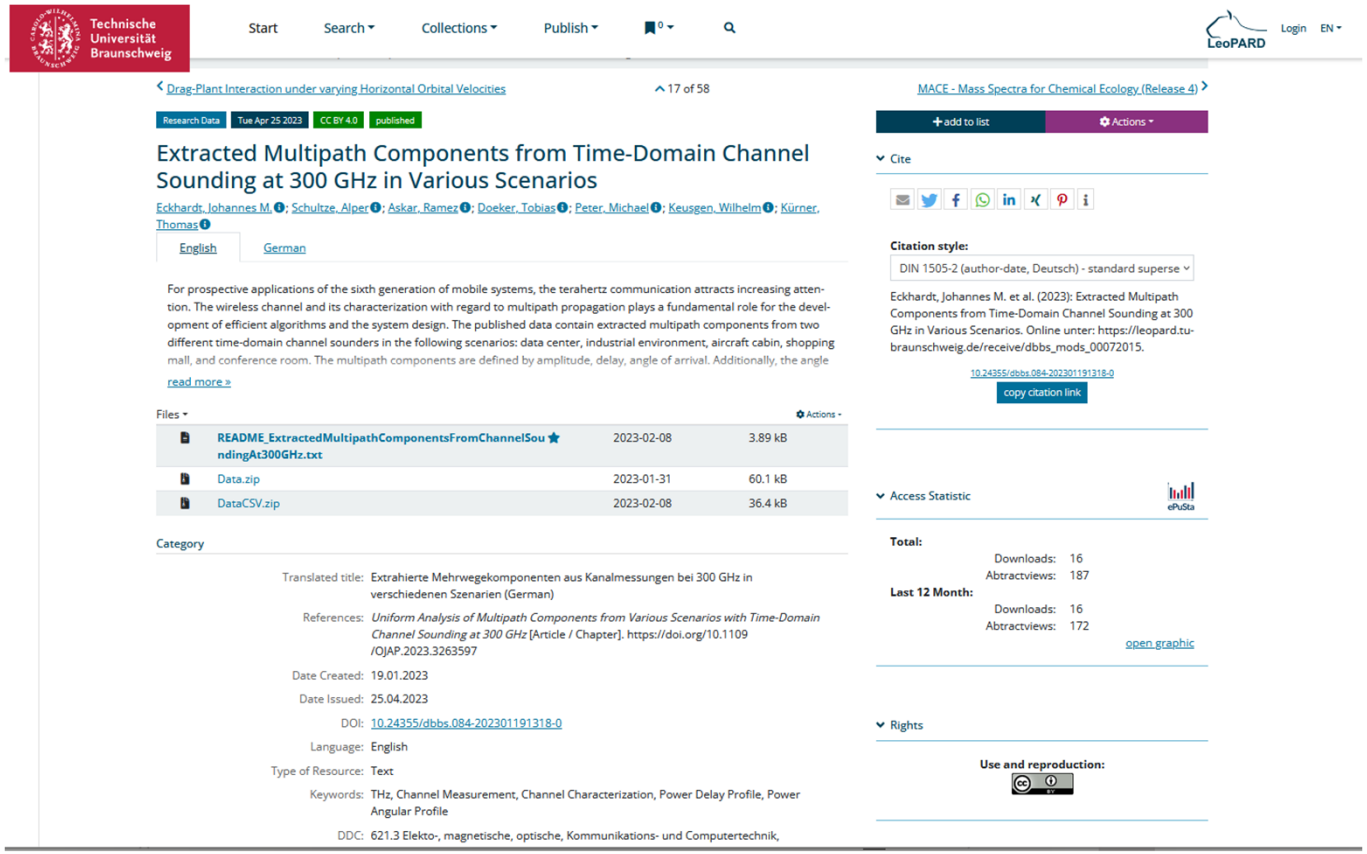
A list of the available scenarios follows. The scenarios are arranged in sections:

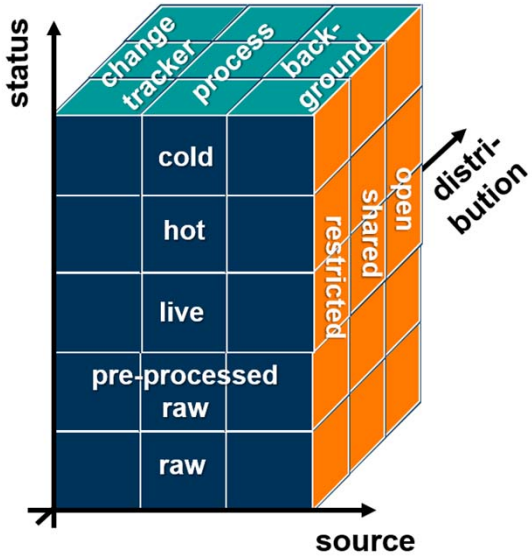
- bradford_nt instances
- bradford instances
- siemens instances
- Swisscom instance
- Tiny instance
- K instance

Acronym	Method	Supplied by	Reference
DC5_IM(ZIB)	"DSATUR with Costs" (5%) followed by "Iterated 1-Opt"	Andreas Eisenblätter, ZIB, Germany	[BEGM98]
SA(Telefonica)	Simulated Annealing	Luis de Urries, Telefonica, Spain	[DeGuBe00]
SA(TUHH)	Simulated Annealing	Dirk Beckmann, TU Hamburg-Harburg, Germany	[BeKi99a]
TA(RWTH)	Threshold Accepting	Martin Hellebrandt, RWTH Aachen, Germany	[HeHe00]
TA(Siemens)	Threshold Accepting	Hans Heller, Siemens AG, Germany	[HeHe00]
U(Siemens)	Unpublished	Reinhard Enders, Siemens AG, Germany	
DTS(Glamorgan)	Dynamic Tabu Search	D.H. Smith, U Glamorgan, UK	
K-THIN(UR1)	Simulated Annealing combined with Dynamic Programming to compute local optima	C. Mannino, G. Oriolo, F. Ricci (University of Rome La Sapienza)	[MaOrRi02]

		sep	in-	un-	total	co-channel			adjacent-ch			TRX			TRX pairs with interference exceeding								
scenario	assignment	viol	valid	ass	intf	max	avg	std	max	avg	std	max	avg	std	0.01	0.02	0.03	0.04	0.05	0.10	0.15	0.20	0.50
Swisscom	Original	0	0	271	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0
	DTS(Glamorgan)	0	0	0	27.21	0.00	0.00	0.00	0.97	0.30	0.16	3.15	0.66	0.58	92	92	92	92	92	92	92	65	9
	SA(TUHH)	0	0	0	27.36	0.00	0.00	0.00	0.96	0.32	0.19	3.48	0.75	0.63	85	85	85	85	85	85	85	57	14
	TA(RWTH)	0	0	0	29.52	0.00	0.00	0.00	0.96	0.33	0.18	2.96	0.77	0.65	89	89	89	89	89	89	89	60	15
	TA(Siemens)	6	0	0	17.71	0.00	0.00	0.00	0.97	0.30	0.18	2.26	0.66	0.51	59	59	59	59	59	59	59	44	5

Early COST Actions have been quite Visionary on providing Open Access Data Sets – the Forerunner of today‘s Research Data Management



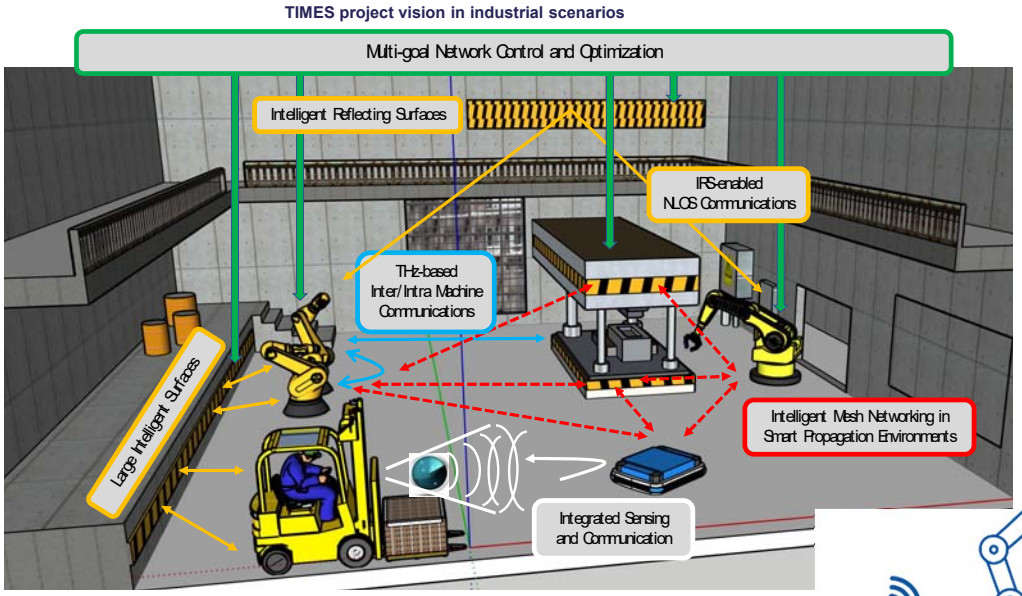


Outlook

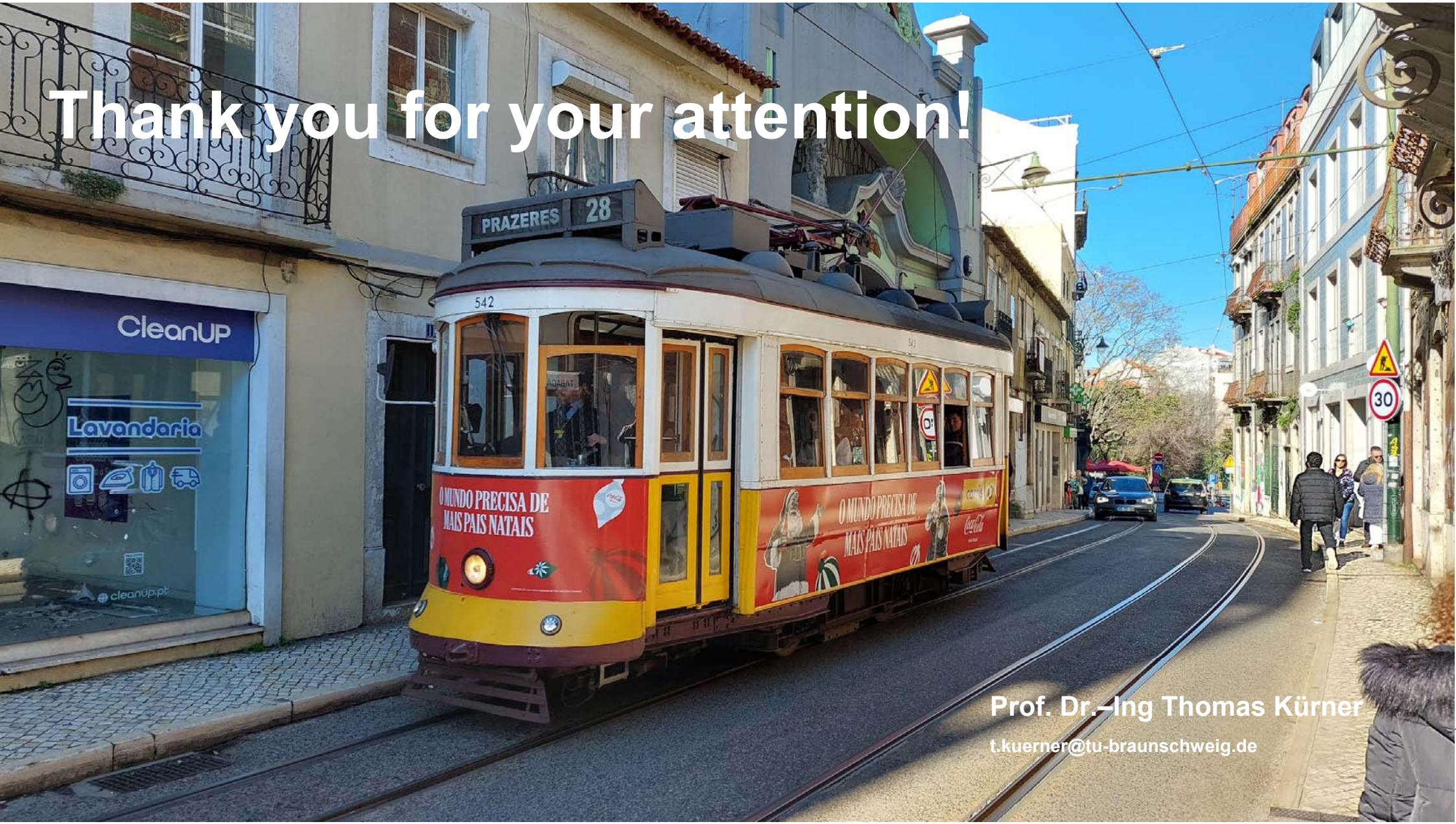
- What‘s next?

What‘s Next?

- New topics are already discussed:
  - THz Communications
  - Reflective Intelligent Surfaces
  - Integrated Sensing and Communication
  - Machine Learning for Channel Modelling
  - ….
  - New application areas such as
    - Industrial environments
    - Health and medical appications
    - Agriculture
    - Drones
    - …
- You will hear about many of these topics in the next talk given by Andy Molisch



Propagation and Channel Modeling has not come to an end!



Thank you for your attention!

Prof. Dr.–Ing Thomas Kürner

t.kuerner@tu-braunschweig.de