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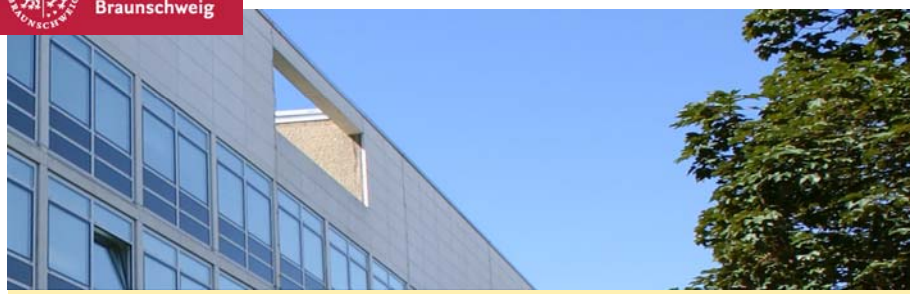

Propagation Models for High-Speed Railways

Prof. Dr.-Ing. Thomas Kürner

Outline

1. Motivation
2. Deterministic Propagation Modeling for the Realistic High-Speed Railway Environment
3. Semi-Deterministic Modeling for Propagation of High-Speed Railway
4. Empirical Modeling for Extra Loss of Semi-Closed Obstacles

Acknowledgement

The work shown in the lecture on Propargation Modeling for High-Speed Railways originates from a cooperation of Insitut für Nachrichtentechnik at TU Braunschweig with the State Key Lab for Rail Traffic Control at Beijing Jiaotong University/China during the scientific stay of Dr. Ke Guan at IfN in the period August 2011 to August 2013.

RCS 轨道交通控制与安全 国家重点实验室 State Key Laboratory of Rail Traffic Control and Safety

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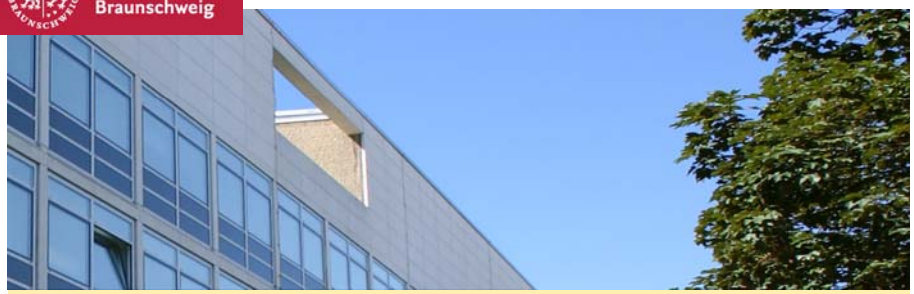
IfN Institut für Nachrichtentechnik



Motivation

High-Speed Railway in China

- In China, by 2020: 120,000 km – rail lines; 16,000 km – high speed rails.
- To support the safe operation of high-speed railway, the channel characterization of the railway communication systems (e.g., GSM-R and LTE-R) is of great importance.

Basic framework of high-speed rails in China

Relevance of Channel Characterisation

- Since 2000, over **70** disasters of railways happened all over the world, over **4000** people died, and over **4000** people got hurt.
- In order to avoid collision and guarantee a safe operation, a reliable signalling and train control communication system is mandatory.
- Channel characterization is the basis of train communication systems (GSM-R, LTE-R (surveillance video)).

High-speed railway accident in China, 23,07,2011

Propagation Models fo High-Speed Railway

- Most of the models for the high-speed railway are **empirical models, statistical models, and deterministic models.**

Model Type	Pros	Cons
Empirical models Statistical models	▪"First-hand information" ▪Easy to be used	▪Average description of the environment ▪Dependency on measurement environment
Deterministic models	▪Accurate predictions	▪Highly accurate topographical databases ▪Numerically intensive to process ▪High resolution digital elevation model is expensive.
Semi-deterministic modes	▪ Few information on the environment required: totally free sources ▪ Less computational time: simple methods ▪ Sufficient accuracy: better than the existing empirical and statistical models.	▪ not as accurate as deterministic models

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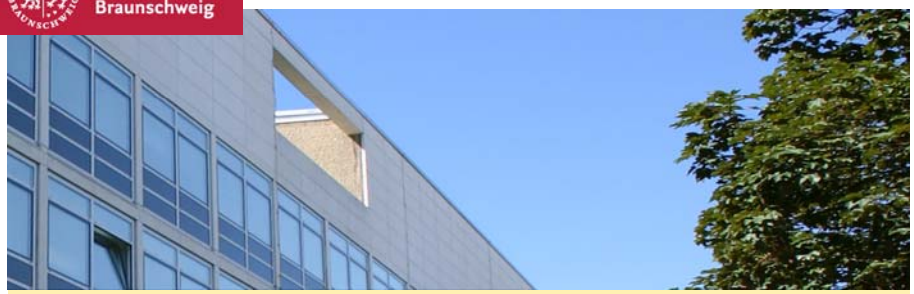
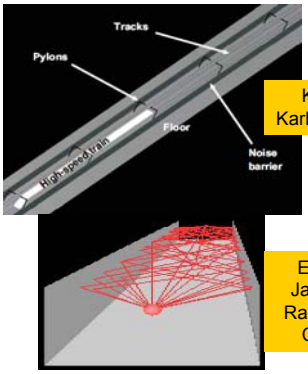


Deterministic Propagation Modeling for the Realistic High-Speed Railway Environment

Introduction

- Most of the models for propagation of high-speed railway are **empirical models** and **stochastic models.**
- Some deterministic models have been presented, but simplified or assumptive.
- Deterministic modeling towards a realistic high-speed railway environment is still absent.



KIT Karlsruhe

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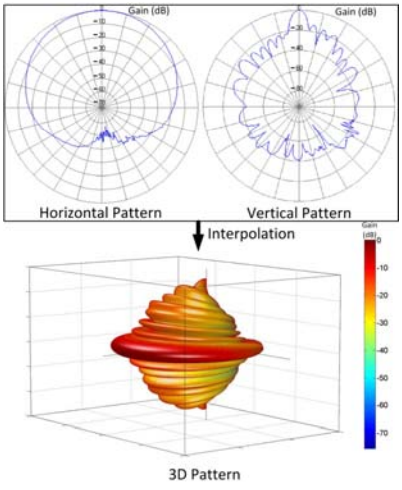
Deterministic Modeling Approach

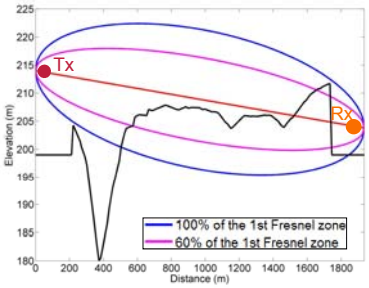
- The deterministic modeling approach consists of the **3D ray-optical channel model** and the **multi-edge diffraction model**.

- 3D ray-optical channel model
  - Antenna modeling:
    - Polarization is described by Jones vector.
    - 3D pattern of the antenna is interpolated by the horizontal and vertical patterns.
  - Ray-optical approach:
    - Direct path
    - Reflections (Image method)
    - Scattering (Surfaces divided into tiles)



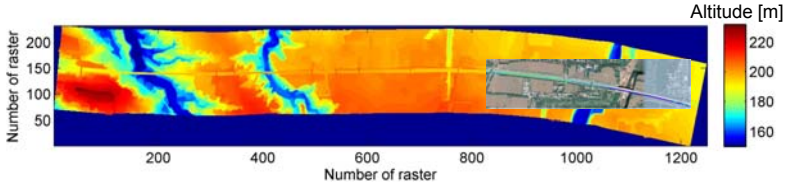
Deterministic Modeling Approach

- Diffraction:
  - In the train communication system, most of the diffraction happens on the upper edge of obstacles.
  - Diffraction model based on the raster database can support sufficient accuracy and avoid complex computation.
  - Classical multi-edge diffraction model: **Deygout model**.

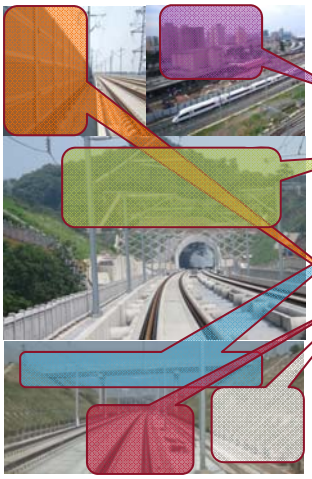


Generation of Realistic High-Speed Railway Environment

- The generation of the realistic high-speed railway environment is composed of two parts: **Construction of the 3D digital elevation model** and **modeling of the structures**.
- The 3D DEM:
  - Vector database for the 3D ray-optical channel model:
    - The vector database of terrain (resolution of 5 m) is produced based on the satellite images from Cartosat-1.
    - Information of the track is from China Railway Survey and Design Group Company.
    - The dimensions and altitudes of the structures along high-speed railway are measured by a Laser distance meter manually.
  - Raster database for the multi-edge diffraction model:
    - The raster database (resolution of 5m) is easily converted from the vector database.



Generation of Realistic High-Speed Railway Environment



- Modeling of the structures along high-speed railway
  - The large-scale structures: Objects whose dimensions are considerably larger than the wavelength.
    - Building: a cuboid composed of walls and the rooftop with measured dimensions.
    - Terrain is divided into many 10m × 10m equal-sized grids, where each grid has a height that is averaged from the terrain data within the grid.
    - Crossing bridge is modeled as a cuboid according to the real dimension of the bridge.
    - Track, cutting and barrier are modeled as patch composed of 2m × 2m squares.
    - The scattering effects are modeled by using the Lambert's approach.

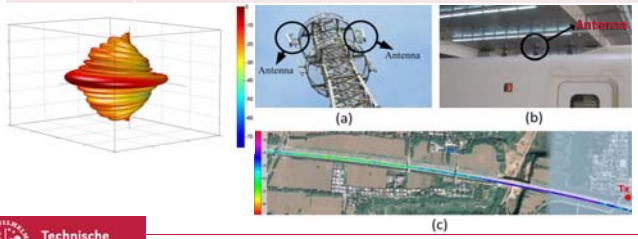
Generation of Realistic High-Speed Railway Environment

- Modeling of the structures along high-speed railway
  - The small-scale structures: Objects whose dimensions are on the same order of magnitude with the wavelength: **pylons** and **trees.**
    - A pylon is modeled as a finite-length conductor cylinder with bistatic radar cross section.
    - The forest:
      - Trees following the uniform distribution with the separation of 8 - 10 m.
      - A tree is modeled by a 8-facet polygonal prism with the diameter of 6 - 10 m
      - Each facet consists of 2m × 2m squares.
      - Scattered field of tree is obtained by using the multiple scattering theory of Foldy-Lax.

Modeling Approach Validation

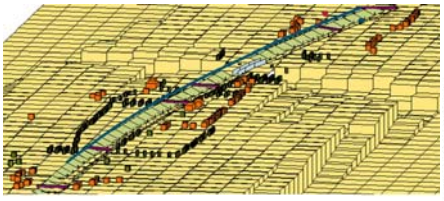
- Measurement campaign
  - Measurements: Zhengzhou-Xi'an high-speed railway in China at 930 MHz, with a CRH2 high-speed train with the speed up to 350 km/h.

Item	Description
Transmitter	GSM-R base station
Transmitting antenna	Dual-polarization antenna, with 17 dBi gain, 43 dBm power, and 65 degree horizontal and 6.8 degree vertical beam widths.
Receiving antenna	Omni-directional, with 4 dBi gain, deployed on the top of carriage at a height of 30 cm above the roof
Receiver	Willtek 8300 Griffin receiver, the sampling Interval is shorter than half of the wavelength.

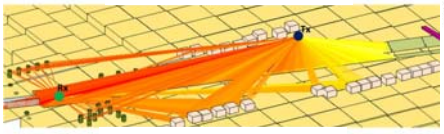


Modeling Approach Validation

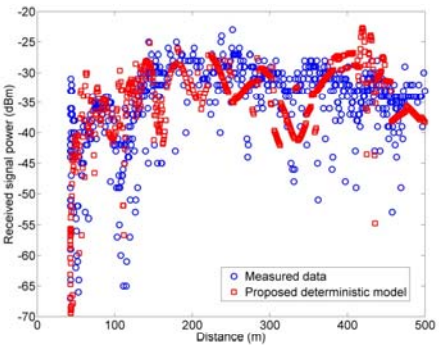
- Results



Generated ray-tracing map

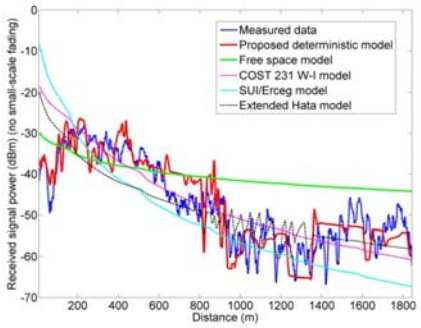


One snapshot in simulation



Modeling Approach Validation

- Results
  - Large-scale fading:
    - Proposed model
    - Free space propagation model
    - COST 231 Walfisch-Ikegami (LOS)
    - Extended Hata model (Open Area)
    - SUI model.



Model	Proposed model	Free space model	Extended Hata	COST 231 W-I (LOS)	SUI/Erceg
ME (dB)	0.28	6.94	1.08	0.67	3.76
Std (dB)	4.92	7.77	6.49	6.67	9.02
RMSE (dB)	4.93	10.42	6.58	6.71	9.77

Conclusion

- Conclusion:
  - A realistic high-speed railway oriented deterministic modeling is presented:
    - Antenna pattern and polarization: The propagation in the first 500 m can be predicted.
    - Reflections and scattering are taken into account based on the image method.
    - The multi-edge diffraction model based on the raster database supports an easy way to evaluate the diffraction loss.
  - The presented model has the mean error close to 0 and achieves an improvement of 30% - 50% in the RMSE compared with the well-known models.

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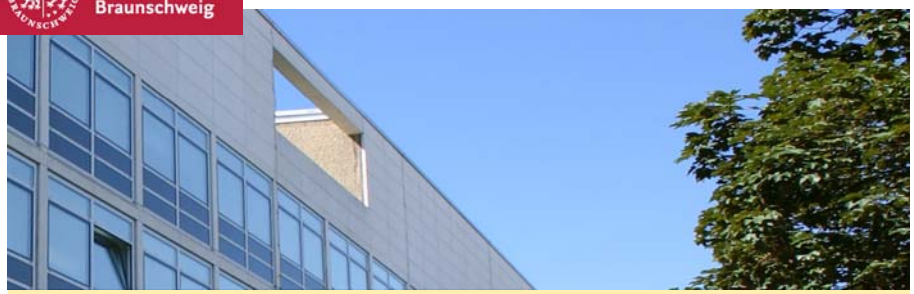


Semi-Deterministic Modeling for Propagation of High-Speed Railway

Semi-Deterministic Propagation Modeling

- For a high-speed railway, the viaduct and the cutting on average make up more than 70% of the whole line.
- Viaduct: Clear LOS, little scattering, and little diffraction, similar to the open area.
- Cutting: The propagation is considerably affected by the steep walls and terrain changes on both sides. Diffraction loss can be serious in this scenario.

(a) Viaduct (b) Cutting

Semi-deterministic model

Extended Hata Model | Multi-Edge Diffraction Models

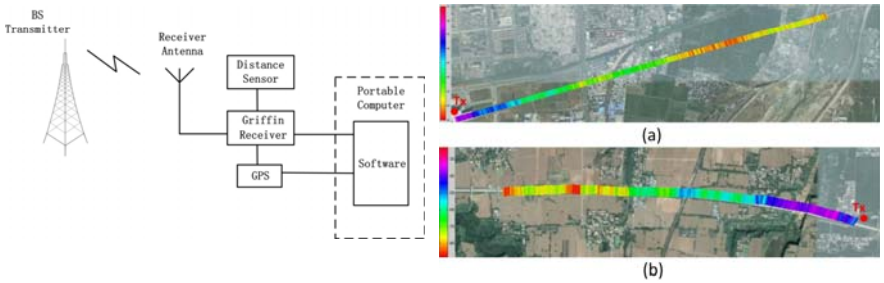
Semi-Deterministic Propagation Modeling

- Extended Hata model:
  - It can predict propagation loss in the 30-3000 MHz band for different environments.
  - Path loss of the open area in the extended Hata model can be employed.
- Raster data:
- From Shuttle Radar Topography Mission (SRTM-3) with 90 m resolution – freely available
- Width of the rail is10 - 20 m, the resolution of the raster data should be enhanced up to 10 m by interpolation.
- Parameters of communication system:
  - from railway design and construction organizations.
- All the data sources are totally free and easy to be controlled by designers.

- Multi-edge diffraction model:
  - Longley & Rice model
  - Epstein-Peterson model
  - **Deygout model**

Measurement Campaign and Model Validation

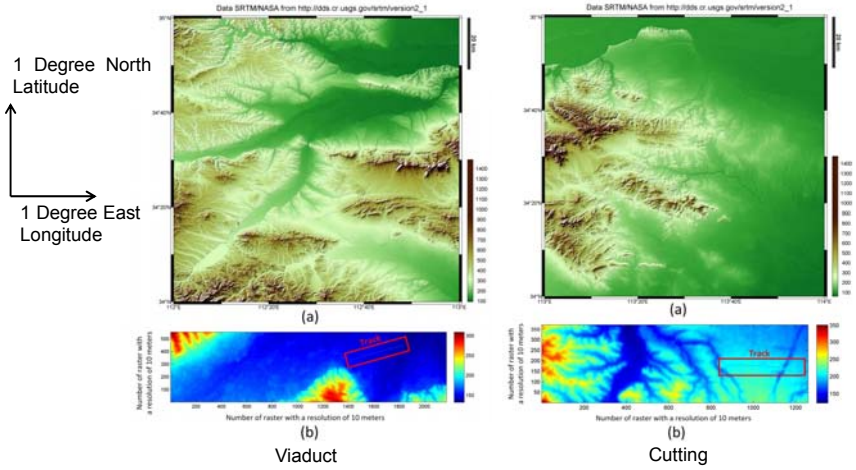
- Measurement campaign
  - Measurements: Zhengzhou-Xi'an high-speed railway at 930 MHz, using standard GSM-R base station and CRH2 high-speed train with the speed up to 350 km/h.



Scenario	H (m)	h(m)	W (m)	L (m)	f (MHz)
Viaduct	38	4.1	12.39	4500	932.8
Cutting	28	4.1	15.54	3000	930.4

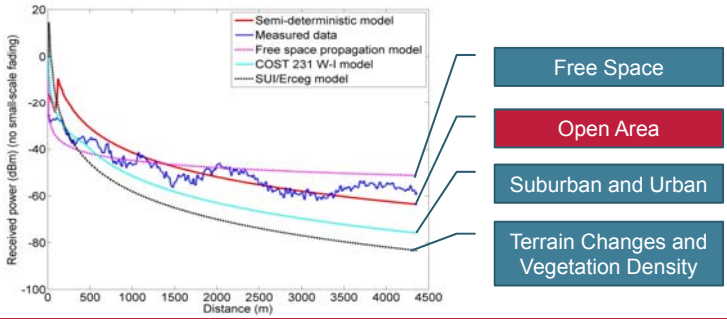
Measurement Campaign and Model Validation

- Model Validation



Measurement Campaign and Model Validation

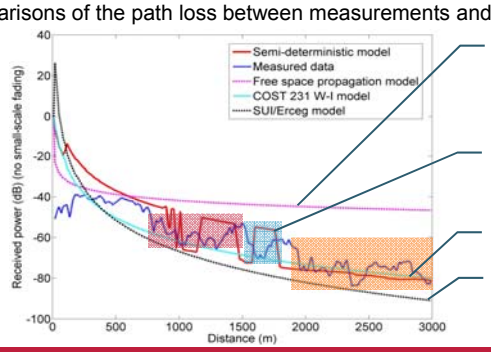
- Comparisons of the path loss between measurements and predictions.



Scenario: Viaduct				
Model	Semi-deterministic model	Free space model	COST 231 W-I (LOS)	SUI/Erceg
ME (dB)	0.40	3.15	11.63	18.70
Std (dB)	4.35	4.92	5.14	5.41
RMSE (dB)	4.37	5.84	12.72	19.46

Measurement Campaign and Model Validation

- Comparisons of the path loss between measurements and predictions.



Lack of consideration of reflection, scattering, and diffraction

Reveal the number, approximate locations, and values of diffraction loss.

Fail to reflect the diffraction.

Fail to reflect the diffraction.

Scenario: Cutting				
Model	Semi-deterministic model	Free space model	COST 231 W-I (LOS)	SUI/Erceg
ME (dB)	0.19	19.07	2.44	11.62
Std (dB)	7.56	10.33	8.20	4.59
RMSE (dB)	7.57	21.70	8.56	12.49

Conclusion

- The semi-deterministic model for the propagation of high-speed railway is proposed.
- The characteristic of high-speed railway determines that the extended Hata model and multi-edge diffraction models are proper to be conjunctively utilized.
- The proposed model has the smallest mean error lower than 0.5 dB and achieves an improvement of 12% - 78% in the RMSE compared with empirical and statistical models.
- The validation shows that a satisfactory accuracy can be achieved by the presented model even based on the totally free raster data.

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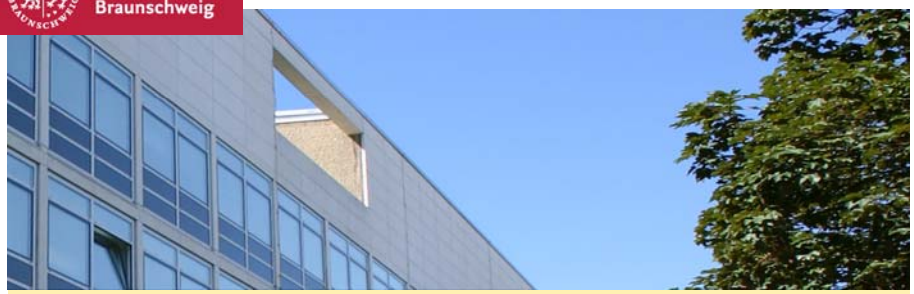
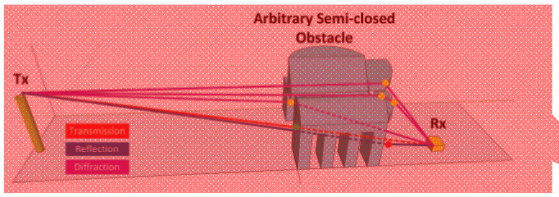
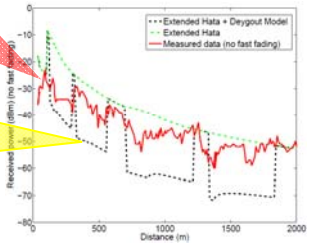


Empirical Modeling for Extra Loss of Semi-Closed Obstacles

Introduction

- What is the meaning of semi-closed obstacle?
  - semi-closed obstacles have some voids or free space among their components, and this allows certain line of sight, diffraction gain, and reflected waves to be obtained even when the receiver is inside, under, or behind the obstacle.





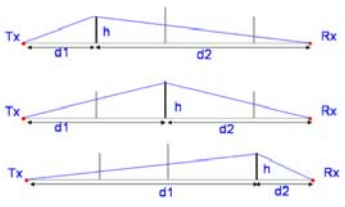
Closed Obstacles

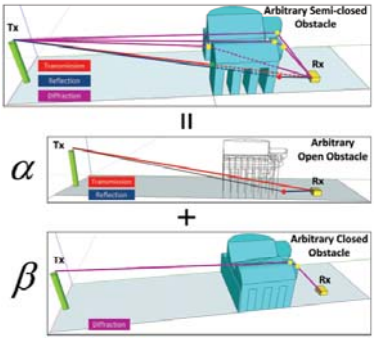
Introduction

- Examples of typical semi-closed obstacles in reality

General Model for the Extra Loss of Semi-Closed Obstacles

- Follow some inspirations from classical multi-edge diffraction models:
  - The total diffraction loss of the multi-edge case can be calculated by combining the diffraction of each sub-case of single-edge by using the single knife-edge model.



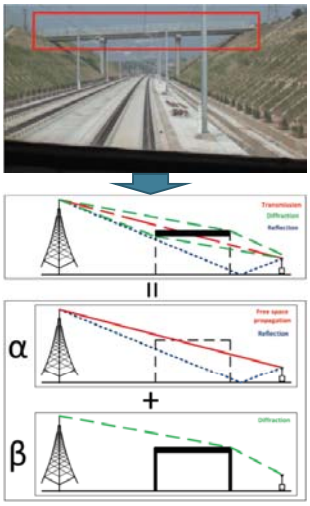


$$L_{Semi-closed} = \alpha_i \cdot L_{dif\_Open} + \beta_i \cdot L_{dif\_Closed}, \quad \alpha_i + \beta_i = 1$$

Implementation Process

- The propagation mechanisms differ along with the positional relationships of transmitter, obstacle, and receiver. Thus, propagation zones corresponding to different positional relationships should be divided firstly.
- A lot of factors (frequency, polarization, material, etc.) make the weight coefficients different in different propagation zones and applications. So, some small-scale measurements are still needed to estimate the weight coefficients in the concrete obstacles.
- In the completed research, the coefficients estimated by 3-4 crossing bridges can be used for the other dozens of bridges along high-speed railway; the coefficients extracted from 1 train station can be employed to predict the extra loss of other stations.

Concrete Model for the Extra Loss of Crossing Bridges



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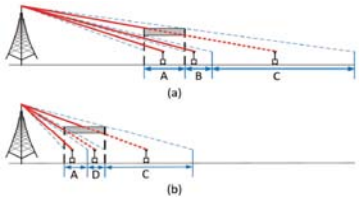

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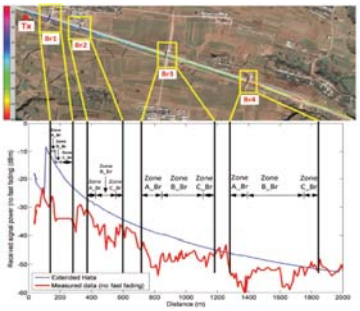
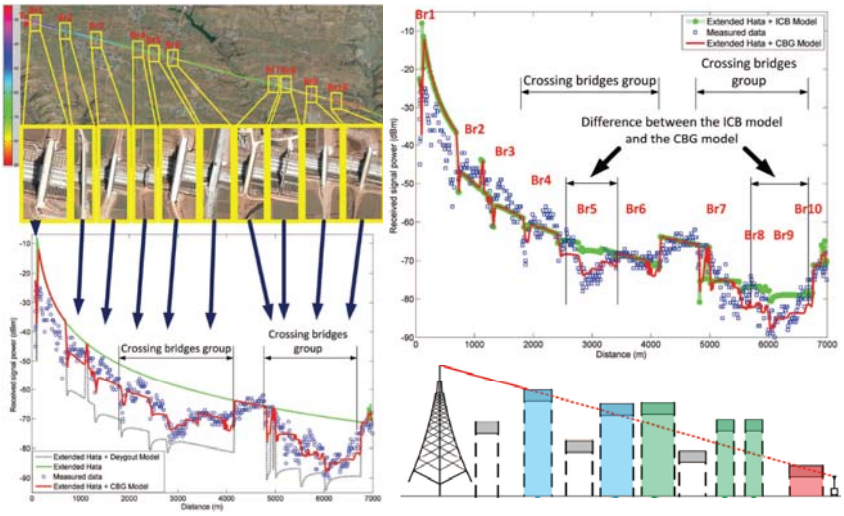
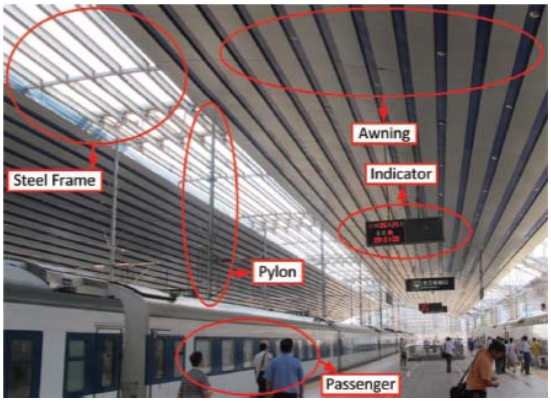


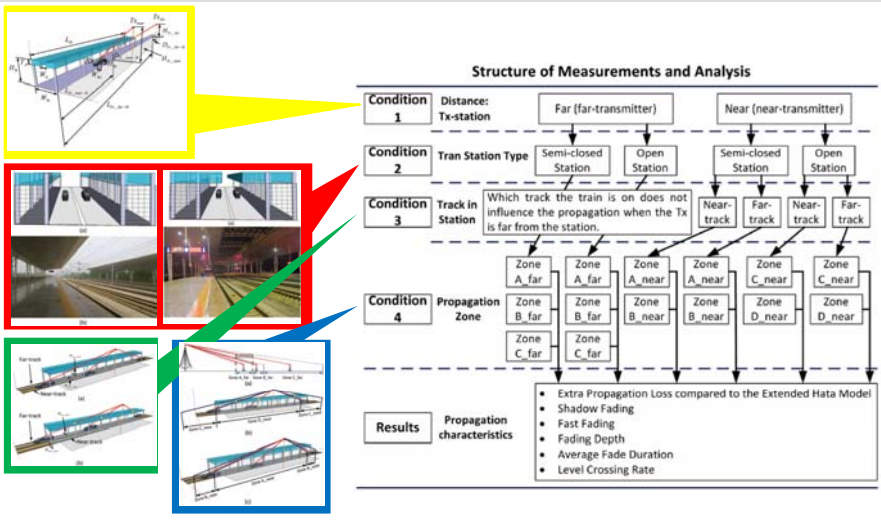
Concrete Model for the Extra Loss of Crossing Bridges



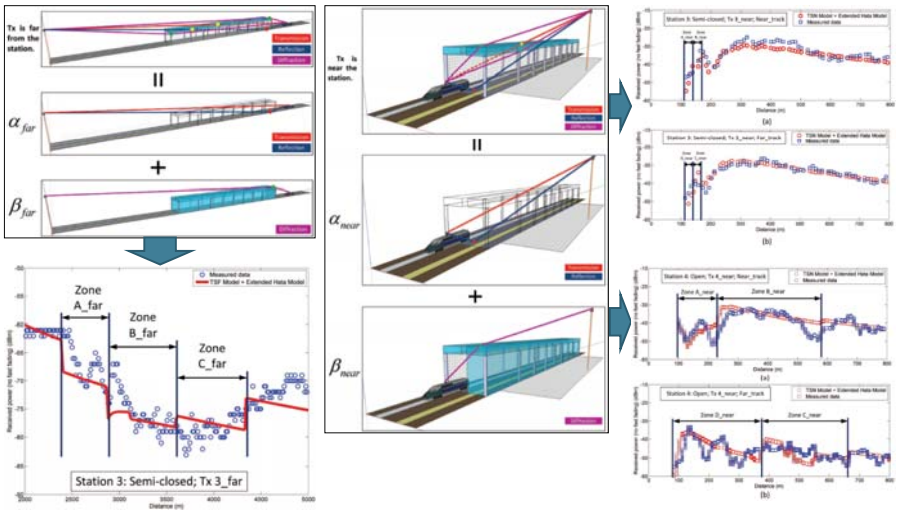
Concrete Model for the Extra Loss of Train Stations



Concrete Model for the Extra Loss of Train Stations

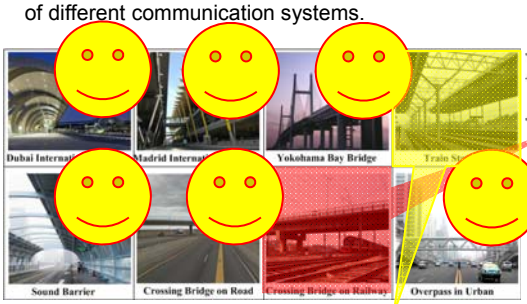


Concrete Model for the Extra Loss of Train Stations



Conclusion

- The two application cases indicate that the general model supports a simple way to estimate the extra loss of semi-closed obstacles.
- In the future, along with the increase of the coefficients extracted from various applications, more and more semi-closed obstacles will be involved in the network planning and design of different communication systems.



	Zone A_Br	Zone B_Br	Zone C_Br	Zone D_Br
α	0.51	0.68	0.55	0
β	0.49	0.32	0.45	1

Station	Type	Dis.: Tx-Station	Track	Mean Error (dB)	Std (dB)	RMSE (dB)
St. 3: Luo Yang Nan	Semi-closed	Far	-	0.53	3.84	3.88
St. 3: Luo Yang Nan	Semi-closed	Near	Near-track	1.61	2.71	3.15
St. 3: Luo Yang Nan	Semi-closed	Near	Far-track	0.88	2.99	3.12
St. 4: Ling Bao Xi	Open	Near	Near-track	1.80	3.30	3.76
St. 4: Ling Bao Xi	Open	Near	Far-track	0.36	4.09	4.10