Deutsche Telekom Laboratories

Dimension Analysis of Wideband-transmitted Speech

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Overview

- Measuring Speech Quality: Perceptual Approach
- Quality Dimensions of Wideband-transmitted Speech
  - Experiment 1: Multidimensional Scaling (MDS)
  - Experiment 2: Semantic Differential (SD)
  - Results
- Modeling Overall Quality
- Perceptually Motivated Degradation Indicators in P.OLQA
- Example: Frequency-related Degradation Indicator
- Summary and Outlook

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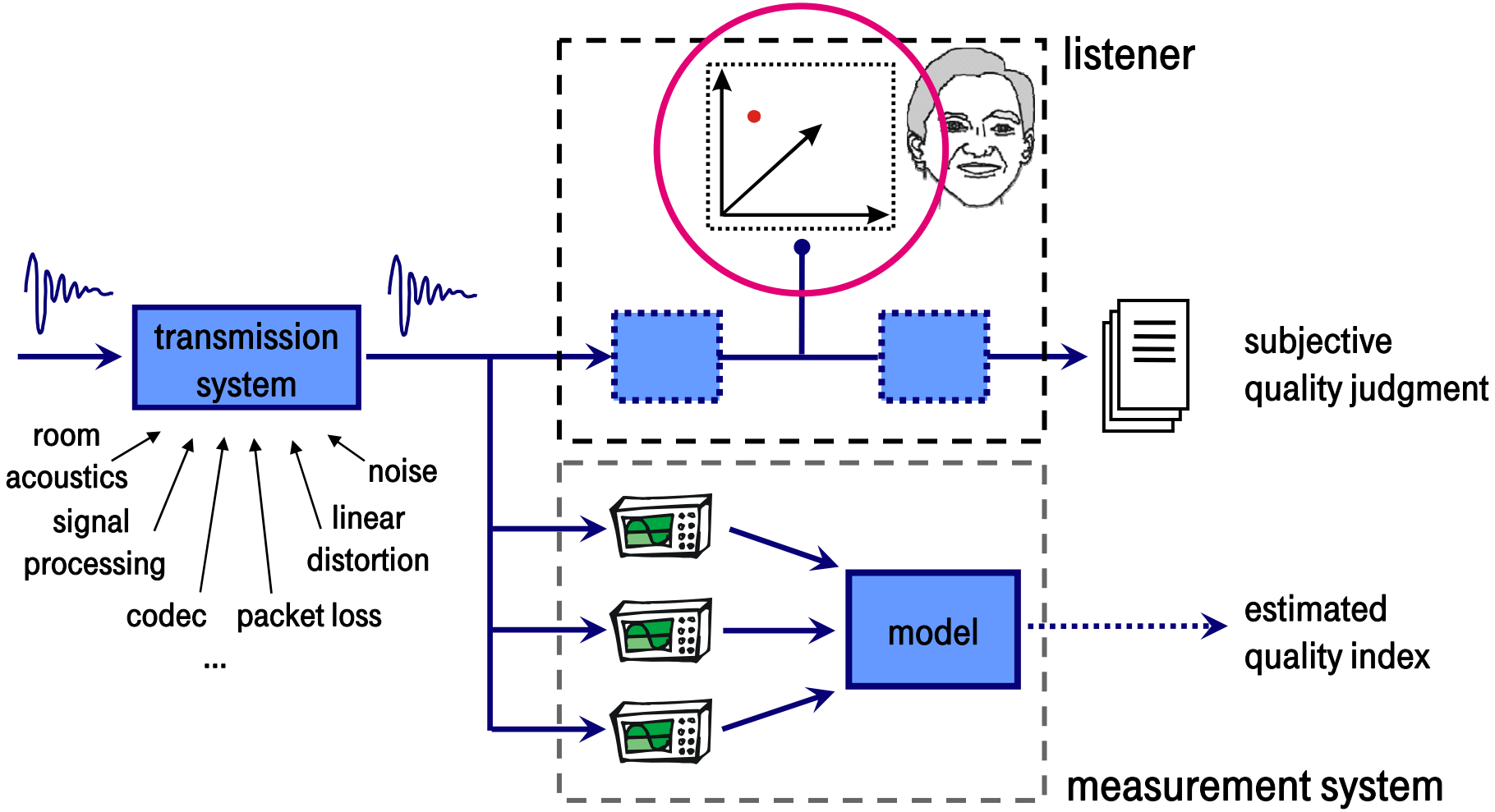
Measuring Speech Quality
Perceptual Approach



[Heute et al., 2005]

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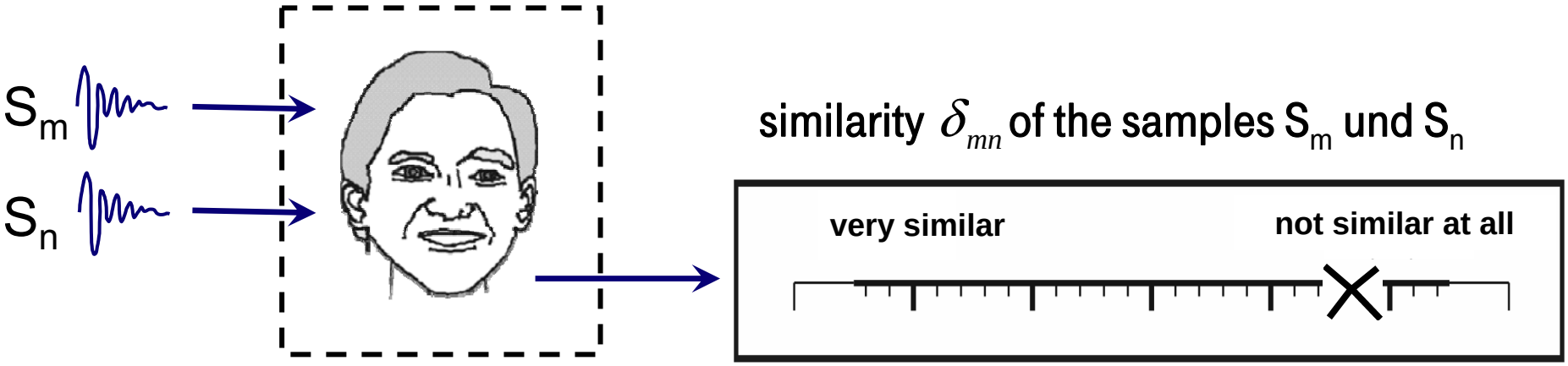
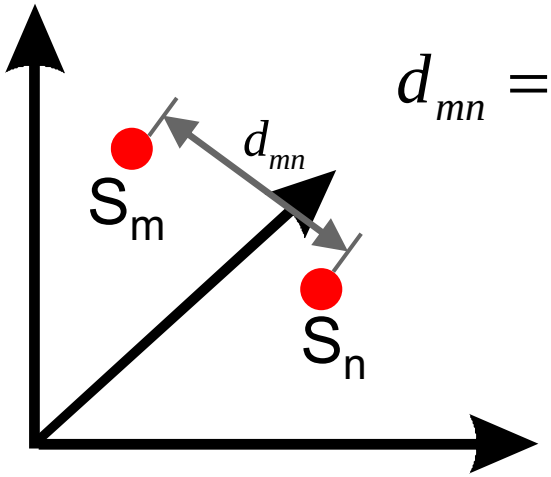
Experiment 1: Multidimensional Scaling (MDS)

Principle





$$d_{mn} = f(\delta_{mn})$$

determine dimensionality, so that

- $\sum_{mn,m\neq n}(\delta_{mn} - d_{mn})^2 \rightarrow \min$

- dimensions interpretable

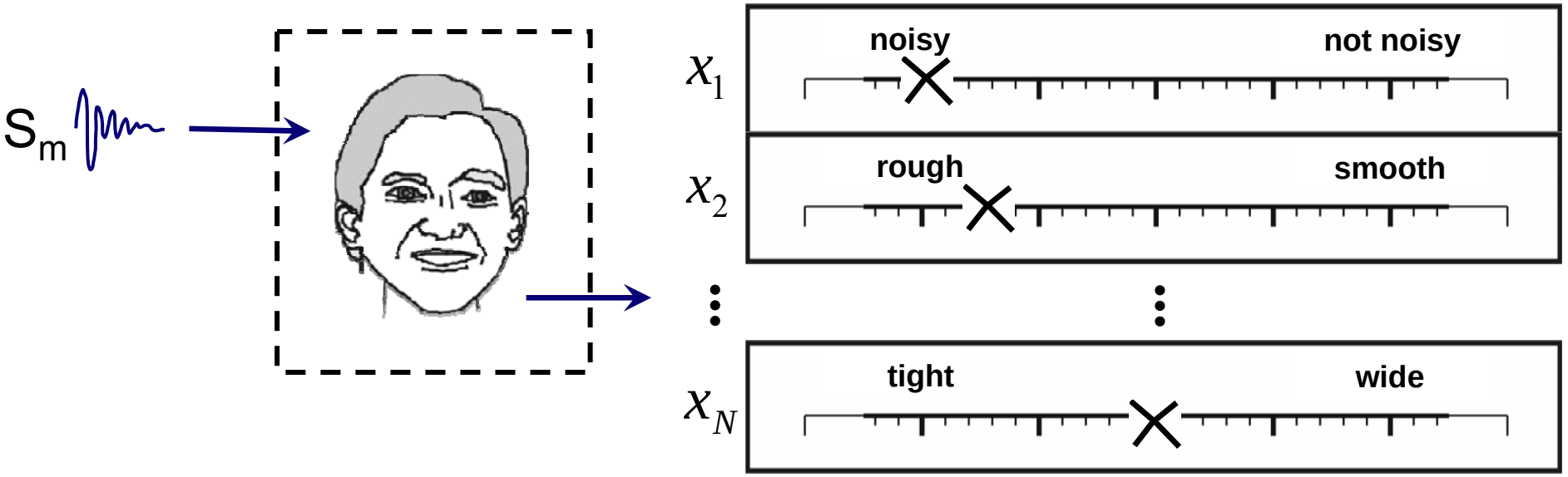
[Borg/Groenen, 2005]

Experiment 1: Multidimensional Scaling (MDS)
Details

- $I \cdot (I-1)$ pairs have to be judged, where I is the number of stimuli
- 2 speakers (male/female), $I = 14$, resulting in 364 judgments
- 19 participants (9 f, 10 m)
- INdividual Differences SCALing (rotationally invariant configuration)

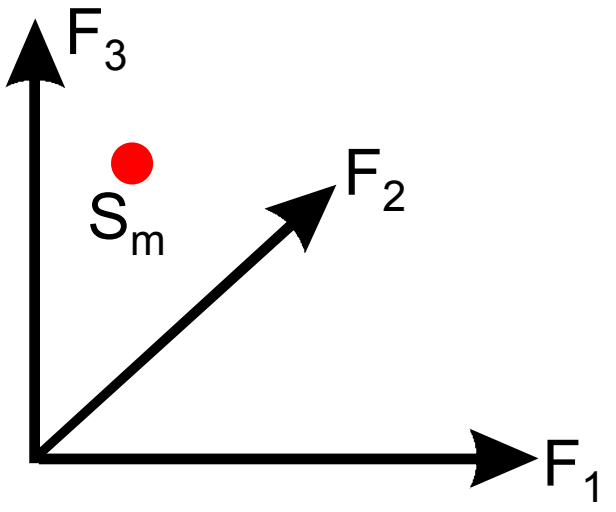
Experiment 2: Semantic Differential (SD)

Principle



[Osgood et al., 1957]

$$\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} \xrightarrow[M < N]{\text{factor analysis}} \begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_M \end{pmatrix}$$



Experiment 2: Semantic Differential (SD)
Details

- 2 pre-tests with 10 “experts“ (5 f, 5 m)
  - pre-test 1: Collection of descriptive terms
  - pre-test 2: Selection of perceptively salient antonyms out of a set of the most frequently named terms in pre-test 1
  - result: 28 Antonym-pairs for semantic differential
- 28 participants (13 f, 15 m), both “experts“ and naïve listeners
- 28 · *l* judgments, where *l* is the number of stimuli
- 2 speakers (male/female), *l*=14, resulting in 784 judgments
- no individual differences were taken into account
- PCA and VARIMAX rotation

Speech Samples

Abbreviation	WB/NB	Processing elements
CLEAN	WB	Direct channel
G7221	WB	G.722.1 @ 24 kbps
AMRWB	WB	AMR-WB @ 6.6 kbps
G711	NB	G.711
BP_N	NB	G.711, 0.5 – 2 kHz bandpass
BP_B	WB	0.1 – 5 kHz bandpass
HFT_NB	NB	Hands-free terminal
HFT_WB	WB	Hands-free terminal
NC	NB	G.711, additional circuit noise
HFT_WB_N	WB	Hands-free terminal, background noise
HFT_WB_NR	WB	Hands-free terminal, noise suppression
PL20_NB	NB	G.729A, 20% packet loss
PL20_WB	WB	AMR-WB @ 23.05 kbps, 20% packet loss
ABE	WB	G.711, artificial bandwidth enhancement

Pre-analysis of the MDS and SD data

General considerations

- between-subject factor *subject-group* is statistically not significant
- interpretation of male and female speaker solution is the same

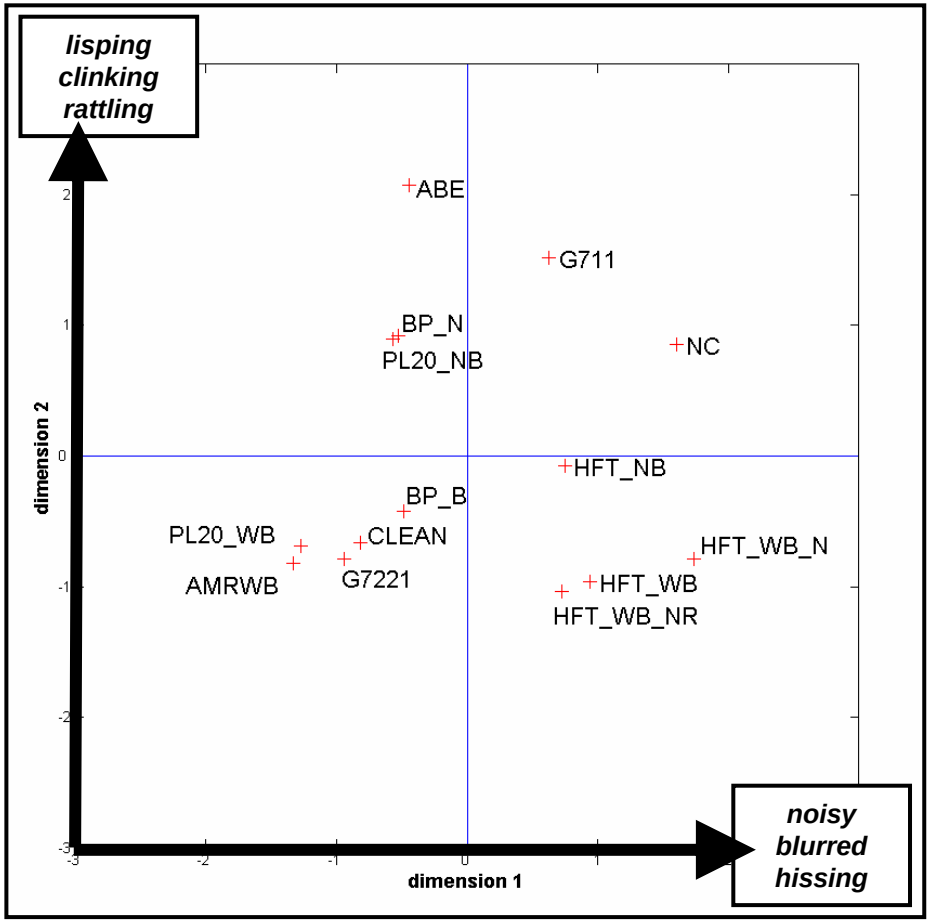
Dimensionality

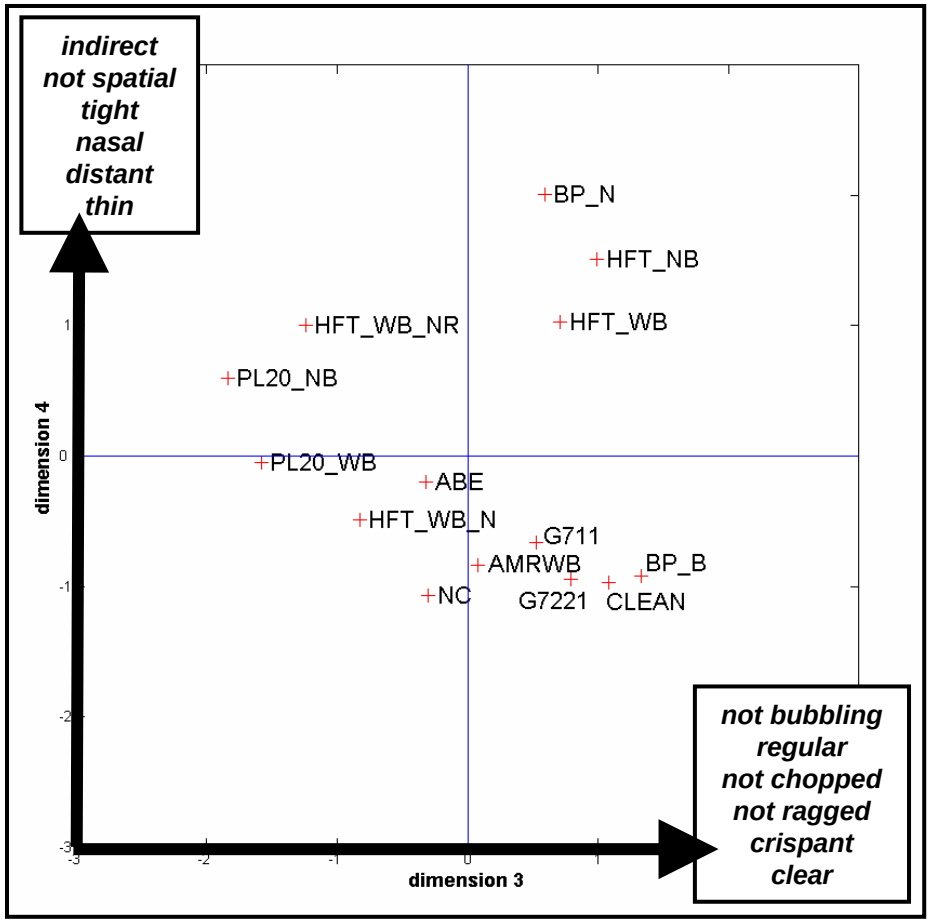
- MDS: 4-dimensional solution well interpretable (Stress = 0.19)
- SD: Kaiser criterion (eigenvalues of the correlation matrix >1) supports a 4-dimensional solution ($R^2 \approx 93\%$)

Comparison between SD and MDS solution

- mappings of the perceptual space highly resemble each other
- high correlations between single factors of SD data and dimensions of MDS data

Mapping of the Perceptual Space





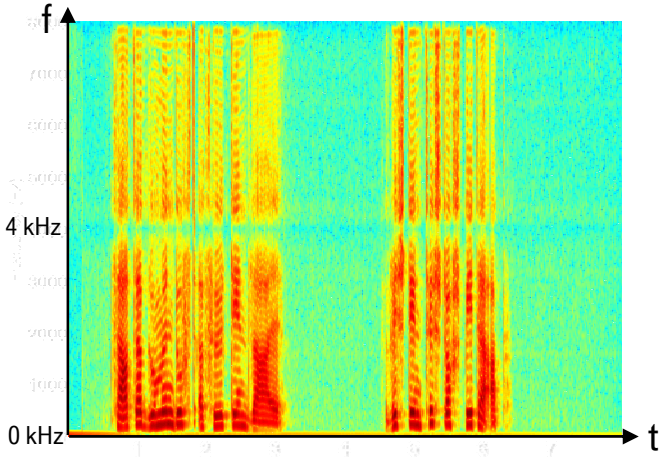
d_1: noisiness
d_2: frequency content/lisping

d_3: continuity
d_4: (in-)directness/distance

The Perceptual Attribute “Lisping”

“Continuity“, “noisiness“ and “directness“ have comparable counterparts in the narrowband-only case [Wältermann et al., 2006] however, “lisping“ does not!

“Lisping“ is the disability to pronounce sibilants properly, and instead replace them with interdentals



narrowband

artificial bandwidth enhancement

wideband

“Lisping“ can be interpreted as an **anomaly** or **lack** of high frequency components which are necessary for rendering sibilants correctly (more general label: “frequency content“)

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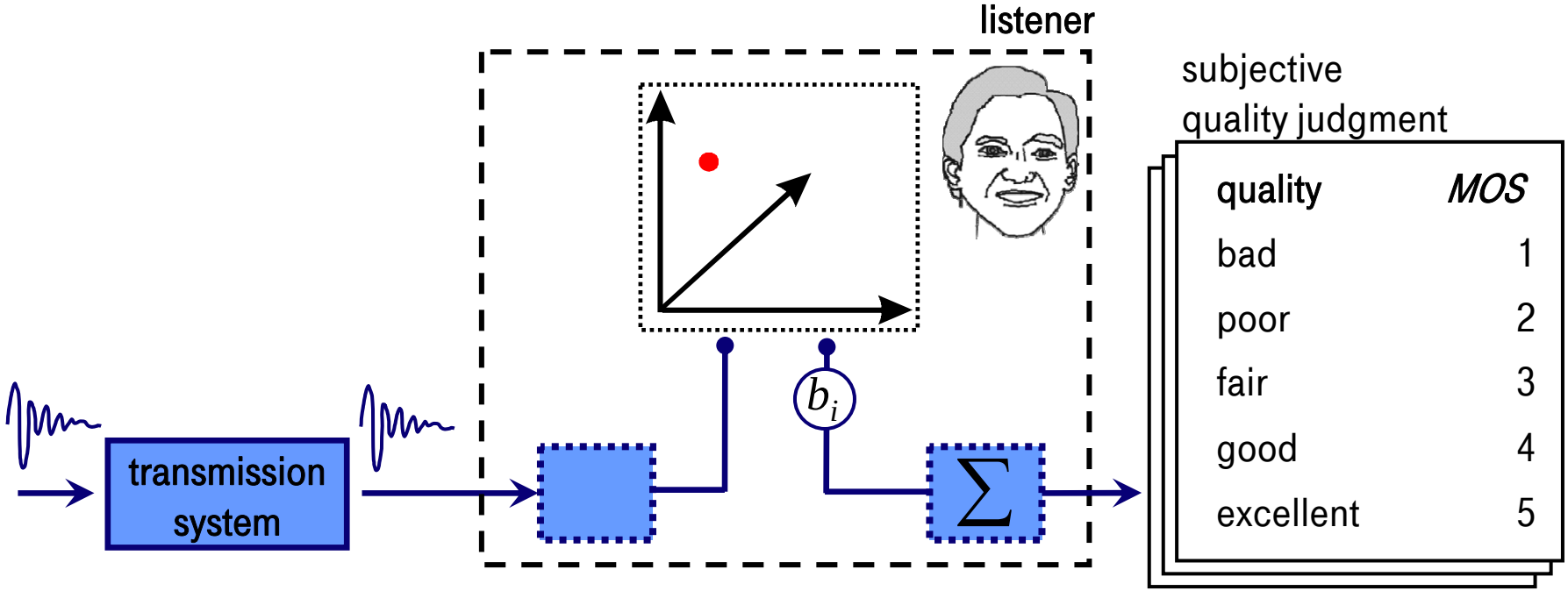
Modeling Overall Quality

Further experiment: Collecting overall quality judgments
Mapping of the dimensions onto Mean Opinion Scores (MOS)



dimension	b_i
noisiness	-0.13
frequency content/lisping	-0.14
continuity	0.78
(in-)directness/distance	-0.30

$$MOS = \sum_{i=1}^{4} b_i \cdot d_i$$

$R^2 \approx 75\%$

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Perceptually Motivated Degradation Indicators in P.OLQA

P.OLQA (Objective Listening Quality Assessment): Future objective quality measure standardized by ITU-T [ITU-T TD 12-57]

Optional feature: degradation indicators [ITU-T COM 12-4, 12-26, 12-53]

Perceptually motivated indicators provide:

- perceptually relevant degradations
- optional output for establishing a link to physical correlates
- proven perceptual orthogonality
- assignment of degradation types to indicators in the training and benchmark phase:
  - Frequency Content/Directness: Linear filters, room-acoustic effects
  - Noisiness: Additive noise, multiplicative noise
  - Continuity: Musical tones, error (packet loss) conditions

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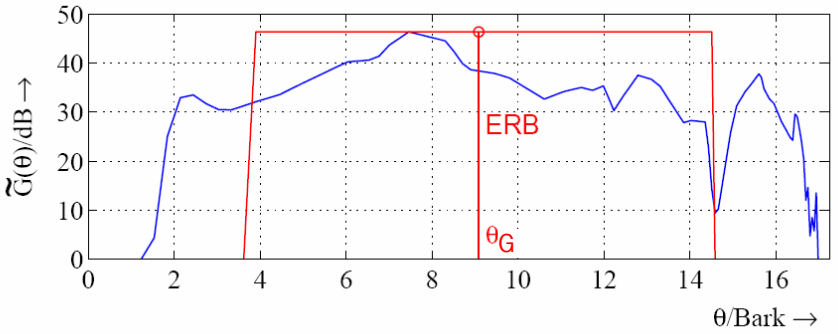
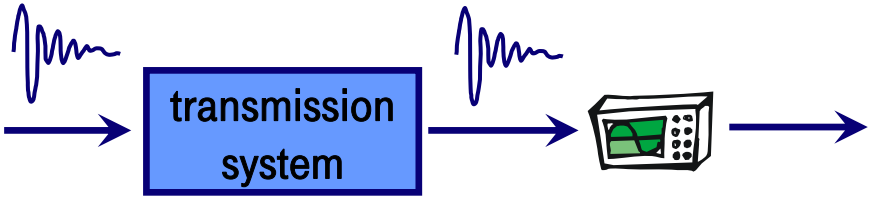
Example: Degradation Indicator "Frequency content"/"Directness"

Pilot Study: Exploit two simple physical parameters to capture the frequency-related dimensions



$$ERB = \frac{\text{area}\{\tilde{G}(\theta)\}}{\max\{\tilde{G}(\theta)\}} \qquad \theta_G = \frac{\int \tilde{G}(\theta)\cdot\theta\, d\theta}{\int \tilde{G}(\theta)\, d\theta}$$

$\tilde{G}(\theta)$ is the smoothed and bandlimited version of the gain function $G(\theta)$ of a system



$$\hat{d}_i = c_0 + c_1 \cdot ERB + c_2 \cdot \theta_G$$

$\hat{d}_2$: $|c_1| << |c_2|$

$\hat{d}_4$: $|c_1| >> |c_2|$

	d_1	d_2	d_3	d_4
r	0.64	**0.86**	0.48	**0.70**
RMSE	0.77	**0.51**	0.88	**0.71**

cf. [Scholz et al., 2005]

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Summary and Outlook

Perceptual approach for **wideband speech quality** measurement.

For the considered set of speech files,

4 speaker-independent dimensions could be identified:

- continuity
- (in-)directness/distance
- frequency content/lisping
- noisiness

Perceptual dimensions provide a means for defining degradation indicators in standardization process of a new objective quality measure.

Example for frequency-related dimension estimator/degradation indicator

Transition from NB to WB is not necessarily enough in order to provide a better quality in telephony!

Exploratory analysis! Increase of resolution of single dimensions needed.

Thank you!

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