Does PMSE waste spectrum? – A balanced view from a Scientist in Communications and Cellular

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Lehrstuhl für Technische Elektronik

Making Bits Fly

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Content

1. Speakers background
2. Basic communications model
3. Source coding
4. Digital versus analogue transmission
5. What is so unique with PMSE?
6. Wireless traffic growth
7. Spectrum considerations
8. Conclusion

1. Speakers background

- *Prof. at University Erlangen-Nuremberg*
- *History in Basestation technology, Cellular, Standardization, Regulation*
- *Erlangen known for MP3 / Fraunhofer IIS /Audiolabs*
- *Starting point for “balanced view”*

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Speakers Background
Experience

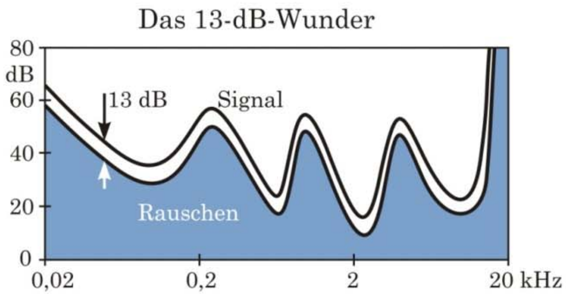
Prof. Georg Fischer (geb. 1965)

1986-1992	Study of Electrical Engineering at RWTH Aachen (Aix La Chapelle) Focus on Communications , Radio Technology, Field Theory
1993-1996	Research assistant at University of Paderborn
1997	Dr.-Ing., Thesis „Adaptive Antenna Arrays for mobile satellite reception“
1996-2008	Lucent, later Alcatel-Lucent, Bell Labs Research Research on Basestation RF Technology
	2000 Bell Labs DMTS (Distinguished Member of Technical Staff)
	2001 Bell Labs CMTS (Consulting Member of Technical Staff)
	Chairman of ETSI SMG2 WPB EDGE
2001-2007	Part time Lecturer at University of Paderborn
April 2008	University of Erlangen-Nürnberg Prof. for Electronics Engineering Research on Cognitive Radio, Frequency Agile Radio, Analog-Digital Balance
Since 2010	ETSI STF 386 Chairman ***„Methods, parameters and test procedures for cognitive interference mitigation techniques for use by PMSE devices”***
Since 2010	Reviewer for EC FP7, COST, DFG, NSERC, IWT Flandern, Helmholtz Society

Speakers Background

Roots of MP3

Chair is the birthplace of MP3 Audio Compression, commercialized by Fraunhofer



D. Seitzer
Datenreduktion
Bilder, Sprache, Musik
Mikroelektronik

K. H. Brandenburg
Effiziente Kodierung
Messung der
subjektiven Qualität

H. Gerhäuser
Signalprozessoren
Echtzeit-Codierung

Bitscheibenprozessor
für erste Echtzeit-
Codierung 1980

Grundlagenforschung am Lehrstuhl
für Technische Elektronik
1970 - 1987

Making Bits Fly

Audio Labs

- A joined activity of Fraunhofer IIS and University of Erlangen-Nürnberg

International Audio Laboratories Erlangen

Deutsche Webseite Contact Impressum Search

You are here: Home Structure

- Home
- About
- Mission
- Research
- Studies and Teaching
- **Structure**
  - Employees
- Career
- Press
- Contact

Fraunhofer IIS

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Structure

The International Audio Laboratories Erlangen (AudioLabs) was founded in August 2008 as a joint institution of Fraunhofer IIS and University of Erlangen-Nürnberg. This research center enables university scientists to develop new technologies for digital processing of multimedia content with Fraunhofer IIS staff and visiting researchers from around the world. The collaborative venture is intended for at least ten years. Creative synergies between researchers from several disciplines, combined with the many years of audio compression experience at Fraunhofer IIS, will drive future research topics and guarantee continuous innovations.

Appointed professors:

Prof. Dr. Juergen Herre (Audio Coding)
Prof. Dr. Bernd Edler (Audio Signal Analysis)
Prof. Dr. Emanuel Habets (Perception-based Spatial Audio Signal Processing)

Executive board:

Prof. Dr. Albert Heuberger (Speaker)
Prof. Dr. Jürgen Herre (Representative University of Erlangen Nürnberg)
Dr. Bernhard Grill (Representative Fraunhofer IIS)

Research Coordination:

Dr. Frederik Nagel

Coordination:

Dr. Stefan Turowski

Founded July 2008

2. Basic communications model

- *We define what is "information"*
- *We identify irrelevant information*
- *What is meant by spectrally efficient?*

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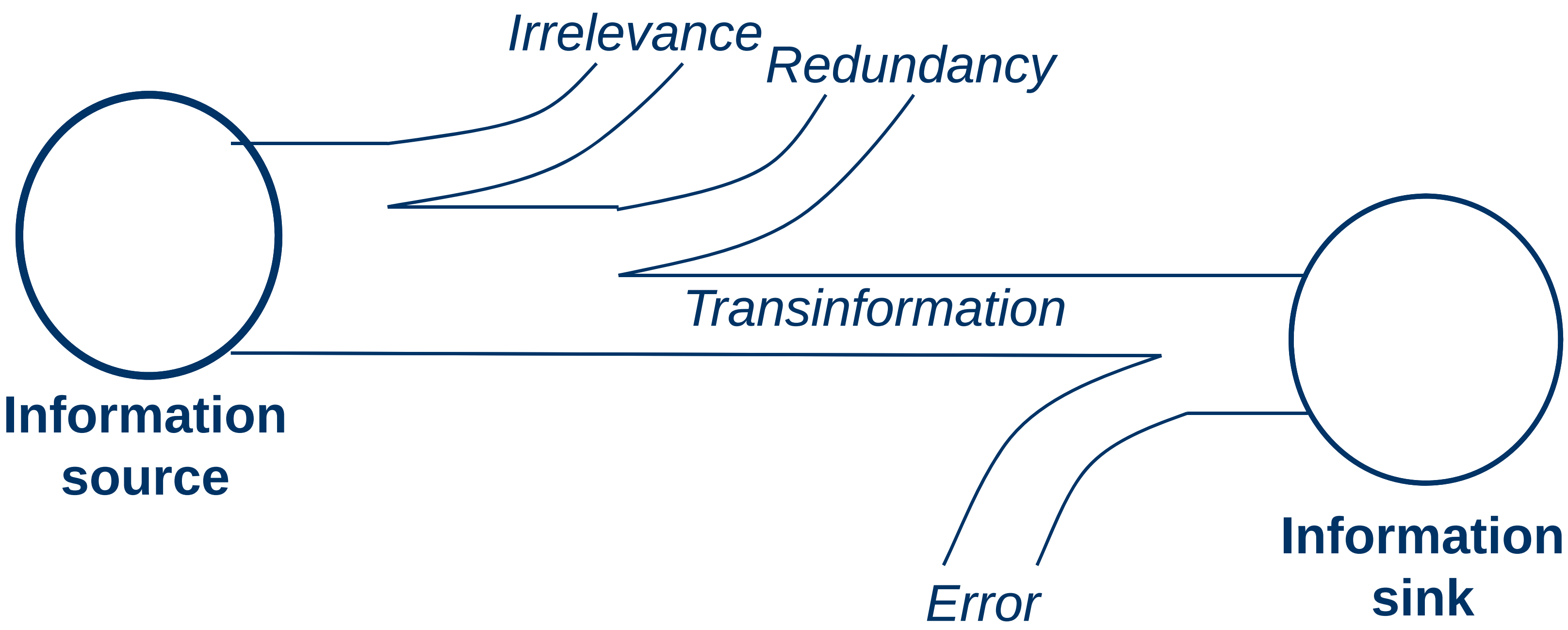
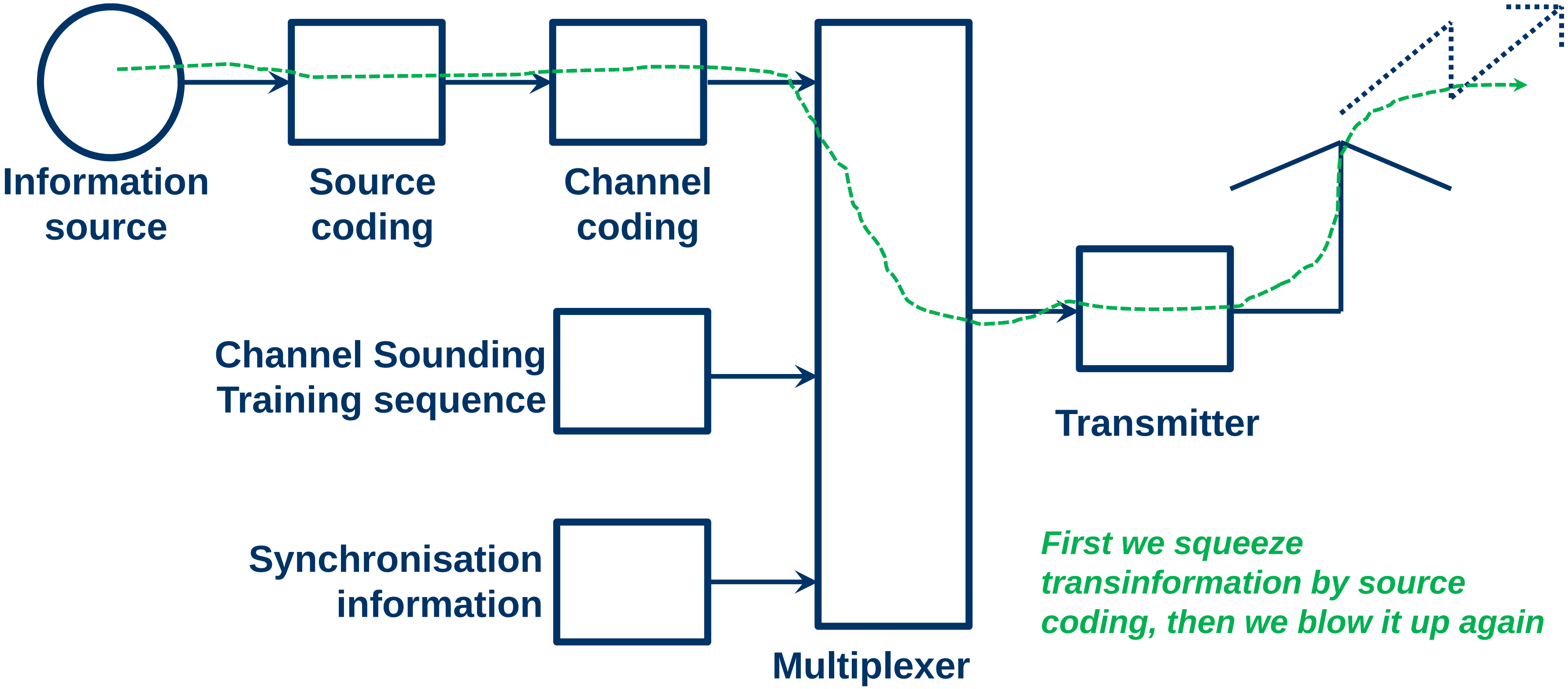
Model

- Information from a communication source is sent to a communication sink
- Goal is to minimize Transinformation
- Only Transinformation is transported over a wireless connection
- Amount of Transinformation=spectrum need



Basic communications model
Flux of Data



There is more than Transinformation

- Supporting equalization of wireless channel by adding fixed trainings sequences
- Addition of synchronisation information
- Channel coding to make transmission more robust, increasing data
- Overhead by digital transmission

3. Source coding (Compression)

- *By compressing data we save spectrum*
- *But we trade compression versus quality*

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Source Coding

What flavours?

Lossless coding

- Only redundancy is stripped off
- Original information can be fully reconstructed – waveform conservative
- Has to be used if receiver is not known (irrelevance can not be identified)
- Examples: ZIP, mp3HD (lossless mode), HD-AAC (lossless mode)
- Always variable rate, Compression ratios limited, depend on content
- variable spectrum consumption

Near lossless

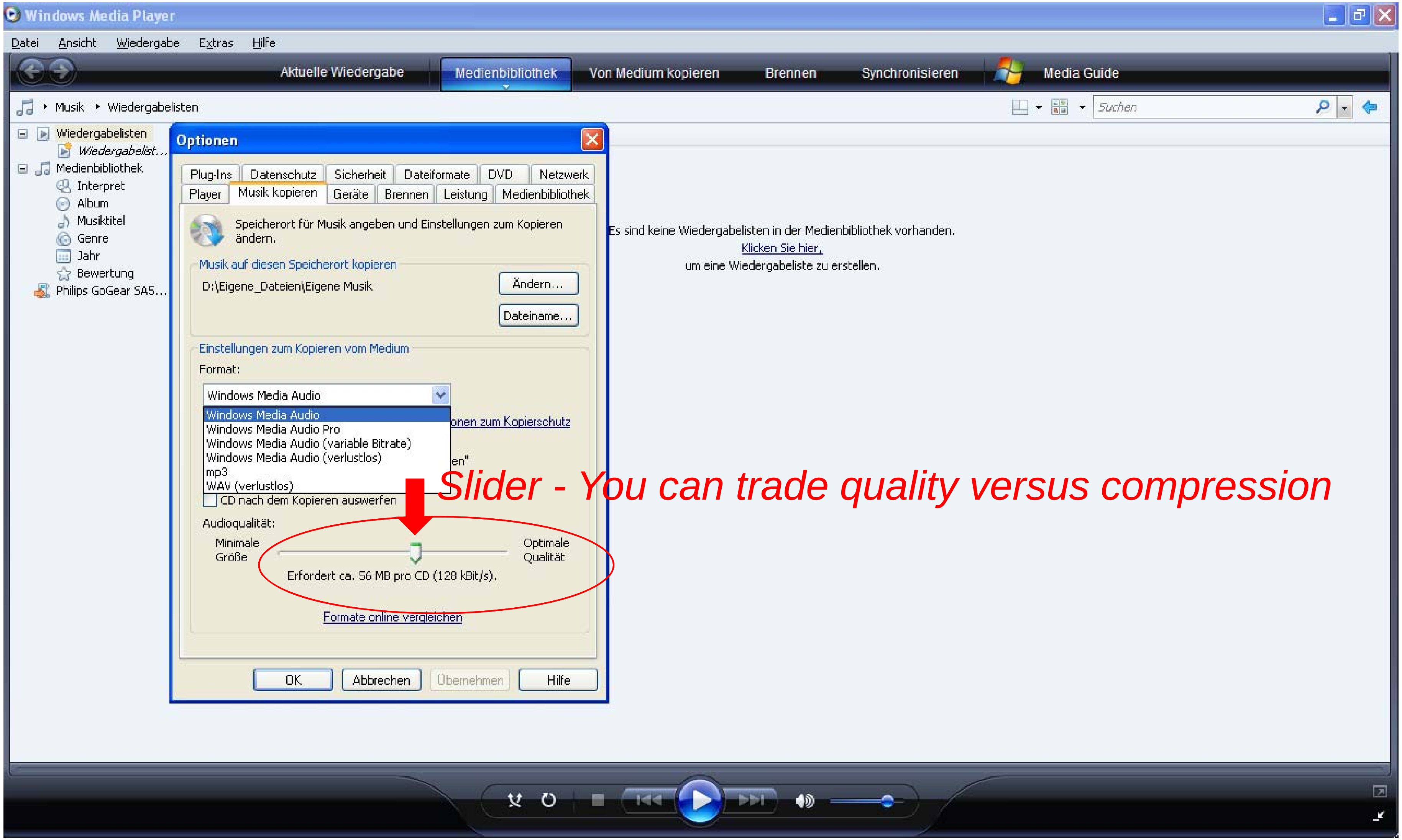
- Nearly reversible, but not appropriate for studio quality
- Examples: mp3HD, HD-AAC, ULD (Ultra Low delay)
- SLQ Spheric Logarithmic Quantization (by Prof. Huber, FAU), Vector Quantization
- Compression ratios limited (8...4:1)

Lossy coding

- Redundancy and Irrelevance is stripped off
- Original information cannot be gained back - irreversible
- Coding has to know what is irrelevant at communication sink
  (Somebody else decides what details are relevant for the consumer or not...)
- Highest compression ratios possible
- Usage of psychoacoustic and psychovisual effects
- Examples: Audio MP3 / Video MPEG, DVB-T/C/S

Source Coding

Examples



Windows Media Codecs

Codec Descriptions

The following table describes the intended uses of the Windows Media codecs.

Codec	Description
Windows Media Audio	An audio codec that supports three categories of encoded content: Standard, Professional, and Lossless.
Windows Media Audio Voice	Audio codec optimized for encoding the human voice at high compression ratios. This is the preferred codec for streams consisting mostly of spoken words. For content that is mixed music and speech, this codec can dynamically change the encoding algorithm used, to get optimal quality.
Windows Media Video 9	A video codec that supports four categories of encoded content: Simple Profile, Main Profile, Advanced Profile, and Image..
Windows Media Video 9 Screen	Video codec optimized for encoding sequential screen shots from computer monitors. This codec is often used for software training or support by recording monitor images while computer applications are being used.

Source Coding

Examples

Audio

- CD: 500 Mbyte
- 10 Tracks → 50 Mbyte per Audio file
- Apply MP3 high compression 1 Mbyte,
- lossy source coding
- Compression Ratio: 50:1

Motivation:
The higher the compression, the less spectrum is needed…

GSM Speech

- Microphone signal: 8 kSa/s x 13 bit =104 kbit/s
- EFR 12 kbit/s, Compression 9:1
- AMR 4,75 kbit/s, Compression 22:1

Actual Analog PMSE

- Analogue Compander System (an analogue source coding)
- Compression 2:1 (equivalent)

SLQ (Spheric Logarithmic quantization)

- Near lossless audio codec, only stripping off redundancy, no irrelevance identification
- 16 bit down to 2..4 bit per sample
- Compression ratio typ. 4:1, max 8:1
- Not too much...

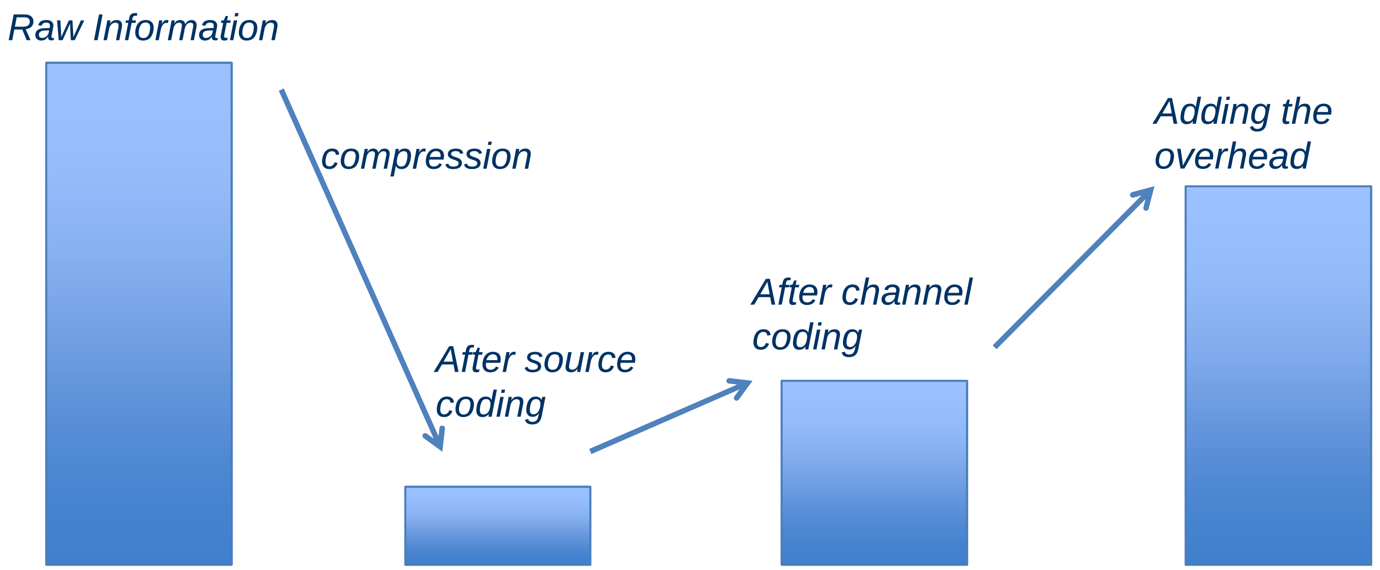
4. Digital versus analogue transmission

- *We compare analogue and digital transmission*
- *Digital allows for scalability of quality, so not always better quality*
- *We have to pay a price for digital transmission – signalling overhead*

Digital versus Analogue transmission
A balanced view

Common misunderstanding
- Digital is better! - wrong
- It can be better, but it also can be worse
- Digital just allows for scalable quality

Digital transmission
- First we apply source coding - we squeeze information, we compress maximal
- Than we blow up by putting on top channel coding to protect digital data
- We pay a further price by signalling overhead (protocol, Training symbols)



Digital versus Analogue transmission

Impact of coding languages

Overhead

- Programming language implies a lot of overhead
- This is waste of spectrum

Quelle: http://code.google.com/p/thrift-protobuf-compare/wiki/BenchmarkingV2

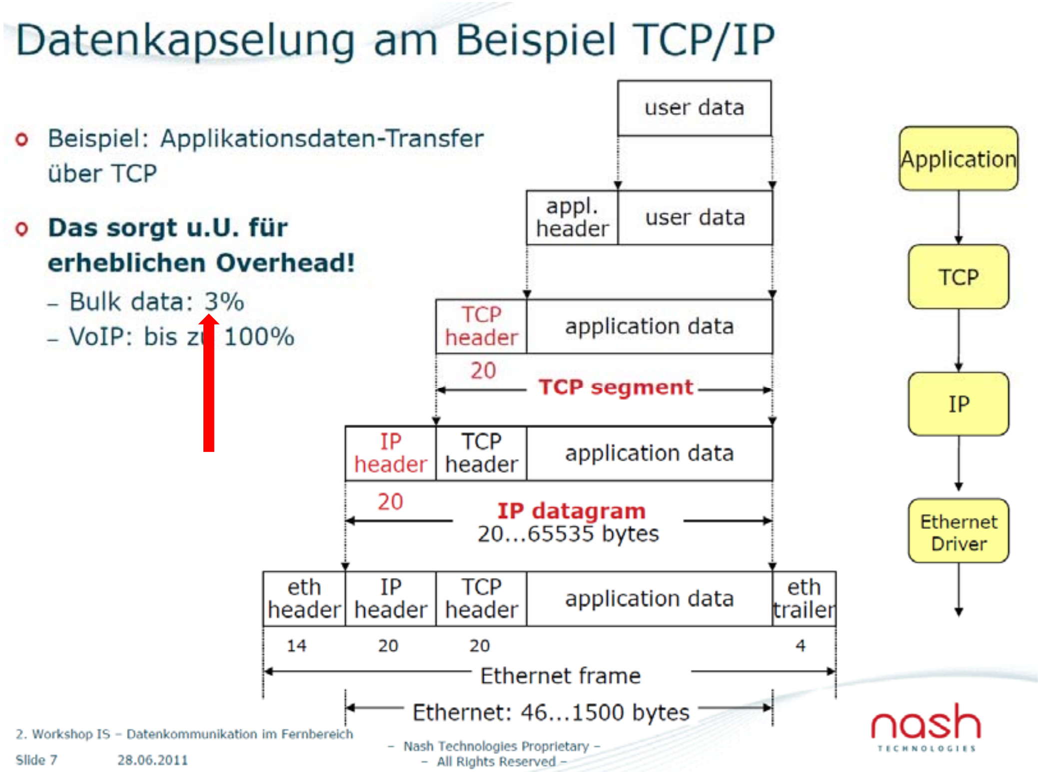
Digital versus Analogue transmission

Impact of protocol stacks

Overhead

- Example VoIP (Voice over IP)
- VoIP=raw voice data x33

Factor 33 overhead !



5. What is so unique with PMSE?

- *There are distinct differences to other systems*
- *PMSE cannot simply take over established solutions from cellular*

What is so unique with PMSE?

Specifics

Latency

- For High Quality low latency required, < 5 ms round trip
- Dilemma: Information source and sink are at identical location
  - Drummer has wireless microphone and wireless In Ear monitor
  - Situation totally different from other wireless systems
- Landline telephone 200 ms
- LTE record today 18 ms demonstrated in Stuttgart area by Alcatel-Lucent
- Analysis of raw data with lossy source coding introduces latency

Battery operation

- Wireless equipment part of costume, should be invisible
- Today analog FM, constant envelope modulation friendly for PA
- Digital Modulations typically have Crest (Amplitude variation)
- Digital CPM (Continous Phase modulation) could cope
- Source coding at wireless microphone also would cost battery power, but Moore’s law works for you

What is so unique with PMSE?
Specifics

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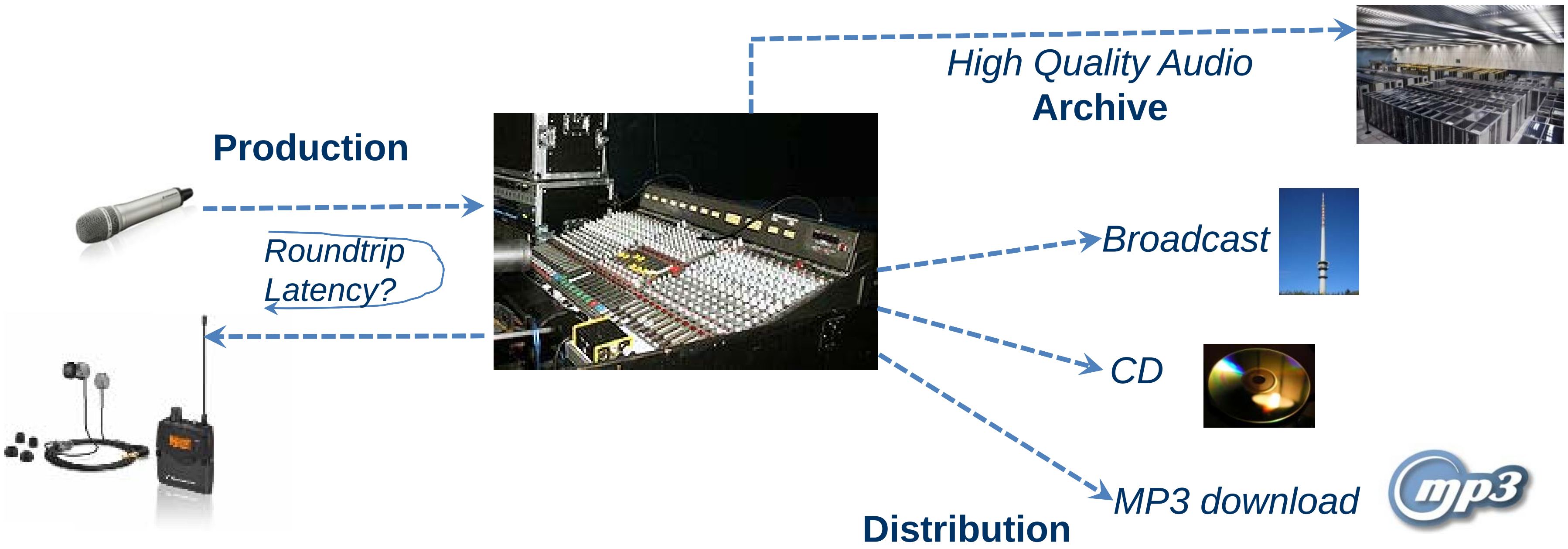
Cascade of source coders

- Two communication links involved (Production+Distribution)
- Cascade of two lossy compression schemes leads to audible artefacts
- Only solution, use lossless coding on production link
- During production you don't know distribution, so irrelevance cannot be identified
- Therefore only lossless source coding can be used
- Compression factors limited, sufficient spectrum necessary



6. Wireless traffic growth

- *Traffic is growing exponentially in Cellular and PMSE*
- *Spectrum is a limited natural resource - How to cope with it?*
- *How can needs by cellular be served?*

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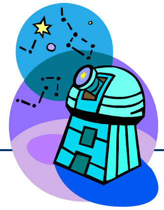
Wireless traffic growth

What will the future bring us?



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Wireless traffic growth

- Moore’s law: Integration density of microelectronics doubles every 2 years
- Edholm’s law: Datarates are as predictable as Moore’s law (CTO Nortel)
- D. Poppen E-PLUS CTO: We see 30x in 5 years equal doubling every year

Channel coding / Transmission schemes

- We are already near the theoretical Shannon Bound *(BPSK with Turbo Codes 0.2 dB)*
- No wonders will come!

Source Coding - lossy

- There is still room for improvement
- However the analysis of raw information requires processing – latency problem
- Knowledge on recipient necessary
- Higher compression will come

Source coding - lossless

- Not widely used due to low compression factors
- However, an Option for digital PMSE
- Compression factor will keep limited

So how to cope with increased traffic ????

Wireless traffic growth
Evolution of Cellular

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LTE (Long Term Evolution)

- Claims x2.4 improvement in spectral efficiency
- Gain x2 is coming mainly from 2x2 MIMO
  (2 Antennas at basestation and 2 and terminal)
- Net Gain by transition from UMTS to LTE x1.2 - what an effort...

What options are there to boost networks?

- MIMO - will we see 4x4 ???
- Network MIMO – coordinated Multipoint
- Source Coding!! ... obviously lossy source coding
- Carrier Aggregation – bundling spectrum, that is here and there
- Flexible Active Antenna Arrays – see Alcatel-Lucent LightRadio
- Network densification
- Femto Basestations (See e.g. EU FP7 BEFEMTO and FREDOM Project)

What is Network Capacity?

- Information theory wise it is just transinformation
- But you are thinking in terms of number of services offered inside given spectrum
- Lossy source coding will enlarge number of services but not the transinformation

Wireless traffic growth
Evolution of Cellular

LTE (Long Term Evolution)
- Claims x2.4 improvement in spectral efficiency
- Gain is coming mainly from 2x2 MIMO *(2 Antennas at basestation and 2 and terminal)*
- Net Gain by transition from UMTS to LTE x1.2 → so +20%, what an effort...

What options are there to boost networks?
- MIMO - will we see 4x4 ???
- Network MIMO – coordinated Multipoint
- Source Coding!! ... obviously lossy source coding
- Carrier Aggregation – bundling spectrum, that is here and there
- Active Antenna Arrays – see Alcatel-Lucent “LightRadio”
- Network densification, new basestation sites
- Femto Basestations (e.g. EU projects BEFEMTO, FREEDOM)

Source: Bell Labs

What is Network Capacity?
- Information theory wise it is just transinformation after source coding
- But you are thinking in terms of number of services offered
- Lossy source coding will enlarge number of services but not the spectral efficiency

It is impossible to cope with an exponential traffic growth just by adding more spectrum

It is a hydra....

Do you know the fairy tale?
1 rice corn on the first field, then 2, 4, 8,16, 32, 64, 128, 256, 512...

7. Spectrum considerations

- *We show that PMSE transmission is more spectrally efficient than UMTS*
- *We identify the monetary value of spectrum*

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Spectrum considerations
Comparison PMSE versus Cellular

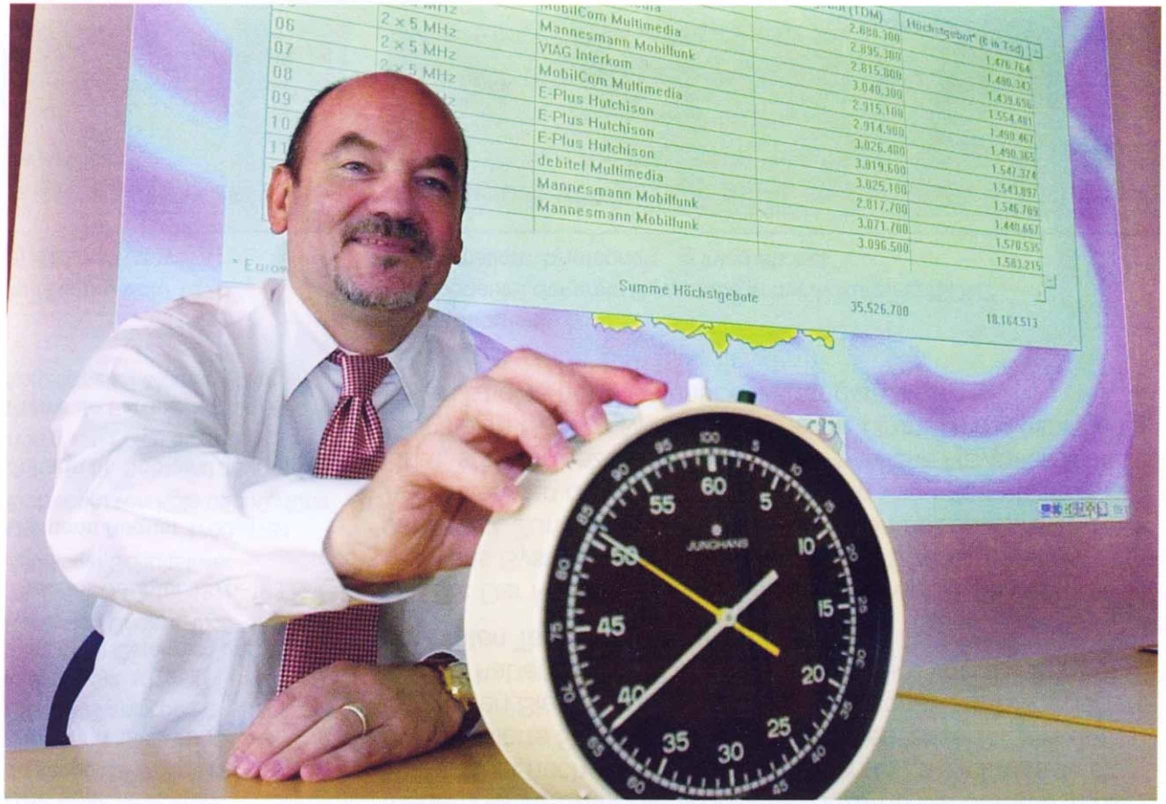
	PMSE	Cellular / UMTS
Audio Quality	High for content production	Only speech
Audio rate	CD: 44 kSa/s, 16 bit 704 kbit/s	8 kSa/s, 13 bit (EFR-codec) 104 kbit/s
Compression	Analogue compander 2:1	Digital source coding 9:1 (22:1 with AMR)
Compressed Audio rate	352 kbit/s	12 kbit/s
Channel arrangements	15 channels in 20 MHz	75 channels in 5 MHz
Raw Audio related spectral efficiency	0.5 bit/s/Hz	1.56 bit/s/Hz
Compressed Audio related spectral efficiency	0.25 bit/s/Hz	0.18 bit/s/Hz

Findings

- Today's analogue PMSE slightly more spectrally efficient than cellular
- PMSE is not a waster of spectrum - in light of high audio quality to be delivered
- Cellular high number of services mainly a consequence of heavy source coding
- Analogue PMSE already contains analogue source coding 2:1
- Near lossless Audio coding (e.g. SLQ) could do 4:1, not a dramatic gain to draw from digitization, but not HD

Spectrum considerations

What is the value of spectrum? – Legendary UMTS Auction



17. August 2000: Versteigerung der deutschen UMTS-Mobilfunklizenzen für fast 100 Mrd. DM *(Foto: Matthias Kurth von der Regulierungsbehörde für Post und Telekommunikation nach der 106. Versteigerungsrunde in Mainz)*

Value of spectrum: 98.8 Mrd DM for 60 MHz paired

⇒ 1,6 Milliarden DM/MHz

⇒ 800 Mil€/MHz

Spectrum considerations

What is the value of spectrum? – Recent UHF auction

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Auktionsrundenergebnis

Ende der Auktion

Frequenzbereich	Block	Ausstattung	Höchst-bieter	Höchstgebot (€ in Tsd)
0,8 GHz (gepaart)	0,8 GHz A	2x5 MHz konkret	To2 GER	616.595
	0,8 GHz B	2x5 MHz abstrakt	To2 GER	595.760
	0,8 GHz C	2x5 MHz abstrakt	Telekom D	570.849
	0,8 GHz D	2x5 MHz abstrakt	Telekom D	582.949
	0,8 GHz E	2x5 MHz abstrakt	Vodafone	583.005
	0,8 GHz F	2x5 MHz abstrakt	Vodafone	627.317
1,8 GHz (gepaart)	1,8 GHz A	2x5 MHz abstrakt	Telekom D	20.700
	1,8 GHz B	2x5 MHz abstrakt	Telekom D	20.700
	1,8 GHz C	2x5 MHz abstrakt	Telekom D	19.869
	1,8 GHz D	2x5 MHz konkret	E-Plus Grp	21.550
	1,8 GHz E	2x5 MHz konkret	E-Plus Grp	21.536
2,0 GHz (gepaart)	2,0 GHz A	2x4,95 MHz konkret	Vodafone	93.757
	2,0 GHz B	2x4,95 MHz konkret	E-Plus Grp	103.323
	2,0 GHz C	2x4,95 MHz konkret	E-Plus Grp	84.064
	2,0 GHz D	2x4,95 MHz konkret	To2 GER	66.931
2,0 GHz (ungepaart)	2,0 GHz E	1x5 MHz konkret	To2 GER	5.731
	2,0 GHz F	1x14,2 MHz konkret	To2 GER	5.715

Ausgeschiedene Bieter:

Frequenzbereich	Block	Ausstattung	Höchst-bieter	Höchstgebot (€ in Tsd)
2,6 GHz (gepaart)	2,6 GHz A	2x5 MHz abstrakt	Telekom D	19.096
	2,6 GHz B	2x5 MHz abstrakt	Telekom D	19.025
	2,6 GHz C	2x5 MHz abstrakt	To2 GER	17.364
	2,6 GHz D	2x5 MHz abstrakt	To2 GER	17.364
	2,6 GHz E	2x5 MHz abstrakt	Vodafone	18.948
	2,6 GHz F	2x5 MHz abstrakt	Vodafone	19.025
	2,6 GHz G	2x5 MHz abstrakt	Telekom D	19.069
	2,6 GHz H	2x5 MHz abstrakt	Telekom D	19.038
	2,6 GHz I	2x5 MHz abstrakt	To2 GER	18.948
	2,6 GHz J	2x5 MHz abstrakt	E-Plus Grp	18.931
	2,6 GHz K	2x5 MHz abstrakt	E-Plus Grp	17.739
	2,6 GHz L	2x5 MHz abstrakt	To2 GER	17.739
	2,6 GHz M	2x5 MHz abstrakt	Vodafone	17.739
	2,6 GHz N	2x5 MHz abstrakt	Vodafone	17.752
2,6 GHz (ungepaart)	2,6 GHz O	1x5 MHz abstrakt	Vodafone	9.130
	2,6 GHz P	1x5 MHz abstrakt	Vodafone	9.130
	2,6 GHz Q	1x5 MHz abstrakt	Telekom D	8.598
	2,6 GHz R	1x5 MHz abstrakt	Vodafone	8.598
	2,6 GHz S	1x5 MHz abstrakt	Vodafone	9.051
	2,6 GHz T	1x5 MHz abstrakt	Vodafone	9.051
	2,6 GHz U	1x5 MHz abstrakt	E-Plus Grp	8.273
	2,6 GHz V	1x5 MHz abstrakt	To2 GER	8.229
	2,6 GHz W	1x5 MHz abstrakt	To2 GER	8.229
	2,6 GHz X	1x5 MHz abstrakt	E-Plus Grp	8.229

Summe aller gehaltener Höchstgebote (€ in Tsd)	4.384.646
Zahlungsverpflichtung aufgrund zurückgenommener Höchstgebote (€ in Tsd)	0
Summe	4.384.646

81% for UHF spectrum!

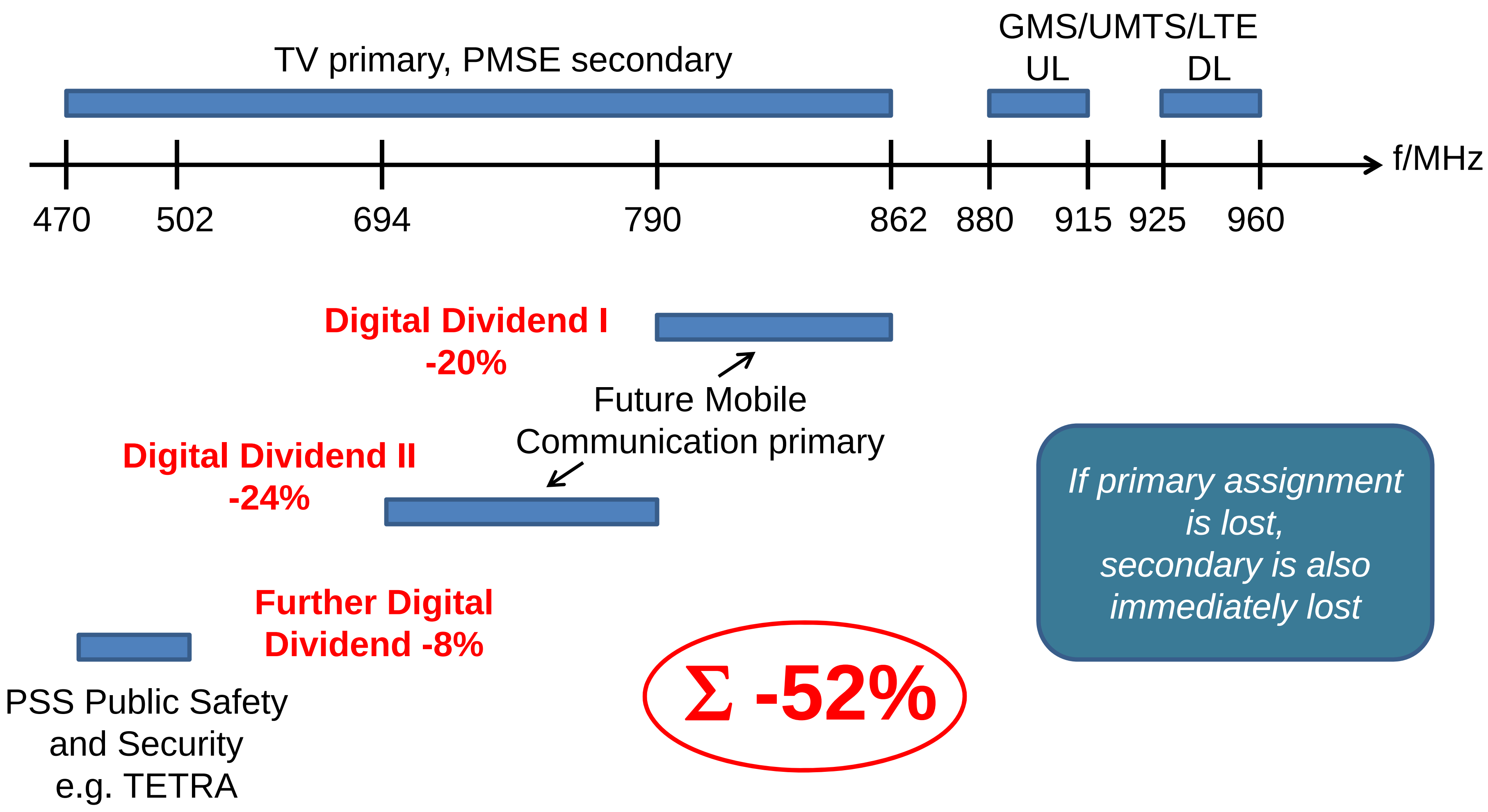
Value of spectrum: 3.6 Mrd € for 30 MHz paired

⇒ 120 Mil €/MHz

Surprisingly, it only decayed 6x...

Spectrum considerations

Spectrum lost for PMSE



Spectrum considerations

Spectrum lost for PMSE

View from a regulator

Historic Capacity Gains in Wireless Networks

Wireless Network Capacity Gains 1950-2000

Digital Dividend card → 15x by using more spectrum (3 GHz vs 150 Mhz)

5x from better voice coding ← *The source coding card*

5x from better MAC and modulation methods ← *Reducing protocol overhead*

The FEMTO option → 2700x from smaller cells

Total gain 1 million fold

Source: William Webb, Ofcom.

Femto Basestations have the highest potential, far more than a total digital dividend, consequence?

8. Conclusions

- *We list the take-aways*
- *Action recommendations*

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Conclusions
Key Take-Aways

How can spectrum need be reduced?
- More efficient transmission technology?
- We are already at the Shannon bound, so not a realistic opportunity
- Analogue to Digital transition will not give us a more efficient spectrum use!
- For digital transmission protocol overhead makes the case even worse

But why are other digital systems doing that well?
- Information to be transmitted is heavily compressed by source coding
- More compression means less spectrum need

Can't we apply compression to PMSE?
- PMSE has very specific needs (latency, drop-outs, quality)
- Only small compression factors can be used 2:1 …4:1
- Recipient is not known (Source coding needs information about recipient)
- Digital archive must be high quality to derive different quality levels
- Analogue transmission already has 2:1 by compander system
- So benefits form digital are therefore small

Consequences
- Spectrum need by PMSE is somehow justified – PMSE is not a waster of spectrum
- Research on lossless compression needed (EU projects?)
- No revolutions to come in reduction of spectrum need for PMSE
- RF Technology improvements can also help a bit

Conclusions

Key Take-Aways

Higher compression of raw information

↓

Less spectrum needed per user

↓

More users can transmit in a given spectrum

↓

Consequence: We have to maximize compression

↓

High Compression in PMSE is not possible in principle due to specifics of PMSE,
Analogue PMSE has already analogue compression
Digital compression would only provide marginally higher compression
Overhead for digital would have to be paid, costs even extra spectrum

↓

PMSE cannot do in less spectrum,
Raising number of users in PMSE as in other systems
Raising interest for HD in PMSE as in other systems

↓

Spectrum need by PMSE is justified