Analysis of Changes in PMSE spectrum - our Prediction for PMSE, operated under changed Conditions

WM06 - Current and Future Use of Spectrum by PMSE -
3rd PMSE Workshop at EuMW

Prof. Dr.-Ing. Georg Fischer
Institute of Electronics Engineering
Chairman of closed ETSI STF386 on C-PMSE

The birthplace of
1. The spectrum situation for PMSE
2. What is the value of spectrum?
3. Multi antenna MIMO in cellular
4. Specifics of PMSE transmission
5. Interference Situation at UHF and L-Band
6. Impact of 5G on PMSE?
7. Conclusions
1. The spectrum situation for PMSE
Gordan Moore, TI 1965:
“Complexity of an IC is doubling every 2 years”
The spectrum situation for PMSE
Edholm’s law of bandwidth

Wireless data rates are growing faster than wireline!

We will run into a serious problem!

Source: Steven Cherry, Edholm’s Law of Bandwidth,
Telecommunications data rates are as predictable as Moore’s Law, IEEE Spectrum, July 2004
Phil Edholm, Nortel’s chief technology officer and vice president of network architecture
The spectrum situation for PMSE
Edholm’s law of bandwidth

Tendenz der Datenrate über die letzten Jahre

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Legende:
- Kabelverbindung
- WLAN
- Mobilfunk

➡ Data Rate of wireless and wireline interfaces is doubling every two years

The spectrum situation for PMSE
Cellular Data amount by application

Figure 5. Mobile Video Will Generate 66 Percent of Mobile Data Traffic by 2015

Petabytes per Month

7,000

3,500

0

2010 2011 2012 2013 2014 2015

Mobile VoIP
Mobile Gaming
Mobile M2M
Mobile P2P
Mobile Web/Data
Mobile Video

VoIP traffic forecasted to be 0.4% of all mobile data traffic in 2015.
Source: Cisco VNI Mobile, 2011

⇒ Mobile Video dominating!
The spectrum situation for PMSE

Interpretation

Growth Laws

• Moore’s law of microelectronics – integration density doubles every 2 years
• Edholm’s law of bandwidth – data rates on wireless interfaces double every 2 years
• CISCO law – wireless data amount doubling every year

Why?

• Video is dominating wireless data
• Horizontal and vertical resolution growths by factor $\sqrt{2}=1.41$ per year thanks to Moore’s law
• Therefore wireless data amount doubles every year
• Wireless interfaces can hardly catch up with this trend

Consequence

• “Hunger” for more wireless capacity is quenchless

Approaches

• More spectrum - the simplest way
• Network densification – costly
• MIMO multi antennas – visual appearance?
• Source coding - compression
• Reduction of protocol overhead - all IP

There is nothing to gain by channel coding and new transmission schemes as we have reached already the Shannon bound
The spectrum situation for PMSE
Cellular spectrum assignment (Germany) versus data volume

It is impossible to serve an exponential data growth by linear spectrum assignment! The game is lost already by today…
The spectrum situation for PMSE
UHF band

What’s going on?

• Digital dividend means that TV spectrum is moved to cellular
• Some people think in future 400…6000 MHz could all be cellular…

In total 52% Spectrum lost for PMSE at UHF!

The spectrum situation for PMSE
What has changed?

Content & Event production
- Production companies
- Need for PMSE

Content management
- Broadcaster’s core business!

Content distribution
- Public address
- TV/Radio
- Internet
- Mediathek
- CD/DVD
- Downloads
- Internet
- Satellite
- Cable
- Shop...

Situation has changed
- Broadcasters no longer are present throughout the whole business chain
- Broadcasters focus on core business - content management
- Broadcasters no longer represent PMSE and Broadcast spectrum inside one institution

Classical Model for PMSE coexistence with Broadcast no longer works

2. What is the value of spectrum?
Value of spectrum: 98.8 Mrd DM for 60 MHz paired
⇒ 1,6 Milliarden DM/MHz
⇒ 800 Mil€/MHz
What is the value of spectrum?
Digital Dividend Auction (2010)

Value of spectrum: 3.6 Mrd € for 30 MHz paired
⇒ 120 Mil €/MHz

Surprisingly, it only decayed 6x...
What is the value of spectrum?
Comparison of auction results over years

Auction result / (Mil€/MHz)

Year

Auction: UMTS

What is the value of spectrum?

Price per MHz
- Strange…at 2000 MHz price went down…
- Strange…at low frequency (LTE bands) 700/800 MHz price went down
- Strange…at 1800 MHz price went up although propagation worse

Analysis
- Is there really a shortage of spectrum?
- We have auctioned spectrum too early…selling silver spoons
- Pressure on PMSE to get out of UHF is not justified to this extend by now
3. Multi antenna MIMO in cellular
Multi antenna MIMO in cellular

Why did Intelligent Antenna Solutions fail?

- Companies offering IA (Intelligent Antenna, MIMO, Beamforming) solutions fail as spectrum is cheaper than IA…
Multi antenna MIMO in cellular
Why did Intelligent Antenna Solutions fail?

Upgrade Scenario
• Upgrade from 1 antenna TX to 4 antennas TX per sector with a basestation
• Intelligent Antenna (beamforming/MIMO)
• Can you get 4x the capacity?
• Theoretically yes! - But practically only on average 2.5

Analysis
• 2.5x the capacity for 4x the RF effort – a bad deal
• There is no attractive reward
• Invest in spectrum looks more attractive than invest in IA/MIMO

Reaction
• Complain about spectrum shortage
• MIMO/IA would be more costly
• Network densification also would be more expensive, costly backhauling
• More spectrum is the easiest and lowest cost way
Multi antenna MIMO in cellular
What options?

View from a regulator – OFCOM UK

Historic Capacity Gains in Wireless Networks

Wireless Network Capacity Gains 1950-2000

- 15x by using more spectrum (3 GHz vs 150 MHz)
- 5x from better voice coding
- 5x from better MAC and modulation methods
- 2700x from smaller cells

Total gain 1 million fold


⇒ Small Cells (Femtos) have the highest potential, far more than more spectrum (e.g. digital dividend), consequence?

Multi antenna MIMO in cellular
And what about Cognitive spectrum management?

C-PMSE Technology
- Spectrum is a scarce and naturally limited resource, that cannot be magnified
- Finding: C-PMSE can only overcome interference scenarios, but it cannot provide additional PMSE capacity
- Will not allow to operate more PMSE links in a given spectrum
- Successful practical studies and demo at Messe Berlin

C-PMSE going into ETSI Standards
- 3 documents generated during STF386
- Now being worked into EN300422

Testing Scanning receivers
Installation at Messe Berlin
4. Specifics of PMSE transmission
### Specifics of PMSE transmission

**Why is PMSE so unique?**

#### Availability

- Drop-outs not acceptable, 100% reliable (!?)
  
  *cellular networks intentionally designed for 95% availability*

- Historic events cannot be repeated “Daß Ihre Ausreise…(Genscher)”

- No Clicks acceptable, especially in quiet periods (e.g. Digital out of sync…)

#### Quality

- High quality must be captured in production archive as otherwise it is not possible to derive the various quality levels in distribution

- Large compression (Source coding) is thus not possible on production, only on distribution

#### Latency

- The “drummer problem”,
  
  roundtrip from wireless mic to wireless IEM should be < 5ms

  *Telephone 200ms, Cellular 20ms, Satcom 500ms*

- Communication theory wise: Information source and information sink are collocated!
Specifics of PMSE transmission

Wireless links involved

Findings
• Wireless Technology on Production 2x (MIC+IEM)
• Wireless Technology on Distribution
• Large variety of distribution CODECs
• Life productions – it must work reliable!

What’s not captured in the archive, cannot be distributed later!

Specifics of PMSE transmission
Information theoretical view

Model
• Information from information source (microphone) is sent to information sink (mixing console, archive, distribution, IEM)
• Goal is to minimize transinformation, it defines spectrum need
• Redundancy: we can strip this off without loss of quality
• Irrelevance: Who decides what is irrelevant? Big brother? The listener should…
• The more irrelevance is identified, the less transinformation, the less spectrum need…

Spectrum need defined by transinformation
Compression = Identifying more Irrelevance

- What quality level/compression level is appropriate?
- If an artist exercised details for very long, can we simply strip these details off?
- The more detail rich the performance, the less opportunity for compression…
- Is the excellence by an artist simply irrelevant?

By compression the excellence of artist is shaded to the listeners (and also not captured in archive…)
5. Interference Situation at UHF and L-Band
Interference Situation at UHF and L-Band
Common problem

Characteristics of PMSE

• PMSE as victim is very vulnerable by interference
• Due to high audio quality requirements in PMSE, it is operating at a fairly high SNR around 40 dB, other systems typically operate at low SNR e.g. 7 dB
• Due to stringent latency requirements in PMSE (5ms round trip), channel coding by interleaving can only by spread across a block of 1 ms, thereby not delivering strong temporal diversity gains
• Interference to PMSE through strong peaks will make block decoding fail

Regulation

• So far protection levels given as average power levels (interference temperature)
• Better specify peak levels

The strong latency and quality requirements make PMSE very vulnerable to peaky interference
Interference Situation at UHF and L-Band
SNR hit by latency constraint

Theoretical background
• Required SNR predicted by Shannon bound assumes infinitely long interleaving
• No analytic formula to derive SNR hit by latency constraint
• Nevertheless theoretical bounds on hit can be identified
• Hit on the order of extra 5 dB to meet latency constraint, under certain cases may go up to 10 dB

Source: Rachinger Ch., Huber J., Müller R., Comparison of Convolutional and Block Codes for Low Structural Delay, IEEE Transactions on Communications, Volume: 63, Issue: 12, Pages: 4629 - 4638, 2015

Interference Situation at UHF and L-Band
Interference next to 4G LTE Node-B/UE

Situation
• PMSE might be operated next to LTE basestations and terminals
• Side emissions are specified as average power limits, however peak levels are crucial for PMSE
• If quantifying interference peak levels should be assessed

Crest factor at channel 7…10 dB
Crest factor at shoulder 40 dB
Average power on shoulder not meaningful!
Interference Situation at UHF and L-Band
Interference next to 4G LTE

New interference situation at L-Band
- Multiple systems present in L-Band
- DME Distance Measurement Equipment (civil and military versions)
- LDACS1 digital avionic radio coming up
- Military Radio Systems: JTIDS/MIDS

DME
- Double Pulses (pulse pairs), ideally Gaussian shaped
- Realistically sharper pulses are used, occupying larger bandwidth
- Repetition rates: Ground station 2700 ppps (pulse pairs per second), Military version TACAN 3600 ppps, Aircraft 150 ppps in the search mode and 30 ppps in the track mode

Interference Situation at UHF and L-Band Interferers

LDACS
• L-Band Digital Aeronautical Communication System
• OFDM System
• Interleaved with DME

![Diagram showing frequency allocation]

Notations
• UAT=Universal Access Transceiver
• SSR=Secondary Radar System
• JTIDS=Joint Tactical Information Distribution System
• MIDS=Multi-functional Information Distribution System

Source: Hirschbeck Martin, Interference Mitigation and Channel Estimation for Digital Aeronautical Communication Systems based on OFDM, Dissertation to be defended, FAU, July 2016

Interference Situation at UHF and L-Band
ISpectrum assignments in L-Band

Coordination

• Forward link FL and reverse link RL coordinated between LDACS and DME

Source: Hirschbeck Martin, Interference Mitigation and Channel Estimation for Digital Aeronautical Communication Systems based on OFDM, Dissertation to be defended, FAU, July 2016

Interference Situation at UHF and L-Band
What about LDACS interference by DME?

LDACS being interfered by DME
• Time domain view

OFDM Symbol
120 μs

Figure 1.2: Magnitudes of unfiltered LDACS1 and DME signals at an LDACS1 receiver input in time domain

• On average every third OFDM Symbol is hurt
• Block length in OFDM (e.g. 20 ms?) much higher than in PMSE (2ms)
• Larger block length gives higher interleaving gain
• Larger block length possible in LDACS as less latency critical

Source: Hirschbeck Martin, Interference Mitigation and Channel Estimation for Digital Aeronautical Communication Systems based on OFDM, Dissertation to be defended, FAU, July 2016

Interference Situation at UHF and L-Band
Time domain view

DME Interference
- DME consist of double pulses with 12us distance
- Pulses are nearly Gaussian
- DME runs at 2700…3600 ppps (pulse pairs per second)

PMSE as victim
- Goal 5 ms roundtrip, 2 ms one way plus 1ms for mixing console
- Then in 2 ms there are 7 double pulses
- A double pulse occupies roughly 20 us duration of interference
- A duration of 20 us * 7= 140 us out of 2 ms would be interfered
- 7% of PMSE transmission interfered
- If DME pulses hit pilot symbols in PMSE transmission, whole frame would be immediately lost
- In case of incoherent PMSE transmission there would be no pilots, e.g. CPM incoherent, however incoherent CPM is limited to about 3 bit/s/Hz

Conclusion
- DME pulses happen several times in a PMSE frame

The assumption of seldom hits is not true!
Interference Situation at UHF and L-Band

Power levels

Transmit power

- TACAN (military version) ground 1…2.5 kW
- DME ground 1 kW
- DME terminal 100W
- PMSE 100mW

Relations

- DME transmission power factor 1000…20,000 equal 30…43 dB higher than that of PMSE

Interpretation

- PMSE is a system with short frame length and short interleaving
- Temporal diversity through interleaving is rarely in place
- For quantifying DME interference into PMSE receiver, peak and not average receive level of interference should be used.

Note

- The Shannon bound is valid only for long (infinite) time interleaved systems
- PMSE as a latency critical system cannot be described by Shannon and is vulnerable through peak interference
- PMSE cannot profit from interleaving as a protection mechanism
6. Impact of 5G on PMSE?
Impact of 5G on PMSE?
5G Research areas

So what is 5G?
“Die eierlegende Wollmilchsau”
Swiss Army Knife

Caught near Waldhäuser/Lusen, Bavarian Forest
Impact of 5G on PMSE?
Generations of cellular

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Communication is everything!


Source: Anritsu
Impact of 5G on PMSE?
Dimensions of 5G

One System does all
- Classical Cellular Communication
- IoT/WSN
- Autonomous driving
- Industry 4.0
- Smart metering/smart grid
- Broadcast? (eMBMS)
- PMSE? (PMSEo5G)
- BOS (Police/Firemen/Ambulance)?

Range of Datarates
- From very low to extreme high
- IoT, Smart Sensors, WSN, Smart Metering
- Immersive Audio/Video

Extreme Low latency
- Autonomous driving
- Remote VR, immersive telepresence
- Realtime, Haptic feedback, tactile internet
- Industry 4.0
- PMSE (Wireless Multimedia)

Network topology
- Virtualization of RAN, edge computing
- Network densification, more cells
- Heterogeneous networks, Macros & Small cells
- 3D Massive MIMO
- Macro Diversity by Coordinated Multipoint CoMP
- D2D Device to Device, direct mode Duplex filter?

Energy
- WSN
- MTC
- CIOT

New Frequency bands
- Higher frequency bands, mm Wave
- More instantaneous bandwidth, Carrier Aggregation CA
- Multiband, Interband CA

Impact of 5G on PMSE?
GSMA view

Source: GSMA
Impact of 5G on PMSE?

Lowest Latency – Tactile Internet

**Low Latency**

- Link budget hit by low latency easily 10 dB…
- Shannon only valid for infinite interleaving
- Channel coding can be treated as temporal diversity….lost
- Fast Resource scheduling

**Applications**

- Gaming, VR, Augmented Reality
- Industry 4.0
- Autonomous driving

Source: GSMA

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**Demos**

- Strong interest in 24-27 GHz, e.g. Korea
- US wants to push this
- But WRC has a different view…wants to go higher in frequency

*Source: NOKIA*
Impact of 5G on PMSE?
Broadcast via eMBMS inside 5G

Broadcast over cellular
• New business opportunities
• TV Distribution
• Software Update
• Local advertisements
• Fleet Management
• Car info
• Tourist/Travel info

Research
• Project in Germany BFS IMB5
• Partners: IRT, NOKIA, FhG IIS, R&S, BR, BMW

Technical approach
• Longer CP as in DVB-T/T2
• 16.6 / 33.3 us, equal to 5 / 10 km
• SFN (Macro Diversity gain)

Source: BFS IMB5
Impact of 5G on PMSE?
Broadcast via eMBMS inside 5G

Schedule
- DVB-T and DVB-T2 unquestioned
- Convergence of Broadcast and cellular

Source: BFS IMB5

5G-Standardisation in 3GPP
DVB-T2 Introduction
BFS IMB5 Follow up project

Pre 5G introduced at Olympic Winter Games in south Korea
5G at Olympic Summer Games in Japan

Introduction of convergent system

Schedule:
- DVB-T and DVB-T2 unquestioned
- Convergence of Broadcast and cellular

Pre 5G introduced at Olympic Winter Games in south Korea
5G at Olympic Summer Games in Japan

Source: BFS IMB5
### Impact of 5G on PMSE?

**Service categories**

<table>
<thead>
<tr>
<th>Use case category</th>
<th>User Experienced Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadband access in dense areas</td>
<td>DL: 300 Mbps, UL: 50 Mbps</td>
<td>10 ms</td>
<td>On demand, 0-100 km/h</td>
</tr>
<tr>
<td>Indoor ultra-high broadband access</td>
<td>DL: 1 Gbps, UL: 500 Mbps</td>
<td>10 ms</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>Broadband access in a crowd</td>
<td>DL: 25 Mbps, UL: 50 Mbps</td>
<td>10 ms</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>50+ Mbps everywhere</td>
<td>DL: 50 Mbps, UL: 25 Mbps</td>
<td>10 ms</td>
<td>0-120 km/h</td>
</tr>
<tr>
<td>Ultra-low cost broadband access for low ARPU areas</td>
<td>DL: 10 Mbps, UL: 10 Mbps</td>
<td>50 ms</td>
<td>on demand: 0-50 km/h</td>
</tr>
<tr>
<td>Mobile broadband in vehicles (cars, trains)</td>
<td>DL: 50 Mbps, UL: 25 Mbps</td>
<td>10 ms</td>
<td>On demand, up to 500 km/h</td>
</tr>
<tr>
<td>Airplanes connectivity</td>
<td>DL: 15 Mbps per user, UL: 7.5 Mbps per user</td>
<td>10 ms</td>
<td>Up to 1000 km/h</td>
</tr>
<tr>
<td>Massive low-cost/long-range/low-power MTC</td>
<td>Low (typically 1-100 kbps)</td>
<td>Seconds to hours</td>
<td>on demand: 0-500 km/h</td>
</tr>
</tbody>
</table>

- **Broadband MTC**: See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories

| Ultra-low latency                          | DL: 50 Mbps, UL: 25 Mbps | <1 ms       | Pedestrian                |
| Resilience and traffic surge               | DL: 0.1-1 Mbps, UL: 0.1-1 Mbps | Regular communication: not critical | 0-120 km/h |

| Ultra-high reliability & Ultra-low latency | DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps | 1 ms       | on demand: 0-500 km/h      |
| Ultra-high availability & reliability      | DL: 10 Mbps, UL: 10 Mbps  | 10 ms       | On demand, 0-500 km/h       |
| Broadcast like services                    | DL: Up to 200 Mbps, UL: Modest (e.g. 500 kbps) | <100 ms     | on demand: 0-500 km/h       |

*Source: NGMN*
Impact of 5G on PMSE?
Audio/Video PMSE inside 5G?

Artist

• Multiple units on actor’s body
• Latency Roundtrip 3…5 ms

PMSE is challenging

• HD Multimedia wireless
• Immersive Sound and Video
• Effect control
7. Conclusions
Conclusions

Spectrum for PMSE
- 50% spectrum lost at UHF
- New spectrum at L-Band proposed

Transmission of PMSE
- Very specific requirements (Latency, reliability, High SNR operation)
- Short Interleaving, vulnerable to peak interference
- Shannon bound only defined for infinite interleaving (temporal diversity)
- Low latency constraint in PMSE easily accounts for 10 dB more SNR

Interference assessment with spectrum scans
- Measure peak levels, not average levels

Interference sources
- LTE NodeB and UEs at UHF, shoulders of LTE signals have 40 dB crest (transients)
- DME pulses at L-Band very peaky

5G
- Broadcast may get integrated into 5G, takes some time, DVB-T2 on roll out
- 5G will allow for 1 ms one way
- Can Audio+Video+Effectcontrol=PMSE be integrated into 5G?
Annex
Speakers Background
Experience

Prof. Dr.-Ing. 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. (summa cum laude),
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

Chair is the **birthplace of mp3 Audio Compression**, commercialized by Fraunhofer

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**D. Seitzer**  
Datenreduktion  
Bilder, Sprache, Musik  
Mikroelektronik

**K. H. Brandenburg**  
Effiziente Kodierung  
Messung der subjektiven Qualität

**H. Gerhäuser**  
Signalprozessoren  
Echtzeit-Codierung

**Commercialized by**

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Grundlagenforschung am Lehrstuhl für Technische Elektronik  
1970 - 1987
Speakers Background
Audio Labs

Audio Labs
• A joined activity of Fraunhofer IIS and FAU
• 6 Professors

International Audio Laboratories Erlangen

Campus Radio
Run by students
DRM+ at Shortwave
DAB+
DAB surround

Founded July 2008