PMSE-xG
Programme Making and Special Events
- Next Generation -
Agenda

10:00 - 10:15 Welcome
   Hr. Kraus, ARRI
   Hr. Hilbich, Sennheiser

10:15 - 10:20 Agenda
   Dr. Wilzeck, Project Office

10:20 - 10:35 Introducing the PMSE-xG project
   Dr. Wilzeck, Project Office

10:35 - 10:45 Demo Overview
   Dr. Pèrez Guirao, Project Office

10:45 - 11:15 Use Case & Demo: Video PMSE
   Hr. Popp, ARRI
   Hr. Bühlmeyer, FAU

11:15 - 11:30 Coffee Break

11:30 - 12:00 Use Case & Demo: Conferencing
   Dr. Thein, Bosch

12:00 - 12:30 Use Case & Demo: Audio PMSE
   Dr. Schmidt, Sennheiser
   Hr. Pilz, HHI

12:30 - 13:30 Lunch Break

13:30 - 14:00 Use Case & Demo: Audience Services
   Hr. Hupke, LUH
   Hr. Nophut, LUH

14:00 - 14:30 Use Case & Demo: Production & Contribution
   Dr. Acher, Smart Mobile Labs
   Hr. Fliegl, Smart Mobile Labs

14:30 - 15:30 Coffee Break & Demo Walk-around

15:30 - 15:45 Live Interactive PMSE Services (LIPS)
   Dr. Septinus, Sennheiser

15:45 - 16:00 Wrap-Up & Closing
   Dr. Wilzeck, Project Office
Introducing the PMSE-xG Project

Dr. Andreas Wilzeck, Project Office
What is Programme Making and Special Events (PMSE)?

- Media & Entertainment
  - Production
  - Contribution
  - Distribution
- Audio, Video, Light, Effects
- Conferencing Solutions
What is PMSE-xG?

- PMSE-xG is a research project.
  - Establishing cooperation of stakeholders in PMSE, Cellular Mobile Industry, Politics, Standardization, and Regulation

- PMSE-xG considers the future-oriented use of mobile broadband radio technology and network infrastructure for PMSE applications.
  - Technological and economic feasibility of PMSE in 4G+/5G
  - Anchoring PMSE applications in the standardization of mobile broadband radio
  - Opening of new chances and opportunities: new business segments, new products, new services, new applications

- PMSE-xG is pioneering project, also for other vertical industries (eHealth, Industry 4.0, Automotive).
PMSE-xG Consortium

- Sennheiser
- Bosch
- ARRI
- Intel
- Leibniz Universität Hannover
- Fraunhofer Heinrich Hertz Institute
- FAU Friedrich-Alexander Universität Erlangen-Nürnberg
- SMART MOBILE LABS
Associated Partners,
Co-operation Partners

Bundesministerium für Verkehr und digitale Infrastruktur

Bundesnetzagentur

NOKIA
Nokia Networks

QUALCOMM

Telefónica | O₂

APWPT

IRT
Project Structure

- **AP 1: Applications, Requirements und Standardisation**
- **AP 2: Implementation concepts and Architectures**
  - A | Radio Access
  - B | Multicast, Broadcast
  - C | Mobile Edge Cloud
  - D | Application
- **AP 3: Proof-of-Concept und Validation**
- **AP 4: Project Management und Project Communication**

- **Duration:** 01.10.2016 bis 31.03.2018, 18 Months
- **Budget:** approx. 3,7 Mio. €
Focusing on Applications

• Live Event, production, distribution und audience services
  • Professional wireless audio / video
  • Assistive live listening / viewing
  • Innovative multimedia services
  • Group communication for production and security services

• Wireless conferencing
  • Seamless communication with outstanding speech intelligibility, regardless of whether the subscriber is on-site or not.
  • Integration of value added services, e.g. simultaneous translation

• Main research topics are, in particular, ultra reliable, low latency streaming technologies for mobile and nomadic applications.
Live Event

Video Screen

Stage

Mixing Desk

4G/5G Network

Services

Remote Artist

Remote Participants

Live Participants
5G and Stakeholders

• 5G has the vision to be a network of networks (physical or virtual).

• An initial open discussion of stakeholder interests does not require details on the business models of each.

• Important are the roles regarding resource ownership and management to find possibilities to do joint businesses.

• All potential stakeholders in 5G will have to reconsider their future roles to develop cooperative businesses.
### Today

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Cellular Mobile Industry</th>
<th>RLAN Industry</th>
<th>PMSE Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>MNO</td>
<td>ISM !</td>
<td>Incumbent</td>
</tr>
<tr>
<td>Manager</td>
<td>MNO</td>
<td>Media Access !</td>
<td>PMSE Service</td>
</tr>
<tr>
<td>Core</td>
<td>MNO</td>
<td>ISP</td>
<td>ISP</td>
</tr>
<tr>
<td>RAN</td>
<td>MNO</td>
<td>Customer</td>
<td>PMSE Service</td>
</tr>
<tr>
<td>Core</td>
<td>MNO</td>
<td>ISP</td>
<td>ISP</td>
</tr>
<tr>
<td>RAN</td>
<td>MNO</td>
<td>Customer</td>
<td>PMSE Service</td>
</tr>
<tr>
<td>Service</td>
<td>3rd Party</td>
<td>3rd Party</td>
<td>PMSE Service</td>
</tr>
<tr>
<td>Customer</td>
<td>Customer</td>
<td>Customer</td>
<td>Customer</td>
</tr>
</tbody>
</table>

**Abbreviations:***
- MNO: Mobile Network Operator
- RLAN: Radio Local Area Network
- ISP: Internet Service Provider
- PMSE: Programme Making and Special Event
PNO operates a **private network** for local applications.
PNO potentially contributes to MNO network (network densification).

**MNO provides Spectrum as a Service (SpaaS).**
PNO with SpaaS by 3rd party

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Cellular Mobile Industry</th>
<th>Private Network</th>
<th>PMSE Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>MNO</td>
<td>Incumbent</td>
<td>Incumbent</td>
</tr>
<tr>
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<td>PMSE Service</td>
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<td>PMSE Service</td>
</tr>
<tr>
<td>Customer</td>
<td>Customer</td>
<td>Customer</td>
<td>Customer</td>
</tr>
</tbody>
</table>

Spectrum Sharing (e.g. LSA) with incumbents, incumbents and 3rd party including MNO.

MNO Mobile Network Operator
PNO Private Network Operator
MVNO Mobile Virtual Network Operator
ISP Internet Service Provider
PMSE Programme Making and Special Events
Conclusions

• Own, local area network deployment and roll-out is a must for many verticals (PMSE, Industry 4.0, ...)
  • Concepts like network slicing / MVNO assume existing suitable network infrastructure, valid configuration, and sufficient coverage.
• PNO-based local area 5G networks can contribute significantly to the success of 5G
• 5G technology will only be adopted by verticals, if there is a value added compared to existing solutions
• Time line
  • There is still a lot of effort required to enable PMSE applications in 5G standards.
  • We hope that by 2023 3GPP standards will support PMSE.
  • Regulatory discussion for local area 5G and PNO is required.
• Open discussions among stakeholders are important and necessary.
Demonstration Overview

Dr. Pérez Guirao, Project Office
Overview on Demonstrations

• From Right to Left:
  • Smart Mobile Labs: Convergent Video Production and Distribution with Multi-Access Edge Computing
  • ARRI, FAU: Video PMSE
  • Fraunhofer HHI, Sennheiser: Audio PMSE
  • Bosch, Smart Mobile Labs: Wireless Conferencing
  • LUH, Sennheiser: Assistive Live Listening Service
Use Case & Demo: Video PMSE
PMSE-xG

Programme Making and Special Events
- Moving Images and Video -
### Classes and Characteristics of Moving Images and Video Productions

(✓ = enabled or significantly improved by 5G)

<table>
<thead>
<tr>
<th></th>
<th>TV ENG (Video)</th>
<th>TV Live (Video)</th>
<th>Scenic “quasi-live” (Moving Images)</th>
<th>Scenic (Moving Images)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Rate</strong></td>
<td>5–10</td>
<td>20–50 / 100+</td>
<td>-- / 200+</td>
<td>-- / (1000+/5000+)</td>
</tr>
<tr>
<td>[Mb/s wireless, HDTV useful signal, today / needed]</td>
<td></td>
<td></td>
<td></td>
<td>(cmp’d./ raw)</td>
</tr>
<tr>
<td><strong>Average Shoot Duration</strong> [per day]</td>
<td>1–3 h</td>
<td>1–5 h</td>
<td>5–8 h</td>
<td>sometimes &gt; 10 h</td>
</tr>
<tr>
<td><strong>Wireless Services</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video as useful signal</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Video as assist signal</td>
<td>--</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Camera Synchronization</td>
<td>--</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lens Control</td>
<td>--</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Project Workload Sharing

• 5G is native IP packet transmission - efficient use requires
  • global substitution of legacy video- and device-specific interfaces by powerful IT/IP interfaces
  • native anchoring of IP in production equipment
  • seamless integration of IP into workflow chains

• Division of Labor for Moving Images and Video PMSE-xG
  • ARRI takes care of the production equipment
  • ARRI implements and evaluates key features expected to be enabled by 5G
  • Details in this talk

  • FAU takes care of the wireless part
  • FAU investigates relevant 5G features and develops a performant Pre-5G wireless system
  • Details in the subsequent talk

16.03.2018
5G Enabled and Improved – The PMSE-xG Approach

• Enabling true Production Codecs through Increased Data Rate
  • **overcoming limits** of currently used distribution codecs
  • supporting **Wide Color Gamut** and **High Dynamic Range**
  • providing widely **unrestricted use of material**

• Improving Closed Loop Response with Low Latency
  • **10 ms latency incl. error correction** by 5G HARQ retransmit (5G Rel. 15)
  • providing reliability and low latency

• Improving Spectral Efficiency needing only 1 System per Camera
  • **1 All-IP wireless system** parallel serves
    Assist Video, Useful Video, Lens Control and all other communication
  • **substituting several dedicated systems**, often in parallel
    image here: 1 for Video Assist + 1 for Lens Control + 1 for Distance Telemetry
    often also: 1 for Synchronization and Time Code
PMSE-xG All-IP Setup for Moving Images and Video

**ARRI Camera**
Image Source (Sender)

**LTE Device**
Transmitter

**Full HD Streaming**
1920x1080, 1..60 fps

**LTE Device**
Receiver

**ARRI Camera**
Image Destination (Receiver + Display)

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ProRes 100 Mb/s wireless Streaming
1..30 fps

ProRes wired Streaming
Debug / Test

**FPGA**
- Image Processing
- ProRes Coder
- ProRes Bitstream Packing
- SMPTE 2022 IP Streaming
- SMPTE 2059 IP Syncing

**CPU (Linux)**
- SMPTE 2022 IP Streaming Control
- SMPTE 2059 IP Sync Stack
- Wireless Device Control

**Sockets**
- 3G-SDI
- 1G Ethernet, RJ45 (CPU)
- 10G Ethernet, RJ45 (FPGA)

**10G Ethernet Switch**

**Tektronix SMPTE 2022 IP WFM Analyser**

**Tektronix SMPTE 2059 IP Sync Generator**

**FPGA**
- Image Processing
- ProRes Decoder
- ProRes Bitstream Depacking
- SMPTE 2022 IP Streaming
- SMPTE 2059 IP Syncing

**Sockets**
- 3G-SDI
- 1G Ethernet (CPU)
- 10G Ethernet (FPGA)

**HD Display**
1920x1080, 60p

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PMSE-xG for Moving Images and Video
Details Hardware - fully integrated

- **Image Processing + IP Streaming in 1 FPGA** (Field Programmable Gate Array)
  - minimized periphery and interfacing (hardware-minimal, power-minimal)
  - complete ARRI image processing chain
  - ProRes Production Codec including all profiles, usable for file and live stream
  - IP packager, streamer and 10G Ethernet Media Access (MAC)

- **PMSE-xG Printed Circuit Board**
  - choice of physical media – usable for 10G-fiber and 10G-copper PHYs
  - both scalable up to 40G (4x 10G)

- **Master Thesis within the PMSE-xG project scope**
  - FPGA based IP Communication and FPGA based highly scalable Ethernet Switch
  - preparing an All-IP Camera Product with support for external IP Periphery
Details Streaming – ProRes Production Codec

• Most Used Codec in Moving Images Productions (>70% market share)
  • Support of **Wide Color Gamut** and **High Dynamic Range**
  • **no transcoding** from camera to end result (IMF ProRes in preparation)
  • live-encoding and decoding in **5 milliseconds** (**200 fps** camera implementation)

• Wireless HiQ Streaming
  • **200 Mb/s** target rate for ProRes 422 LT, HD 1920x1080, 60 fps (**100 Mb/s Pre-5G**)
  • 1 stream for **Assist and Useful Signal** – saving resources manifold

• 5G Error Concealment (PMSE-xG Paper E2.2 – **200 Mb/s streaming**)
  • **10 ms latency** incl. a HARQ re-transmit (**5G Rel. 15, Hybrid Automatic Repeat Request**)

• Workflow and Format Consistency
  • until now (only): ProRes via removable flash media **files**
  • PMSE-xG enabled: ProRes also live via **wired and wireless streams**
Details Synchronization - In Sync at Every Frame Rate

• Replacement of All Dedicated Sync Signals
  • PTP synchronized clock in each device (camera)
  • IEEE 1588 PTP Precision Time Protocol for Clock Synchronization over IP
  • SMPTE 2059 video phase definition for video frame rates (24, 25, 29.97, 50, 59.97 fps)

• Precise Synchronization at Every Frame Rate (PMSE-xG developed 1.000–299.999+)
  • no performance degradation at critical frequencies (as for established PLL solutions)
  • precise representation of all frequencies incl. infinite fractional (not possible with PLL solutions)
  • 1 nano-second precision in relation to PTP clock
    - for every single pulse (starting image frame exposure)

• Camera Synchronization Monitor (PMSE-xG developed)
  • dynamically monitors offset, path delay, settling time, # of resyncs
  • useful also for characterization of transmission paths

16.03.2018
PMSE-xG – Summarizing Goals Reached

• All-IP - integrating Video, Sync, and Control in One Link
  • deep integration of IP streaming into the ARRI camera image chain
  • single chip FPGA implementation

• Production Codec IP Live Streaming (first time according to our knowledge)
  • using ProRes (the dominating moving images production codec)
  • preserving image quality and widely unrestricted use of material

• Format and Workflow Consistency (first time according to our knowledge)
  • independent from signal path
  • for File Transfer, Wired, and Wireless Streaming Links

• Precise Camera Synchronization (extending existing “5 speed only” solutions significantly)
  • each camera on network automatically in sync with all other cameras (at the same frame rate)
  • for every frame rate including infinite fractional rates
5G Needs for Moving Images and Video

• High Local Bandwidth in Mb/s and MHz Spectrum
  • **video data rate increases** significantly (x * y * fps, ~ 3rd power)
  • HD 1920x1080, 60 fps, ProRes 422 LT 200 Mb/s
  • UHD-2 3840x2160, 120 fps (target spec), ProRes 422 LT 1.6 Gb/s

• **Powerful Upstream**
  • PMSE (and other industries) have **other traffic patterns** than standard communication

• **Universal Usability**
  • worldwide Indoor and Outdoor
  • **timely unrestricted** (scenic studio production similar to industrial)

• **Precise Time Distribution** (1 micro-second or better)
  • nothing specific - support of established industry standards (**IEEE 1588**)
  • for synchronization and time stamping (all kind of events and actor triggers, **“timing is everything”**)
Camera A streaming to Camera B (~ 90 Mb/s) and in parallel Camera B to Camera A (~ 25 Mb/s). Both synchronized by a central IP Master Clock, both monitored by an Oscilloscope and IP Analyzer.
Thank you ... 
the BMVI

for funding this important project

you - the audience

for your interest and cooperation in PMSE-xG

all the PMSE-xG and ARRI colleagues

that made the PMSE-xG project alive, at ARRI i.e.

Dr. Alexander Mann
ARRI R&D

Leszek Polak
ARRI R&D

Dr. Michael Meitinger
ARRI R&D

Felix Lampe
ARRI R&D
PMSE-xG
High Data Rate Wireless Link
Programme Making and Special Events
Jonas Bühlmeyer, FAU Erlangen-Nürnberg
Content

1. Use Case Definition
2. Requirements
3. Measurement Setup
4. Measurement Results
   1. Latency
   2. Data Rate
   3. Summary of the Result
5. Future Requirements
Use Case Definition

Deployment of a portable high data rate reliable wireless link.

One bidirectional connection for synchronization, video stream etc.

Analysis of 5G for wireless communication.
Requirements

Latency of 10ms

100MBit/s in UL

Up to 50m distance

16.03.18
Measurement Setup

Workstation with Amarisoft eNodeB, MME and IMS, iPerf, PTP, OWPing

PCIe SDR Card

LTE

Workstation with Amarisoft UE, iPerf, PTP, OWPing

Ethernet

PCIe

PCIe SDR Card
Wireless Hardware Setup
Amarisoft - SDR

LTE release 14 compliant

LTE-A: MIMO 4×4, CA up to five 20MHz carrier in DL and three in UL

Support of all FDD and TDD bands including custom frequencies
Amarisoft - USRP

Support of all LTE FDD and TDD bands including custom frequencies

RF coverage: 70 MHz to 6.0 GHz

RF bandwidth: 200kHz to 56MHz

MIMO 2×2

Up to 3 x 20MHz contiguous carrier aggregation
Latency vs. Round Trip Time
## Typical DL latency - 3GPP

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>processes incoming data</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>TTI alignment</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>Transmission of DL data</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Data decoding in UE</td>
<td>3</td>
</tr>
</tbody>
</table>

Total delay [ms] 7.5

[1]
**DL latency - Results**

<table>
<thead>
<tr>
<th>Requirements [ms]</th>
<th>Results [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>5.84</td>
</tr>
<tr>
<td>Median</td>
<td>6.60</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.28</td>
</tr>
</tbody>
</table>

10.03.18
## Typical UL latency – 3GPP

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average waiting time for PUCCH (10 ms SR period)</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>UE sends Scheduling Request on PUCCH</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>eNB decodes Scheduling Request and generates the Scheduling Grant</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Transmission of Scheduling Grant</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>UE Processing Delay (decoding of scheduling grant + L1 encoding of UL data)</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Transmission of UL data</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Data decoding in eNodeB</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>Total delay [ms]</strong></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>

[1]
## UL latency - Results

<table>
<thead>
<tr>
<th>Requirements [ms]</th>
<th>Results [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>5.16</td>
</tr>
<tr>
<td>Median</td>
<td>14.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>22.2</td>
</tr>
</tbody>
</table>
### UL latency - Results

<table>
<thead>
<tr>
<th>Requirements [ms]</th>
<th>Results [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-</td>
</tr>
<tr>
<td>Median</td>
<td>-</td>
</tr>
<tr>
<td>Maximum</td>
<td>10</td>
</tr>
</tbody>
</table>

⇒ Faster due to static scheduling
Data rate
### UL Data rate - 3GPP

<table>
<thead>
<tr>
<th>MCS Value</th>
<th>Transport Block Size (Number of RBs =100)</th>
<th>Code Rate(Number Antennas: 1; Number PDCCH symbols 2)</th>
<th>Modulation Scheme</th>
<th>Data Rate [Mbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>61664</td>
<td>0.748</td>
<td>64-QAM</td>
<td>62</td>
</tr>
<tr>
<td>27</td>
<td>63776</td>
<td>0.774</td>
<td>64-QAM</td>
<td>64</td>
</tr>
<tr>
<td>28</td>
<td>75376</td>
<td>0.914</td>
<td>64-QAM</td>
<td>75</td>
</tr>
</tbody>
</table>

[2]
# Channel Conditions

<table>
<thead>
<tr>
<th></th>
<th>UL</th>
<th>DL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average MCS</td>
<td>28.0</td>
<td>27.9</td>
</tr>
</tbody>
</table>
**UL Data rate – Results**

<table>
<thead>
<tr>
<th>Data rate [Mbit/s]</th>
<th>Number of Packages</th>
<th>Lost Packages [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.3</td>
<td>54645</td>
<td>0.0</td>
</tr>
</tbody>
</table>
## DL Data rate - 3GPP

<table>
<thead>
<tr>
<th>MIMO configuration</th>
<th>max data rate per 20 MHz carrier [Mbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x1 (no MIMO)</td>
<td>75</td>
</tr>
<tr>
<td>2x2</td>
<td>150</td>
</tr>
<tr>
<td>4x4</td>
<td>300</td>
</tr>
</tbody>
</table>

[2]
# DL Data rate – Results

<table>
<thead>
<tr>
<th>Data rate [Mbit/s]</th>
<th>Number of Packages</th>
<th>Lost Packages [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>102040</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Results

Latency

in UL of around 15ms without static scheduling (4ms with static scheduling)

in DL of around 7ms

Data rate

in UL of around 65MBit/s

in DL of around 120MBit/s
## IMT2020 vs Future Requirements

<table>
<thead>
<tr>
<th></th>
<th>System delay [ms]</th>
<th>Link data rate [Mbit/s]</th>
<th>Reliability [%]</th>
<th>Number of data links</th>
<th>Synchronicity</th>
<th>Area of operation [m x m]</th>
<th>Mobility [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video production</td>
<td>10</td>
<td>2000</td>
<td>99.999</td>
<td>20</td>
<td>1µs</td>
<td>100 x 100</td>
<td>100</td>
</tr>
<tr>
<td>IMT 2020+</td>
<td>1</td>
<td>20000</td>
<td>99.999</td>
<td>10^6</td>
<td>n.a.</td>
<td>1000 x 1000</td>
<td>500</td>
</tr>
</tbody>
</table>
# IMT2020 vs Future Requirements

<table>
<thead>
<tr>
<th></th>
<th>System delay [ms]</th>
<th>Link data rate [Mbit/s]</th>
<th>Reliability [%]</th>
<th>Number of data links</th>
<th>Synchronicity [(\mu)s]</th>
<th>Area of operation [m x m]</th>
<th>Mobility [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>video production</strong></td>
<td>10 (max)</td>
<td>2000 (per link)</td>
<td>99.999</td>
<td>20</td>
<td>1[(\mu)]s</td>
<td>100 x 100</td>
<td>100</td>
</tr>
<tr>
<td><strong>IMT 2020(^*)</strong></td>
<td>1 (min)</td>
<td>20000 (in complete)</td>
<td>99.999</td>
<td>(10^6)</td>
<td>n.a.</td>
<td>1000 x 1000</td>
<td>500</td>
</tr>
</tbody>
</table>

16.03.18
Thank you for your Attention!
Sources


Use Case & Demo: Conferencing
PMSE-xG

Programme Making and Special Events

Audio Distribution over Local Private LTE network with Multi-Access Edge Cloud

Dr. Christoph Thein
Robert Bosch GmbH
Use Case: Conferencing

Local distribution of voice
• Convention centres
• Parliament buildings

Today
• WiFi-based portable solution deployed in license-exempt spectrum

Problem
• Increasing utilization of spectrum
Key Requirements

E2E Latency < 20ms

500 Users @ 1 Mbps

Reliability > 99.99%
Key Requirements

- E2E Latency < 20ms
- Network Delay < 8ms
- Local Multicast
- 500 Users @ 1 Mbps
- Packet Error Rate < $10^{-4}$
- Reliability > 99.99%
- Licensed Shared / Dedicated

Network Technology

Spectrum
Focus

E2E Latency < 20ms

Network Delay < 8ms

Audio distribution over local private LTE networks

Evaluation of network delay

Evaluation of LTE network operation from a vertical perspective

Reliability > 99.99%

Licensed Shared / Dedicated

Spectrum
Setup
Demo
Key Findings

16 ms is lowest achieved network latency in testbed

• Latency with high variance

Spectrum access strongly depends on cooperation with network operator

Optimized network configuration and operation is not plug and play
Conclusion

Today, private LTE networks are not ready to sufficiently support local conference applications.

Open issues

• High delay and jitter in network (further evaluation planned)

• Local access to licensed spectrum for verticals

• Business case for verticals
Thank you

Dr. Christoph Thein
Corporate Research
Robert Bosch GmbH

Mail: christoph.thein@de.bosch.com
Fon: +49 5121 49 4717
Use Case & Demo: Audio PMSE
PMSE-xG
Low Latency Audio PMSE

Jens Pilz, Ralf Lindstedt (HHI)
Axel Schmidt, Konstantin Septinus (Sennheiser)
Final Workshop, 16th of March, 2018
Motivation

• How to ensure secure operation of wireless production equipment in the future

• Audio PMSE key requirements:
  • a continuous, isochronous data stream
  • no perceivable audio disturbance
  • low latency
  • a deterministic medium access
  • a secure, interference free environment

Decreasing spectrum efficiency
Demonstrating Subset of KPIs

- Application latency ≤ 4ms

- Synchronicity ≤ 1µs
Demonstrator Setup
Radio Module

• Basic tradeoff between bandwidth/delay/reliability
Radio Module

- Basic tradeoff between bandwidth/delay/reliability
- Low delay + high reliability = high bandwidth
Radio Module

• Basic tradeoff between bandwidth/delay/reliability
• Low delay + high reliability = high bandwidth
• We don’t need the extreme, but we have challenging requirements
Radio Module

- 4G (LTE) fixed frame structure and position of information in time and frequency, fixed subcarrier spacing
- Fixed Time Transmission Interval (TTI) of 1ms or one subframe
Radio Module

• Transmission delay (1ms) only one part
Radio Module

- Transmission delay (1ms) only one part
- Complex stack processing takes time

![Diagram showing data flow and processing delays](image)
Radio Module

- Transmission delay (1ms) only one part
- Complex stack processing takes time
- Each interface has buffers and delays

=> Audio traffic will lose its deterministic behaviour
Radio Module

• **Our Solution**
  • C + U-Plane combining
  • TTI shortening (1 symbol)

=> Reduces transmission delay
Radio Module

- Our Solution
  - C + U-Plane combining
  - TTI shortening (1 symbol)

=> Reduces transmission delay
- local-break out

=> Reduces stack processing
Radio Module

• Our Solution
  • C + U-Plane combining
  • TTI shortening (1 symbol)
    => Reduces transmission delay
  • local-break out
    => Reduces stack processing
  • Synchronous data interface
    => Reduces buffer length
Radio Module

- Outlook (5G)
  - Change subcarrier spacing (overclocking), 5G NR
  - Basic tradeoff between bandwidth and latency
Demo 1: Application Latency
Demo 2: Synchronicity
Conclusion

• Audio PMSE requirements concerning latency and synchronicity are not yet met due to implementation details

• Show-cased modified LTE downlink is a feasible solution concerning the demonstrated KPIs

• Demonstrated optimized LTE approach is not spectrum efficient

• Way from demonstrator to product still unclear
Open Questions

• How to meet the remaining audio PMSE requirements and to guarantee the needed QoS as vertical
• Does the demonstrated concept fit into ongoing IMT development
• How to integrate PMSE requirements into multi-user uplink
• How to handle the power consumption of active terminals
• What kind of spectrum access and network integration is feasible / necessary
• Will 5G be the right technology for PMSE
• ...
Thank you very much for your attention
Backup Slides
Typical Setup of Live Audio Production

- up to 250 microphones
- up to 50 IEMs
## Requirements

<table>
<thead>
<tr>
<th>Characteristic system parameter</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application latency</td>
<td>&lt; 4 ms</td>
</tr>
<tr>
<td>End-to-end latency</td>
<td>&lt; 1 ms</td>
</tr>
<tr>
<td>User experienced data rate</td>
<td>150 kbit/s – 4,61 Mbit/s</td>
</tr>
<tr>
<td>Control data rate</td>
<td>≤ 50 kbit/s</td>
</tr>
<tr>
<td>Communication service availability</td>
<td>99,9999%</td>
</tr>
<tr>
<td>Reliability</td>
<td>99,99%</td>
</tr>
<tr>
<td># of audio links</td>
<td>50 - 300 Simultaneous audio links</td>
</tr>
<tr>
<td>Service area</td>
<td>≤ 10,000 m² Event area, indoor and outdoor. Typical heights of indoor stages: 5 – 10 m</td>
</tr>
<tr>
<td>Synchronicity</td>
<td>0,25 µs – 1 µs All wireless mobile devices of one local high quality network shall be synchronized at the application level within the specified accuracy</td>
</tr>
<tr>
<td>User speed</td>
<td>≤ 50 km/h</td>
</tr>
<tr>
<td>Security/ Integrity</td>
<td>The user data is encrypted</td>
</tr>
</tbody>
</table>

End-to-end maximum allowable latency, includes application and application interfacing

Latency that is introduced per link of the wireless communication system

Different user data rates per audio link need to be supported for different audio demands

Data rate per control link

The packet error ratio (PER) of the system shall be below $10^{-4}$ for a packet size corresponding to 1 ms audio data

Simultaneous audio links

Event area, indoor and outdoor. Typical heights of indoor stages: 5 – 10 m

All wireless mobile devices of one local high quality network shall be synchronized at the application level within the specified accuracy

The user data is encrypted
Use Case & Demo: Audience Services
Assistive Live Listening Service

Demonstration of an Audience Service for Live Events

Robert Hupke and Marcel Nophut, Leibniz Universität Hannover
Live Scenario

Listener

Mixing Desk

Stage
Assistive Live Listening Service

Mixing Desk
- PA Signal
- Wireless Link
- Audio Inputs

Stage
- Ambient Sound (AS)

Audience
- Individual Mix
- Assistive Live Listening Signal (ALLS)

Listener
Assistive Live Listening Service

- In-ear headphones with external microphones capturing Ambient Sound (AS)

- Assistive Live Listening Signal (ALLS) received from low-latency wireless link

- Individual mix of Ambient Sound (AS) and Assistive Live Listening Signal (ALLS) presented through headphones
Today’s Setup

- **Mixing Desk**
  - PA Signal
  - Audio Inputs (2)
- **Stage**
  - Ambient Sound (AS)
  - Individual Mix (2)
- **Listener**
  - Assistive Live Listening Signal (ALLS)
  - 2 Mix
  - Audience Service
- **Wireless Link**

Date: 22.03.18
Today’s Setup

Mixing Desk

Stage

Listener

PA Signal

Wireless Link

Ambient Sound (AS)

Assistive Live Listening Signal (ALLS)

Individual Mix

Audio Inputs

2

You

2

2

2

2
Features of the Service

Presented applications today:

• Improving speech intelligibility (e.g. in reverberating environments)

• Instrument highlighting

Many more possible applications...
Speech Intelligibility

- Speech in a church
- Low direct to reverberant ratio

- Increasing the direct sound energy by mixing the AS with the ALLS
- Result: Enhancement of Speech Intelligibility
Speech Intelligibility

- Speech in a church
- Low direct to reverberant ratio

- Increasing the direct sound energy by mixing the AS with the ALLS
- Result: Enhancement of Speech Intelligibility
Speech Intelligibility

• Speech in a church
• Low direct to reverberant ratio

• Increasing the direct sound energy by mixing the AS with the ALLS
• Result: Enhancement of Speech Intelligibility
Research Question

Does the ALLS enhance the speech intelligibility without loss of live experience (Liveness)?
Perceptual Evaluation

• ALLS
  • 17s long male speech signal

• AS signal
  • Recording of the speech signal played back in a church

• Five mixing ratios:
  • Signal #1: 100% AS and 0% ALLS
  • Signal #2: 75% AS and 25% ALLS
  • Signal #3: 50% AS and 50% ALLS
  • Signal #4: 25% AS and 75% ALLS
  • Signal #5: 0% AS and 100% ALLS
Listening Experiment

• Customized SAQI Test

• Perceptual qualities:
  • Reverberation Time
  • Speech Intelligibility
  • Naturalness
  • Presence
  • Degree-of-Liking
Speech Intelligibility and Live Experience

• ALLS enhances speech intelligibility and preserves live experience
Degree-of-Liking

• Optimal mixes achieve higher “Degree-of-Liking”
• “Degree-of-Liking” seems correlated to speech intelligibility while live experience is preserved
Optimal mixes achieve higher “Degree-of-Liking”
“Degree-of-Liking” seems correlated to speech intelligibility while live experience is preserved
Speech Intelligibility

• Results are nearly identical to calculated STI values
• Assistive Live Listening Service can improve speech intelligibility

Put your headphones on
Infrared-Receiver

Volume → Channel 0
Different Mixing Ratios

You hear:

100% AS + 0% ALLS
Different Mixing Ratios

You hear:

0% AS + 100% ALLS
Different Mixing Ratios

You hear:

25 % AS + 75 % ALLS
Perceptual Evaluation – Results

• ALLS enhance speech intelligibility while preserving “Live-Experience”
• Optimal mixing ratios achieve higher “Degree-of-Liking”
Temporal Alignment of Signals

- **Mixing Desk**: PA Signal
- **Stage**: Ambient Sound (AS)
- **Listener**: Individual Mix
- **Audio Inputs**: Wireless Link
- **Assistive Live Listening Signal (ALLS)**

Diagram showing the flow of signals from the mixing desk to the stage and then to the listener, including wireless links and assistive services.
Temporal Alignment of Signals

Mixing Desk

PA Signal

Wireless Link

< 5 ms

Stage

Ambient Sound (AS)

~ 3 ms/m

Individual Mix

Assistive Live Listening Signal (ALLS)

Audience Service

Audio Inputs

Listener

22.03.18
Temporal Alignment of Signals

- Time delay $\Delta t$ has to be estimated
- ALLS has to be delayed accordingly
Temporal Alignment of Signals

You hear:

ALLS + AS

WITHOUT TEMPORAL ALIGNMENT
Temporal Alignment of Signals

You hear:

ALLS + AS

WITH

TEMPORAL ALIGNMENT
Temporal Alignment of Signals

You hear:

ALLS + AS

WITHOUT TEMPORAL ALIGNMENT
Temporal Alignment of Signals

You hear:

ALLS + AS
WITH TEMPORAL ALIGNMENT
Demonstrator Setup

- Analog Devices ADSP-SC589 “Griffin” SoC evaluation board
  → Real-time estimation of time delay and compensation
- RME Fireface UFX+ audio interface (incl. remote faders)
  → Mixing of signals
Demonstrator Setup

- ALLS
- AS

RME

UFX+

Audio Mixer

Remote Fader

DSP Board

UART Monitor
Estimation Procedure on DSP

1. **Peak detection**
   - Raw peak detection (maximum peak)

2. **Confidence Check**

3. **Check for non-causal peaks** (special case)

4. **Consistency Check**

5. **Recursive averaging**
   - Raw TDE estimation (FD-CC)

6. **Sample Delay Line**
Estimation Procedure on DSP

\[ \Delta t = 30 \text{ ms} \]

\[ \Delta t = 20 \text{ ms} \]
Temporal Alignment – Live Demo

• Estimated time delays via UART Monitor from DSP
  • **Blue Curve**: Raw Estimation Results
  • **Red Curve**: Stabilized Estimation Results
  • **Green Curve**: Result Confidence Level

• Switch between different time delays
  • Real-time estimation and adaption
Temporal Alignment – Results

• Temporal alignment necessary to avoid irritating echoes, etc.
• Computational efficient method for time delay estimation and compensation
• Post-processing stabilizes results
• Implementation on real-time processing platform
Instrument Highlighting

- “Summertime” played by saxophone and guitar
- Highlighting of guitar
Instrument Highlighting

• “Summertime” played by saxophone and guitar

Put your headphones on

• Highlighting the instrument
Instrument Highlighting

- “Summertime” played by saxophone and guitar

- Highlighting of guitar
Summary

Assistive Live Listening Service – Demonstration today:

• Useful applications at live events:
  • Improving speech intelligibility
  • Instrument highlighting

• Perceptual evaluation:
  • Proves enhancement of the live experience by our service

• Real-time Assistive Live Listening Service demonstrator:
  • Prototype headsets with external microphones
  • Delay estimation and compensation on DSP
Outlook

Assistive Live Listening Service – in the future:

• Usage of our service within reach during the next years
• Processing and control performed by app on smartphone
• External microphones will be default feature on headphones
Use Case & Demo:
Production & Contribution
PMSE-xG

Demonstration
Convergent Video Production and Distribution with Multi-Access Edge Computing

Georg Acher, Detlef Fliegl, Smart Mobile Labs
Smart Mobile Labs

• Founded in 2013
  • Nokia Spin-off
  • Currently 24 employees

• Core competence
  • Low latency video and data transmission over LTE
  • Management & operation of LTE infrastructure
  • Many-2-Many distribution (EVO = Edge Video Orchestrator)
  • Venue & event environments
  • Live video production

• Further business areas
  • Real-time CDN
  • Public safety
  • Connected car
LTE with SML@PMSE

• Large events
  • Large coverage area
  • Many data sources (cameras, etc.)
  • Big number of visitors (smartphones, etc.)
  • Create live content in place
  • Distribute video & audio in real-time
  • Internal usage: telemetry, intercom, team radio

• Limitations of LTE networks
  • Number of users
  • Bandwidth
  • Real-time (latencies and synchronization)
  • Internal processing capabilities („MEC“)
MEC details

**MEC** = [Multi-Access | Mobile] Edge Computing

- Computing infrastructure ("cloud") at the edge of the mobile core network
  - Lowest possible latency to UE, high bandwidth
  - Additional networking features like
    - Proxy
    - Interception
    - Duplication
  - Access to UE properties (location, ... )
- Currently in standardization, no "full MEC" products yet
- SML EVO is already certified for Nokia Edge Cloud

MEC deployment
- Fully owned network and MEC
- Attaching own "MEC" to existing infrastructure (local breakout)
- Using MEC from MNO
Demonstration - Goals

• Measurements and (mainly) versatile functionality demonstration

• Integration of LTE equipment into traditional production
  • Interfaces, latencies, compatibility issues

• Moving “traditional” production into mobile network & MEC
  • Interaction with legacy equipment
  • Exploring requirements, possibilities and challenges
    • Required CPU/GPU/network resources
    • Technical workflows, setups, parameters, ...
    • Useful “standard” MEC applications for video, audio and other control
    • Soft/hard limitations

• Finding topics for further cooperation (→ LIPS project)
Demonstration - Key components

16.03.2018

4G eNodeB EPC

MEC Video Switcher Master Controller

---

PTZ SDI LTE-Video-Codec

DMX

PTZ SDI LTE-Video-Codec

---

Smartphone Audio Intercom

Display

LTE-Raspi Intercom

Controller

Ethernet GbE-Switch

Video-Codec

HDMI USB

Audio

---

PDSE xG

16.03.2018
Demonstration – Components details

• LTE eNodeB (base station)
• EPC (Evolved Packet Core)
• MEC-like local processing units
• PTZ-cameras with LTE-video encoders (h.264)
• HW video mixer (SDI I/O)
• Intercom between camera operators and editor
• Other input and output
  • SDI I/O ("legacy interfaces")
  • DMX (demo by Light)
  • Telemetry (visualization demo with game controller)
  • Mobile device (demo by tablet)
Demonstration - MEC applications

- Video processing
  - CasparCG (patched)
- Raw video encoding/decoding
  - ffmpeg (patched)
- Video mixer command interface
  - (SML)
- Common VISCA/remote head control
  - (SML)
- Simple DMX control (lightshow)
  - (SML)
- Telemetry reception and visualization
  - (SML)
- Overall setup + scripting for easy integration
  - (SML)
- Intercom/teamradio
  - Asterisk
- AoIP switch matrix
  - (SML)
Now the demonstration...
Some numbers and test results

- Ping HW-encoder, LTE, HW-decoder 14-200ms, avg. 50ms
- Latency HW-encoder, LTE, HW-decoder 350-450ms
- Latency HW-encoder, LTE, ffmpeg 300-600ms (with optim.)
- Latency HW-encoder, LTE, CasparCG 600-1200ms (with optim.)

- Encoder/decoder mainly determine latency
- Still a lot of optimization potential in SW processing
- No synchronization of video sources
- Network jitter more important for VoIP/AoIP/DMX
Conclusion

• PMSE can benefit from 5G+MEC
  • Reduced latency
    • Better synchronization of wired and wireless 5G cameras
    • Live distribution of signals to audience on the spot
  • Allow more bandwidth
    • More cameras
    • Higher framerates
    • Higher resolution
    • (Ultra)Low-latency codecs
  • MEC resources (standard to be finalized)
    • Local processing power for audio & video production without HW setup
    • Traffic handling (stream distribution), UE discovery
    • Low-latency access to network traffic
LIPS (Live Interactive PMSE Services)

Dr. Konstantin Septinus

(LIPS Project Overview – PMSE-xG Final Workshop, 16.03.2018)
On Technological Convergence

• 5G only as „cable replacement“ does not make sense
• In today’s big events, TV productions and conferences, multiple different wireless systems are hooked-up together or run in parallel
• Having one technology serving production, local networking, and distribution sounds very promising
• However, all workflows and business models would need to change
Medium to Long Term Vision
Interactive Live Events in 5G Ecosystem

Konstantin Septinus | LIPS Project Overview @ PMSE-xG Final Workshop

16.03.2018
PMSE within 5G - A Long Way Down the Road

• Several open points (latency, time-sync, reliability...) need to be considered and integrated into the 5G standard in order to enable operation of PMSE – here we’ve just started activities at 3GPP

• Similar to other verticals like e-health, industry automatization etc., PMSE require having their own local high quality networks – here we’re discussing all kinds of deployment models

• The PMSE-xG testbeds have only been a very first step and much further work towards appropriate technical solutions is required

• Will PMSE be confronted with new media, such as VR, AR, or RR?
LIPS (Live Interactive PMSE Services)

- Develop smart services for the interactive and immersive linking to or between live events (Remote Reality)
- Technological convergence of production and distribution networks for production and live distribution
LIPS (Live Interactive PMSE Services)

- Project schedule: April 2018 to August 2020
- Co-Funding: BMWi (Smart Service Welt II)
- Project lead: Sennheiser

- Advisory board
- Further discussion of 5G networks:
  - feasibility
  - demonstration
  - standardization
  - regulation

Konstantin Septinus | LIPS Project Overview @ PMSE-xG Final Workshop
LIPS (Live Interactive PMSE Services)
Integration and New Services based on 5G Ecosystem

- Immersive A/V plus adaptive, matched lighting: ARRI Lighting
- Assistive live listening: Sennheiser Streaming Technologies
- Sennheiser targets
  - professional audio application
  - complete wireless production setup within IMT
  - test hardware and system development
- We’re interested in enabling our applications – spectrum, chips, ecosystem
Your contact persons:

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