5G Tactile Internet
Lab Experimentation @ King’s

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UK 5G Testbed Meeting, London
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Internet of Skills “Human 4.0”
Breaking Physics
Fundamental Shift

Proprietary Circuit-Switched Audio & Video Technologies

Yesterday's Innovation & Standards:
- network technologies, audio & video codecs

Standardized Packet-Switched Internet, enabling Economy of Scale

Proprietary (and expensive) Haptic-Edge Technologies

Today's Innovation & Standards:
- network, intelligence, tactile codec

Standardized Tactile Internet, enabling Economy of Scale

Fundamental Shift
Haptics, i.e. the complete perception of form, position, surface texture, stiffness, friction, temperature, etc.

**Closed Loop Communications:**
- 1,000-4,000 Hz sampling/packet rate
- very strict delay constraints (<10ms)
- lack of realism (can’t feel)

**Open Loop Communications:**
- 5-200 Hz sampling per tactile point
- very relaxed delay constraints (ca 100ms)
- improved realism (but can’t move)
1) Ultra-Fast Networks (Tactile Internet)
2) Haptic Encoders (both kinesthetic & tactile)
3) Edge Artificial Intelligence (to beat light-limit)

Core Enablers of the “Internet of Skills”

Operator(s) with haptic human-system interface (possibly distributed)

Internet, transmitting audio-visual and haptic information.

Telecommunications Core and Radio Access Network, and an intelligent Haptic Support Engine.

Haptic edge composed of e.g. remotely controlled robots.

**Technology Components**

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**Master Domain**

- Haptic Codec
- Router
- Packet Gateway
- Serving Gateway
- Haptic Support Engine
- Base Station

**Network Domain**

- Bi-Directional Haptic Control with perception of low delay
- Response (e.g. force)
- Command (e.g. velocity)

**Controlled Domain**

- Haptic Codec
- Haptic edge composed of e.g. remotely controlled robots.
Multi Service and Multi Tenancy based Network Slicing to cater for:

- service quality and performance
- service-specific functionality
- adaptation to available infrastructure

Mobile Network Multi-tenancy to support on-demand allocation of RAN and CN resources in a fully multi-tenant environment

Multi-service- and context-aware adaptation of network functions to support a variety of services and corresponding QoE/QoS requirements

5G NORMA interface
Understanding (tactile) touch:

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<thead>
<tr>
<th></th>
<th>Merkel cell</th>
<th>Ruffini ending</th>
<th>Meissner corpuscle</th>
<th>Pacinian corpuscle</th>
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</thead>
<tbody>
<tr>
<td><strong>Best stimulus</strong></td>
<td>Pressure, edges,</td>
<td>Stretch</td>
<td>Lateral motion</td>
<td>High-frequency</td>
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<tr>
<td></td>
<td>corner, points</td>
<td></td>
<td></td>
<td>vibration</td>
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<td><strong>Example</strong></td>
<td>Reading Braille</td>
<td>Holding large</td>
<td>Sensing slippage</td>
<td>Sensing texture</td>
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<td>objects</td>
<td>of objects</td>
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<tr>
<td><strong>Frequency range (Hz)</strong></td>
<td>0-100</td>
<td>/</td>
<td>1-300</td>
<td>5-1000</td>
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<tr>
<td><strong>Best Frequency (Hz)</strong></td>
<td>5</td>
<td>/</td>
<td>50</td>
<td>200</td>
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</tbody>
</table>

**Haptic Encoders**
Encoding (tactile) touch:

Vibrotactile signals are similar to speech signals

Codec performance: 2.3 kbps at full perceptual transparency
Encoding kinesthetic signals:

Perceptual haptic data reduction approach:
- exploits limits of human haptic perception
- packet rate reduction of up to 90% (no perceivable distortion)
- leads to a variable packet rate → event-based sampling and communication
Edge-AI
Model-Mediated Teleoperation Systems:

Stable haptic interaction for delays 10ms ... 200ms

Model errors / updates lead to reduced transparency

© Prof Eckehard Steinbach, TU Munich
Transforming Industries

Prokar Guy's Hospital NHS, UK

Matt
Transport for London, UK

Ali
Cinema Arts Network
Disrupting Health

Co-Design with Prof Prokar (5ms challenge)
THIS IS WHERE WE ARE TODAY:

- Lag – 250ms
- Hacking
- ELS Implications
- Cost
- Lack of “The Human Touch”
Remote Haptic Diagnostics & Intervention

5G RAN/CN

SDN/VPN/tunnel

Patient’s Remote Location

Doctor’s Location

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Haptic Service Testbed, step #1 @ 5G Mobile Summit, London, 29-30 June 2016
Co-Design with Ali Hossaini (Gbps challenge)

Disrupting Arts
Co-Design with TFL/Heathrow/Tata/others (reliability challenge)

Disrupting Transport
The Tactile Internet will be an enabler for remote skillset delivery and thereby democratize labour and wealth globally.
None of that would be possible without colleagues & PhD students as well as our collaborators:

Gerhard Fettweis, TUD
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Thrish Nanayakkara, KCL
Frank Sardis, KCL
Prof Prokar, KCL
Ali Hossaini, artist
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Hamid Aghvami, KCL
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Tactile Internet Standardisation

- IEEE ETC Tactile Internet Committee:
  - founded by TUD, KCL & many others
  - chaired by Meryem Simsek (TUD)

- IEEE 5G Tactile Internet WG:
  - founded by KCL, E///, TUD and others
  - chaired & largely made possible thanks to Oliver Holland (KCL)
  - IEEE standards portal opened, mailing list created
  - first meeting in Kuala Lumpur this week --- JOIN IN!
Internet of Things --- MOOC

Supporting References:


[2] “Changing the world with tech – Part I & II” televised globally on CNBC (showing our 5G and Tactile Internet developments), 4 May 2016.


