An Internet of Skills

… where Robotics meets AI and the Tactile Internet

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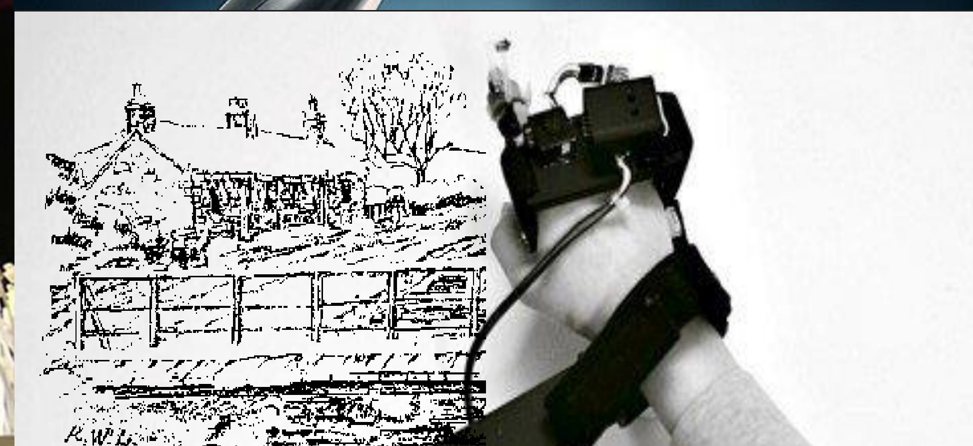
IEEE ICC 2016, Plenary Keynote
Kuala Lumpur, Malaysia, 26 May 2016



Internet of Skills

"Human 4.0"

Yesterday's

Innovation & Standards:

network technologies, audio & video codecs

Proprietary Circuit-Switched Audio & Video Technologies

Standardized Packet-Switched Internet, enabling Economy of Scale

Today's

Innovation & Standards:

network, intelligence, tactile codec

Proprietary (and expensive) Haptic-Edge Technologies

Standardized Tactile Internet, enabling Economy of Scale

Fundamental Shift

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

Kinesthetic Perception

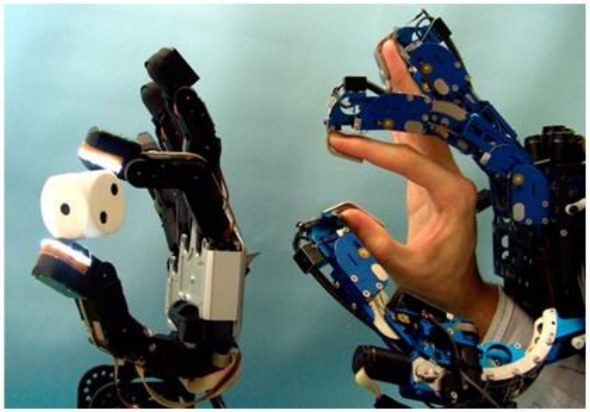


Image Source: Katsunari Sato, Dept. of MEIP, The University of Tokyo/Japan

position & forces

+

Tactile Perception

sense of touch of the skin

<u>Closed Loop Communications:</u>

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

<u>Open Loop Communications:</u>

- **5-200 Hz sampling per tactile point**
- **very relaxed delay constraints (ca 100ms)**
- **improved realism (but can't move)**

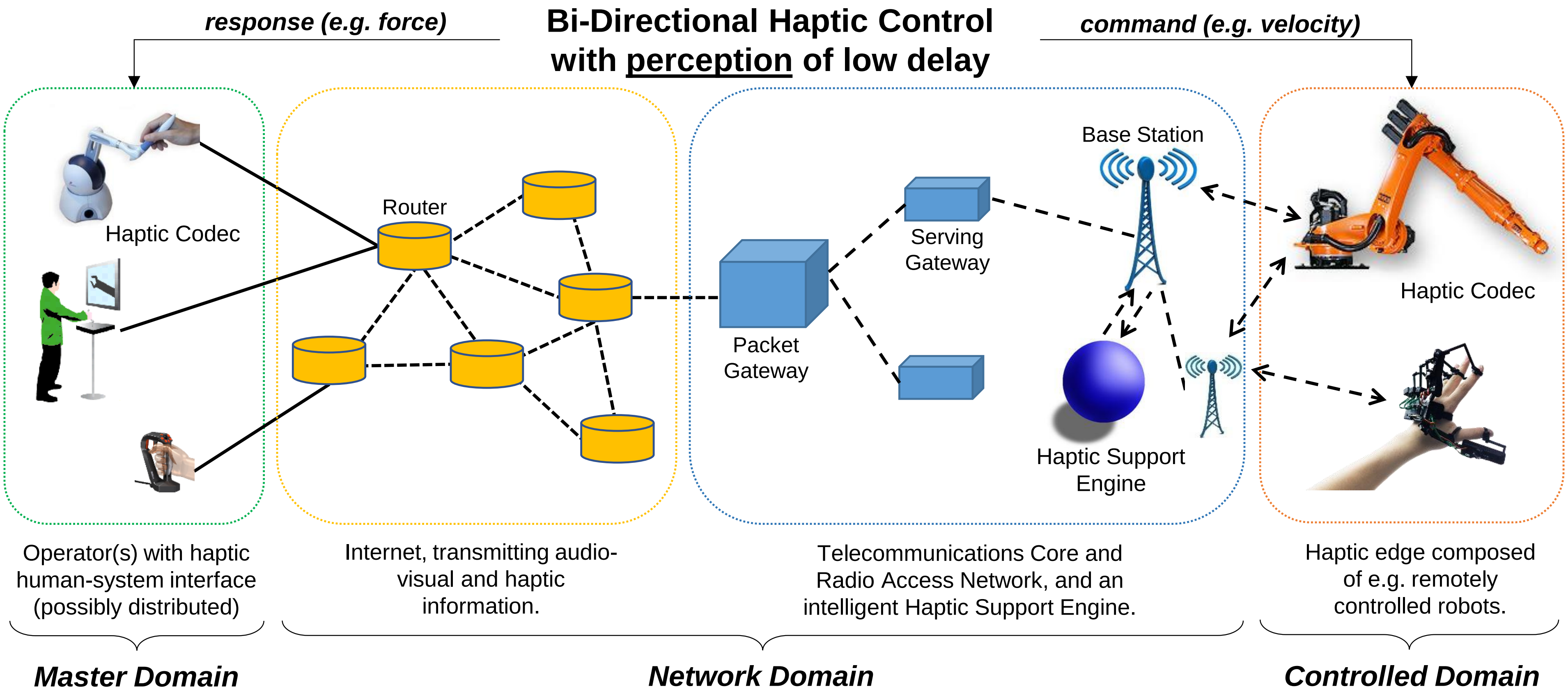
A Little Secret

1) Ultra-Fast Networks (Tactile Internet)

2) Haptic Encoders (both kinestaethic & tactile)

3) Edge Artificial Intelligence (to beat light-limit)

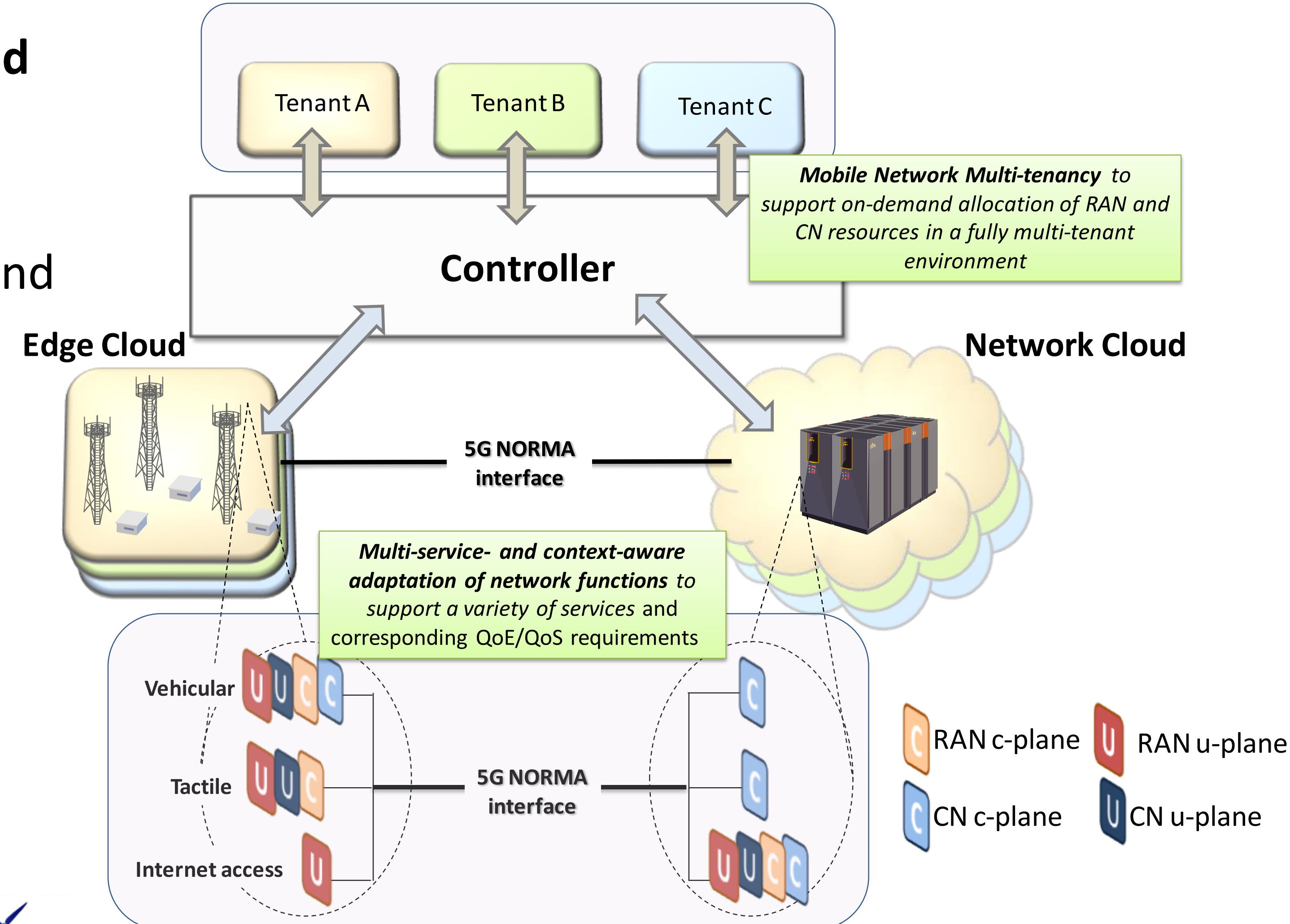
Core Enablers of the "Internet of Skills"



Technology Components

Multi Service and Multi Tenancy based Network Slicing to cater for:

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



5G NORMA VIRTUWIND

Ultra-Fast Network

Unsolved or partially unsolved challenges to enable ultra-fast network:

1. sort out SLA capabilities over LE spectrum
2. make device-to-device (D2D) work properly
3. enable fully decoupled RAN architecture (e.g. DUDe)
4. full cellular functionality without core network
5. trade-off cloud-RAN & content clouds
6. keep an eye on net-neutrality

Ultra-Fast Network

Understanding (tactile) touch:

Thrish, King's

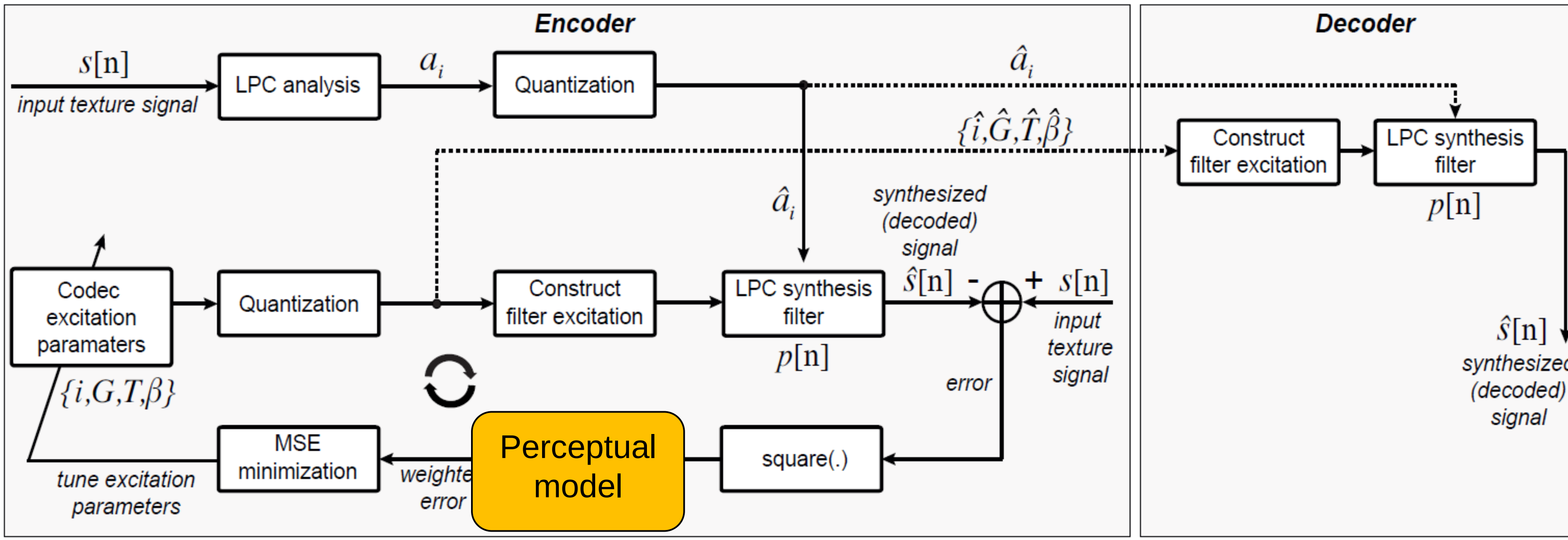
	Merkel cell	Ruffini ending	Meissner corpuscle	Pacinian corpuscle
Best stimulus	Pressure, edges, corner, points	Stretch	Lateral motion	High-frequency vibration
Example	Reading Braille	Holding large objects	Sensing Slippage of objects	Sensing texture
Frequency range (Hz)	0-100	/	1-300	5-1000
Best Frequency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

Haptic Encoders

Encoding (tactile) touch:

Eckehard Steinbach, TUM

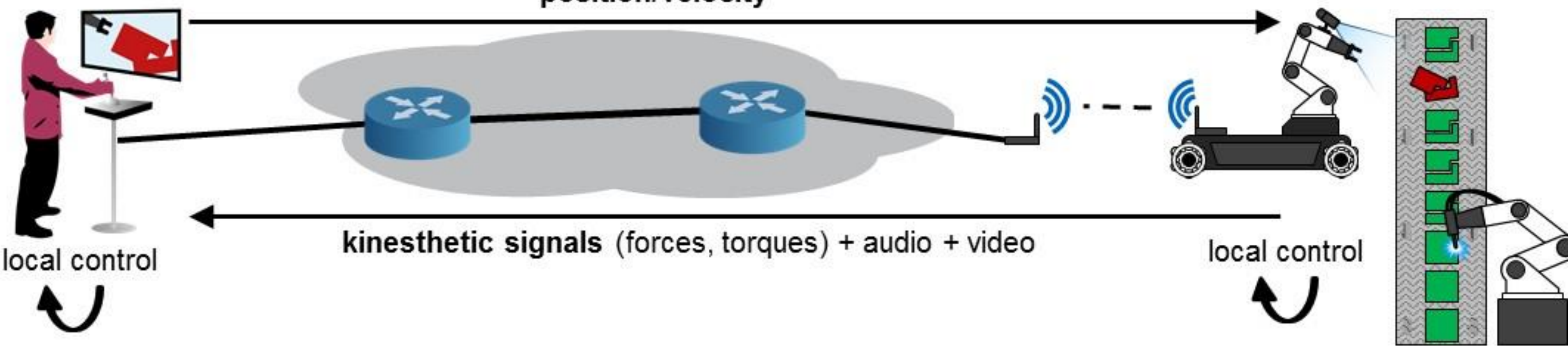
Vibrotactile signals are similar to speech signals



Codec performance: 2.3 kbps at full perceptual transparancy

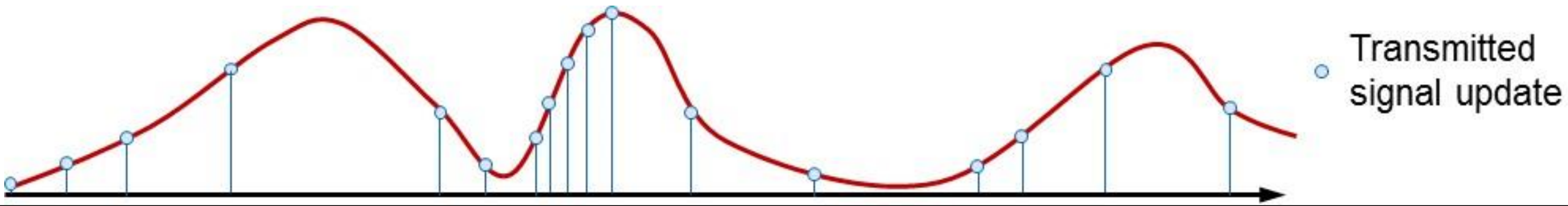
Haptic Encoders

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**



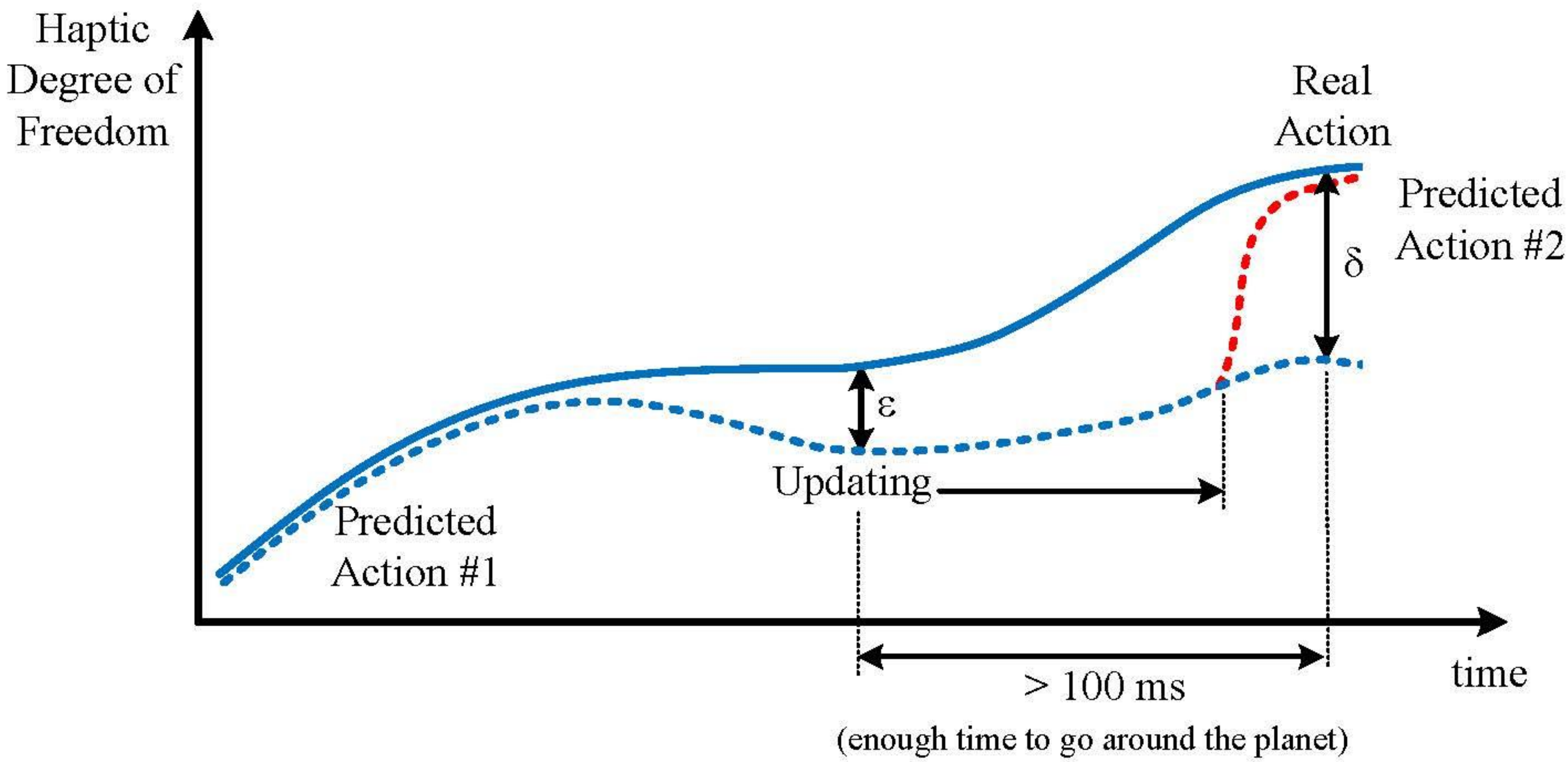
Haptic Encoders

Unsolved or partially unsolved challenges to enable tactile + kinesthetic encoders:

1. haptic mean opinion score (h-MOS)
2. trade-off & standards for joint tactile and kinesthetic
3. trade-off studies for integration with other codecs
4. adapting (below) audio codecs vs eg compressed sensing

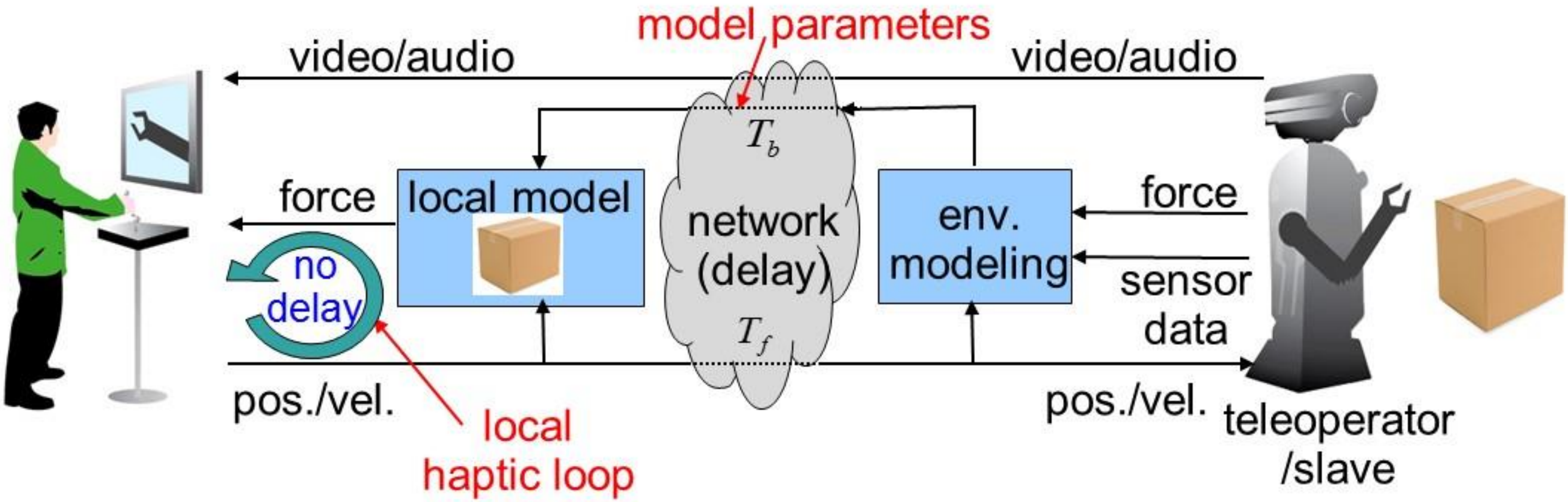
Compression Method	Bit rate (Kps)	Framing size	MOS score
G.711 PCM	64	0.125	4.1
G.726 ADPCM	32	0.125	3.85
G.728 LD-CELP	16	0.625	3.61
G.729 CS-ACELP	8	10	3.92
G.729a CS-ACELP	8	10	3.7
G.723.1 MP-MLQ	6.3	30	3.9
G.723.1 ACELP	5.3	30	3.65

Haptic Encoders


Haptic Degree of Freedom
Real Action
Predicted Action #2
δ
ε
Updating
Predicted Action #1
time
> 100 ms
(enough time to go around the planet)

Edge-AI

Model-Mediated Teleoperation Systems:



Stable haptic interaction for delays 10ms … 200ms

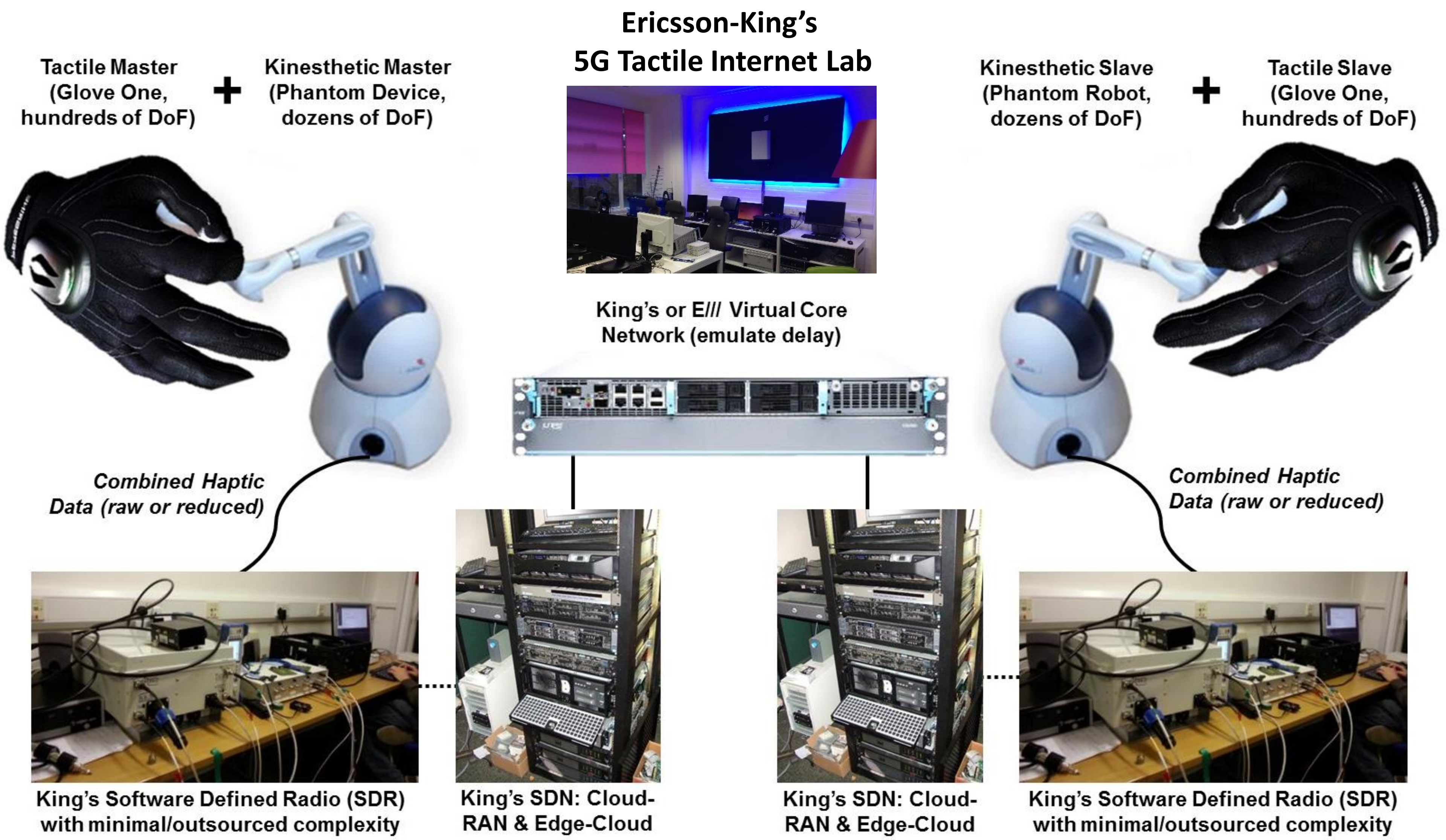
Model errors / updates lead to reduced transparency

Edge-AI

Unsolved or partially unsolved challenges to enable edge artificial intelligence (AI):

1. environment modeling (geometry and physical properties)
2. stable force rendering on the master side
3. standardised database of environmental models
4. cloud placement of intelligence and functionalities
5. quickly converging predictive-AI solutions (e.g. docitive systems)

Edge-AI



5G Tactile Internet Lab

Video available under
https://www.youtube.com/watch?v=CwaGOQM3vGE

Disrupting Health

Disrupting Arts

Video available under https://www.youtube.com/watch?v=LNxXSIRXTvg

Have your say!


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 my colleagues & PhD students as well as our collaborators:

Gerhard Fettweis, TUD

Eckehard Steinbach, TUM

Toktam Mahmoodi, KCL

Peter Marshall, Ericsson

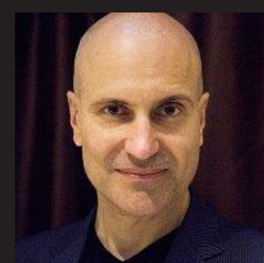
Maria Lema, KCL

Oliver Holland, KCL

Thrish Nanayakkara, KCL

Hamid Aghvami, KCL

Prof Prokar, KCL



Ali Hossaini, artist

Meryem Simsek, TUD

Frank Fitzek, TUD

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

Sign up on for free with my next course starting 6 June 2016:
https://www.futurelearn.com/courses/internet-of-things.

Thanks … and please follow me on …

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Supporting References:

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