Go2Edge Kick-off Meeting
University of Valladolid (UVa), February 12-13, 2020

THE WAY OF THE DAO: TOWARDS DECENTRALIZING THE TACTILE INTERNET

Prof. Martin Maier

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INRS | Tactile Internet | The DAO

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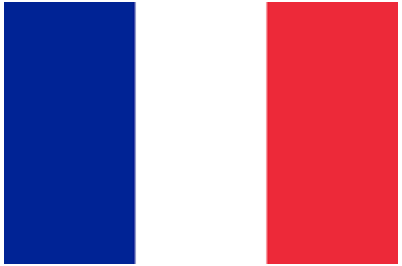
INRS: Research Arm of University of Quebec (UQ)



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INRS: Canada's #1 university for research intensity

November 4, 2016 // by Stéphanie Thibault

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According to Research Infosource, INRS for a third year in a row ranks first for research intensity among Canadian universities without a Faculty of Medicine. In 2015, INRS professors brought in an average of $358,100 in per capita funding for research.

INRS has maintained this stellar performance year after year on the strength of its 149 dedicated and competitive faculty members, its graduate students, its state-of-the-art facilities, and its innovative structure.

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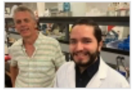

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- **Mission:** Finding solutions to problems facing Quebec's society
- **Four research centers**
  - Water, earth, environment
  - Human/animal health
  - Urbanization, culture, society
  - Energy, materials, telecommunications
- **150 professors**
- **No undergraduate program**

www.ZeitgeistLab.ca

Optical Zeitgeist Laboratory

Research team

The group is headed by Prof. Martin Maier, the founder and creative director of the Optical Zeitgeist Laboratory. Students and researchers interested in joining or visiting the research group are encouraged to contact Prof. Martin Maier for further information.

- Founder & creative director
- Group members
- Visitors
- Alumni
- Collaborators

Openings

News

Scientific research

Current research activities focus on the projects listed below. For more technical details the interested reader is referred to our publications

Ethereum: Decentralized Applications and Autonomous Organizations
The objective of this research project is to combine the capabilities of Ethereum blockchain and emerging Tactile Internet technologies to build a truly distributed P2P architecture that is capable of adopting a resilient, autonomous, and decentralized control for the Tactile Internet applications. Furthermore, this project will promote interaction between humans, machines, and smart contracts. The outcomes of this research project will lead to significant transformations across several industries and open new challenges and business opportunities that are set to revolutionize our digital world.
read more

Toward 6G: The Internet of No Things
Future 6G networks should not only explore more spectrum at high-frequency bands but, more importantly, converge upcoming technological trends such as multisensory extended reality (XR), connected social robots, human-machine interaction, and blockchain technologies. This project will explore the so-called Internet of No Things with its human-intended services that appear when needed and disappear when not needed. The Internet of No Things aims at helping realize the paradigm shift "from 5G engineering to 6G humanity," as envisioned in the world's first 6G White Paper.
read more

Previous projects

Artificial Intelligence based Mobile-Edge Computing
Two-level cloud-cloudlet architectures leverage both centralized and distributed cloud resources and services, whereby the cloudlet infrastructure is typically based on data-centric FiWi access networking technologies. Cooperative automation is a key feature that is expected to enhance unified FiWi and Het-Net networks by means of artificial intelligence (AI) based mobile edge-computing (MEC) capabilities. This research project will address the key challenges towards enabling AI based MEC in FiWi enhanced 4G networks to meet key design requirements such as ultra-low latency. Moreover, TensorFlow, an open source machine-learning library, will be exploited to realize collaborative automation as an important stepping stone towards human-robot symbiosis.
read more

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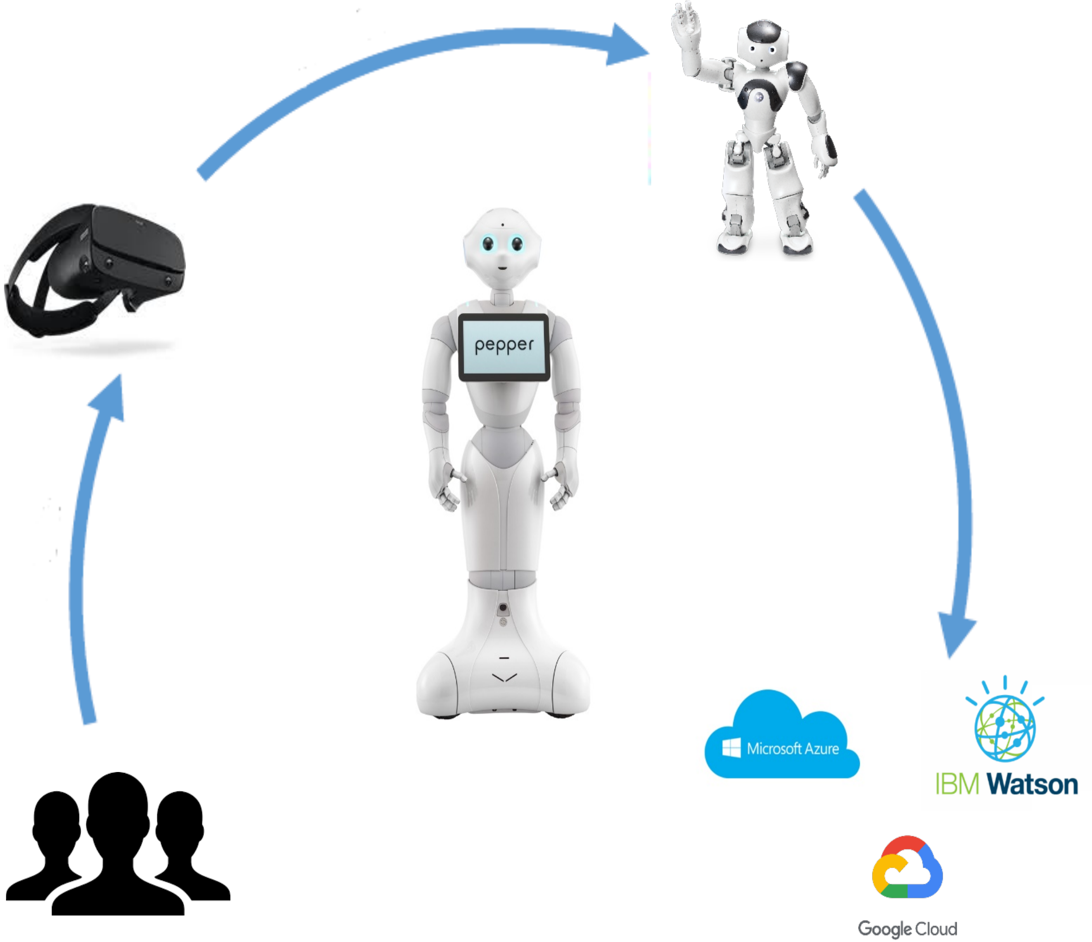

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Social robot “pepper” as hub between different research directions

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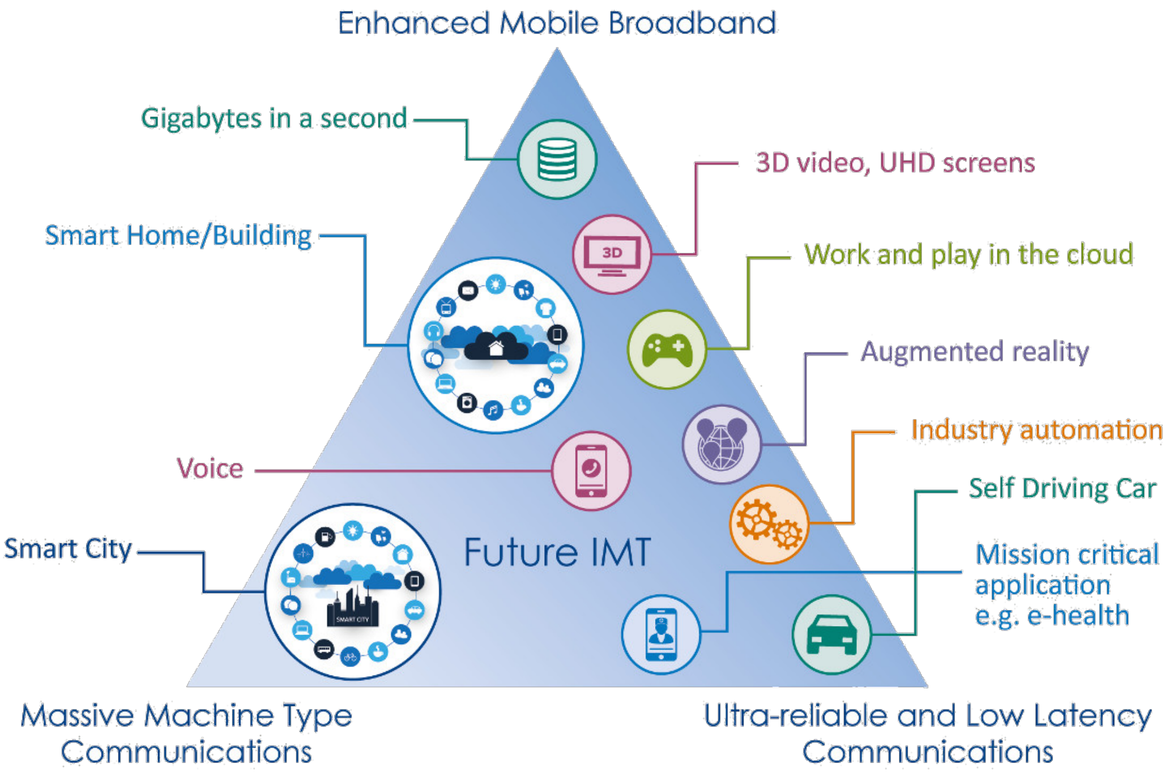
5G Services: URLLC

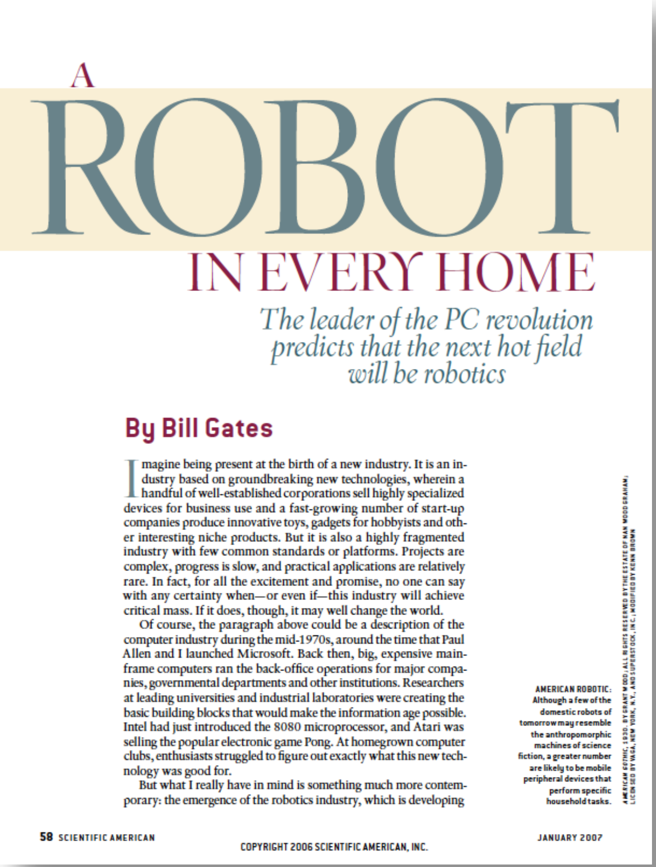


“A Robot in Every Home”

Bill Gates, 2007:

- Robotics industry is developing in much the same way as PC business did 30 years ago

- Vision: PC will get up off the desktop & allow us to see, hear, touch and manipulate objects remotely



A ROBOT IN EVERY HOME

The leader of the PC revolution predicts that the next hot field will be robotics

By Bill Gates

Imagine being present at the birth of a new industry. It is an industry based on groundbreaking new technologies, wherein a handful of well-established corporations sell highly specialized devices for business use and a fast-growing number of start-up companies produce innovative toys, gadgets for hobbyists and other interesting niche products. But it is also a highly fragmented industry with few common standards or platforms. Projects are complex, progress is slow, and practical applications are relatively rare. In fact, for all the excitement and promise, no one can say with any certainty when—or even if—this industry will achieve critical mass. If it does, though, it may well change the world.

Of course, the paragraph above could be a description of the computer industry during the mid-1970s, around the time that Paul Allen and I launched Microsoft. Back then, big, expensive mainframe computers ran the back-office operations for major companies, governmental departments and other institutions. Researchers at leading universities and industrial laboratories were creating the basic building blocks that would make the information age possible. Intel had just introduced the 8080 microprocessor, and Atari was selling the popular electronic game Pong. At homegrown computer clubs, enthusiasts struggled to figure out exactly what this new technology was good for.

But what I really have in mind is something much more contemporary: the emergence of the robotics industry, which is developing

AMERICAN ROBOTIC: Although a few of the domestic robots of tomorrow may resemble the anthropomorphic machines of science fiction, a greater number are likely to be mobile peripheral devices that perform specific household tasks.

“The Tactile Internet”

March 2014:

- G. P. Fettweis coins the term Tactile Internet:

  “Enabling unprecedented mobile applications for tactile steering and control of real and virtual objects”

August 2014:

- ITU-T Technology Watch Report “The Tactile Internet”

“The Tactile Internet”

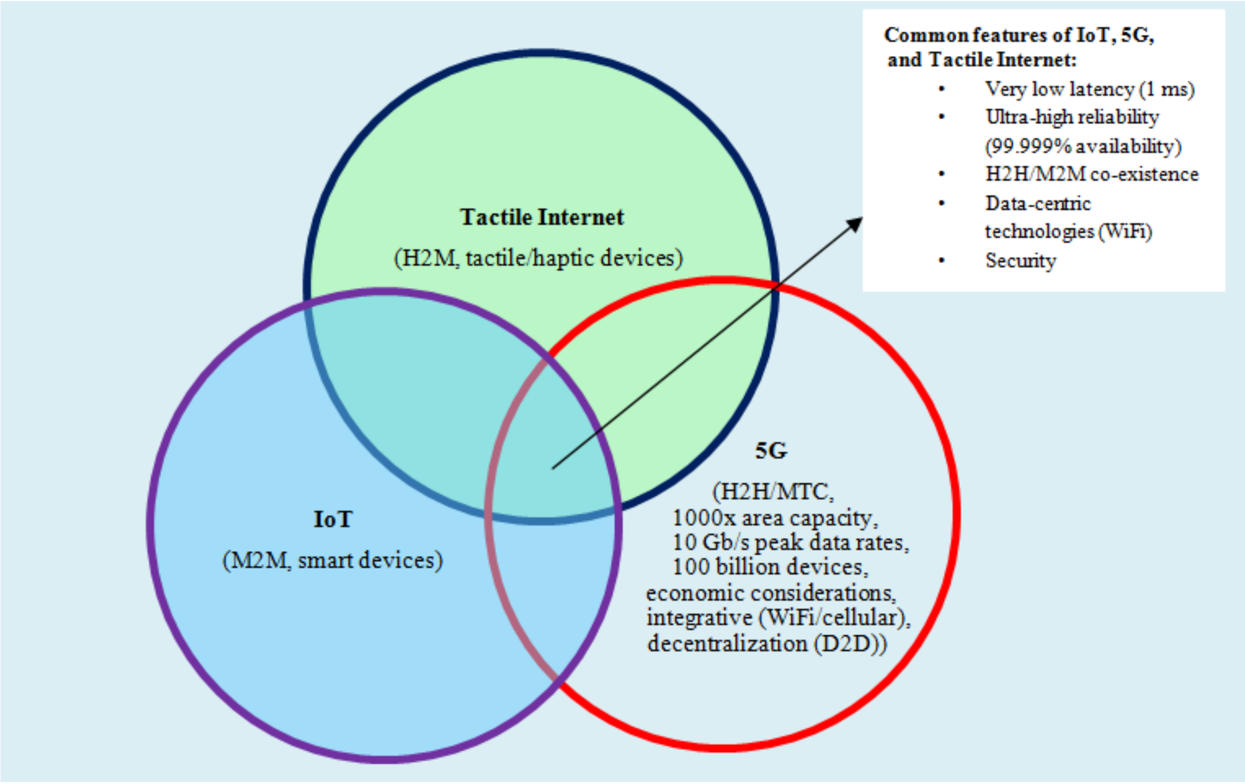
March 2016:

- IEEE P1918.1 standard working group approved by IEEE Standards Association
- Definition of Tactile Internet:

  “A network, or a network of networks, for remotely accessing, perceiving, manipulating or controlling real and virtual objects or processes in perceived real-time”

- Key use cases:
  - Teleoperation, haptic communications, and immersive virtual reality

Tactile Internet vs. IoT & 5G



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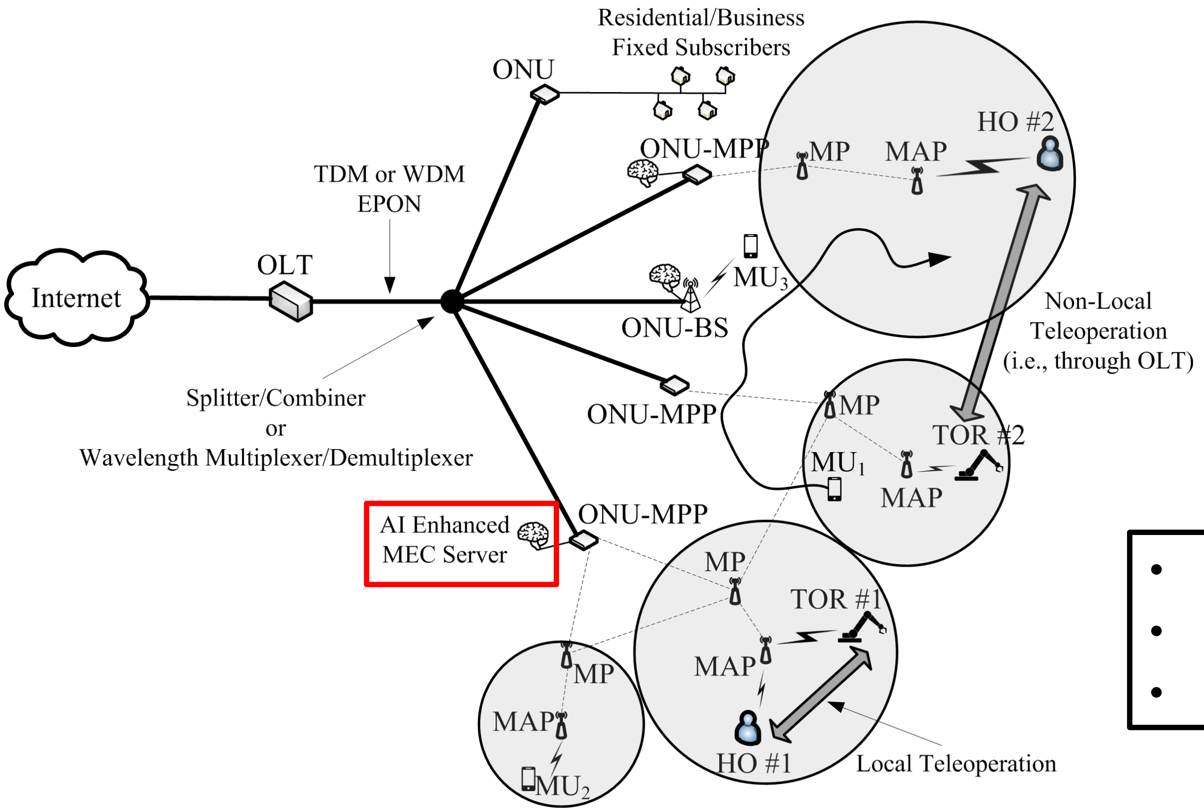
FiWi Enhanced 4G LTE-A HetNets



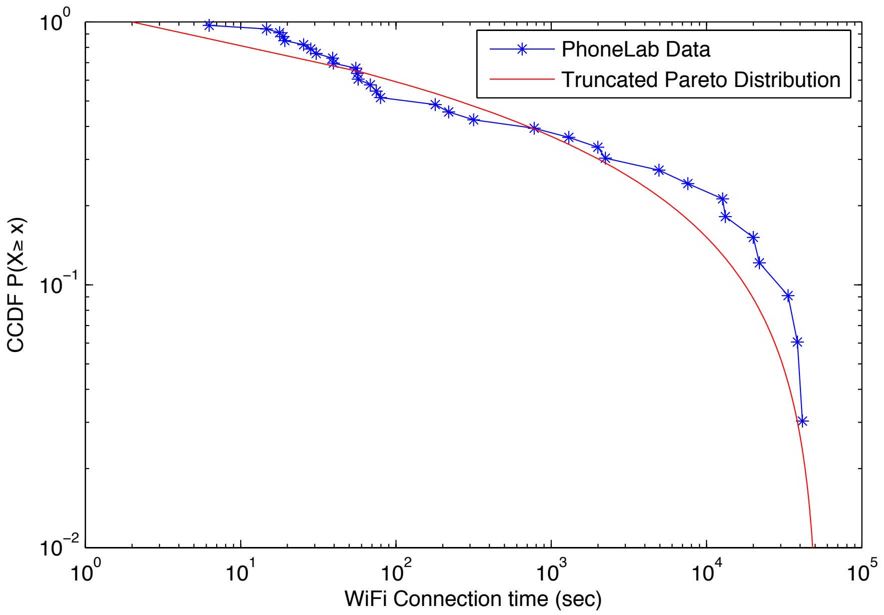
- MU: Mobile User
- HO: Human Operator
- TOR: Teleoperator Robot

WiFi Connection Times of MUs

- CCDF of WiFi connection time of MUs fits truncated Pareto distribution:

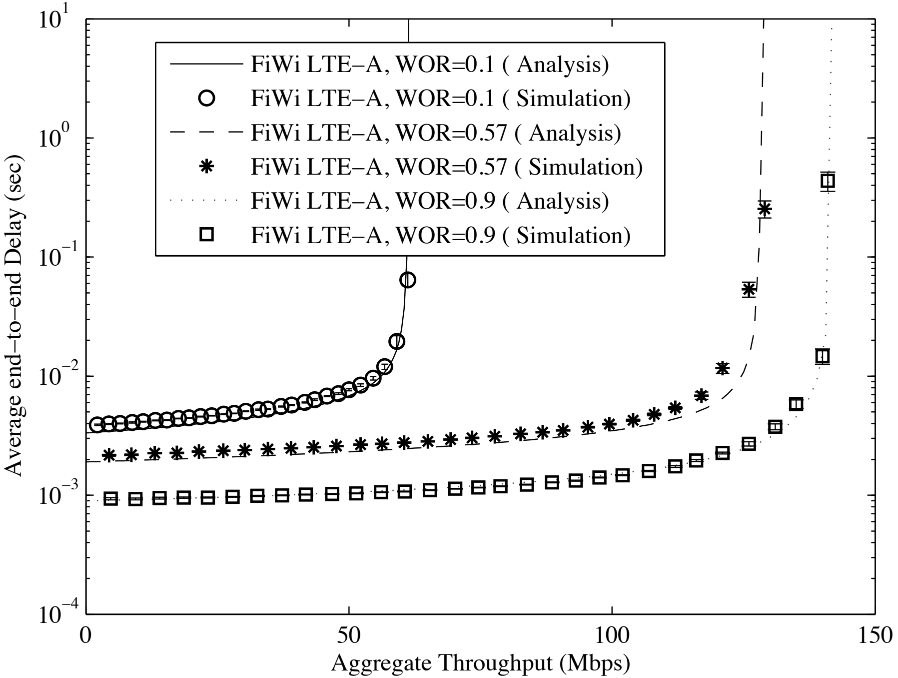
$$\frac{\alpha\gamma^{\alpha}}{1-\left(\frac{\gamma}{\nu}\right)^{\alpha}} \cdot x^{-(\alpha+1)}, 0 < \gamma \leq x \leq \nu$$

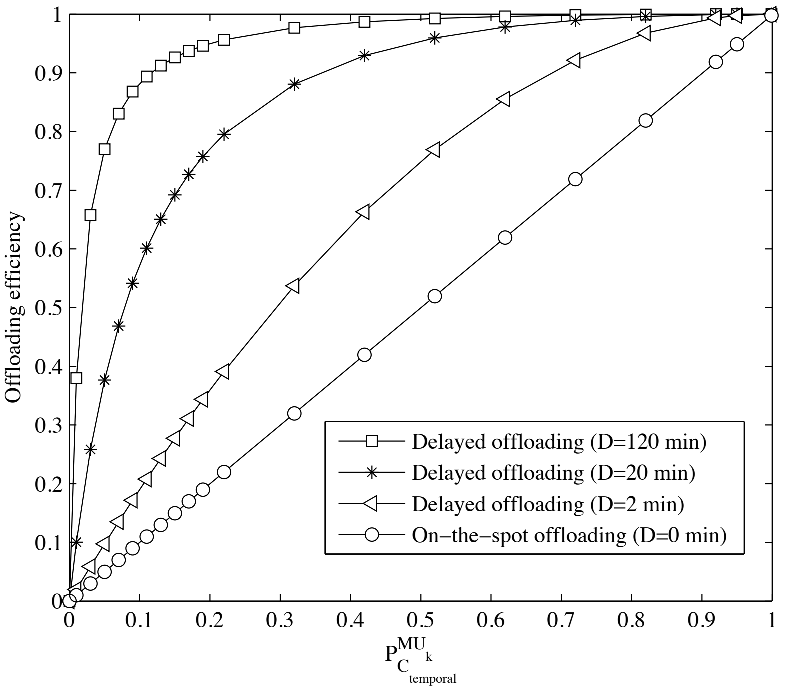
- Verified by using comprehensive **smartphone traces** of PhoneLab data set



H. Beyranvand, M. Lévesque, M. Maier *et al.*, "Toward 5G: FiWi Enhanced LTE-A HetNets With Reliable Low-Latency Fiber Backhaul Sharing and WiFiOffloading," *IEEE/ACM Transactions on Networking*, vol. 25, no. 2, pp. 690-707, April 2017.

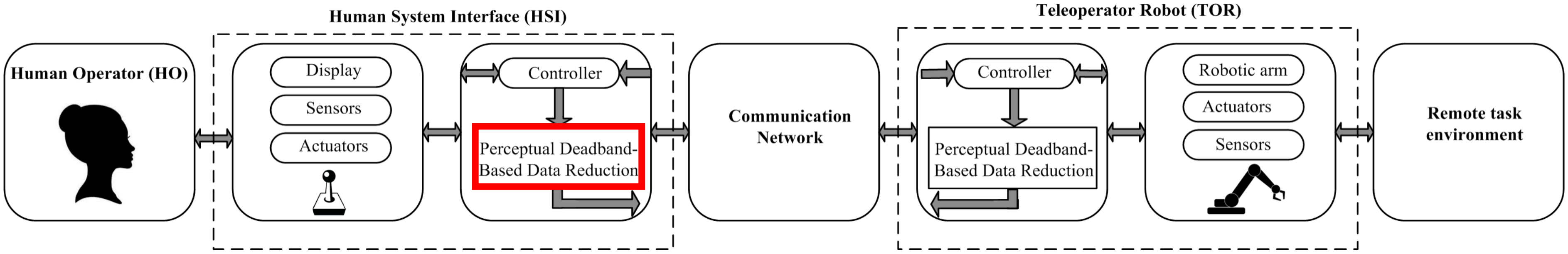
URLLC in FiWi Enhanced 4G LTE-A HetNets

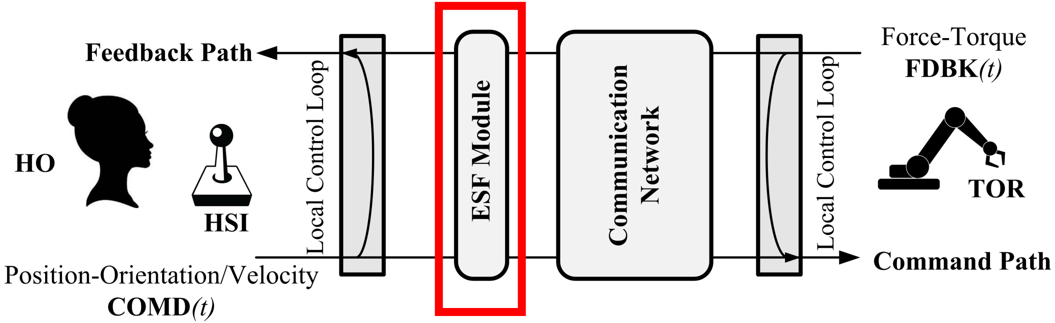




H. Beyranvand, M. Lévesque, M. Maier *et al.*, “Toward 5G: FiWi Enhanced LTE-A HetNets With Reliable Low-Latency Fiber Backhaul Sharing and WiFi Offloading,” *IEEE/ACM Transactions on Networking*, vol. 25, no. 2, pp. 690-707, April 2017.

Teleoperation & Haptic Communications





Edge Sample Forecast (ESF) via AI Enhanced MEC

ESF: Multi-Layer Perceptron (MLP)

Algorithm 1 Edge Sample Forecast

Input: $\mathcal{T}, \mathcal{S}, t_0, \Xi$

Output: θ^*

$\delta = 1/F_s$

$\mathcal{T}^\delta, \mathcal{S}^\delta = \text{SAMPLE\_ALIGNER}(\mathcal{T}, \mathcal{S}, \delta)$

$\Delta \leftarrow \left\lceil \frac{t_0 - \mathcal{T}^\delta(L)}{\delta} \right\rceil$

$\mathcal{A}_0 \leftarrow (s_1^\delta, ..., s_L^\delta) \in \mathbb{R}^L$

for $i = 1$ to Δ **do**

  $t_i^* \leftarrow t_L^\delta + i \times \delta$

  $\theta_i = \Psi(\mathcal{A}_{i-1}, \Xi)$

  $\mathcal{A}_i = (\mathcal{A}_{i-1}(2), \mathcal{A}_{i-1}(3), ..., \mathcal{A}_{i-1}(L), \theta_i)$

end for

$\theta^* \leftarrow \frac{\theta_\Delta - \theta_{\Delta-1}}{t_\Delta^* - t_{\Delta-1}^*}(t_0 - t_{\Delta-1}^*) + \theta_{\Delta-1}$

return θ^*

Algorithm 2 SAMPLE_ALIGNER()

Input: $\mathcal{T}, \mathcal{S}, \delta$

Output: $\mathcal{T}^\delta, \mathcal{S}^\delta$

$L \leftarrow \left\lceil \frac{t_K - t_1}{\delta} \right\rceil$

for $i = 1$ to L **do**

  $t_i^\delta \leftarrow t_1 + (i-1)\delta$

end for

$s_1^\delta \leftarrow s_1$

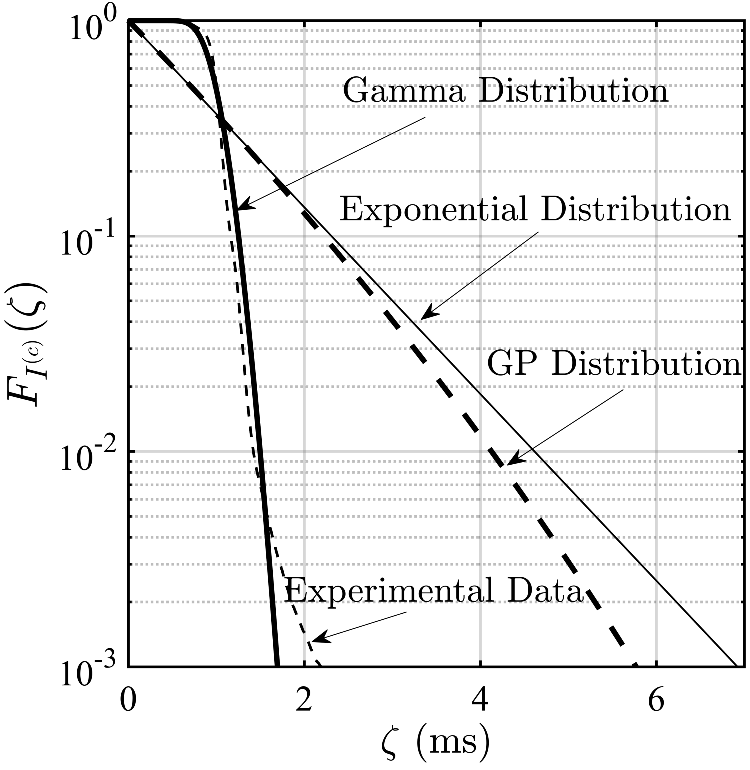
for $i = 2$ to L **do**

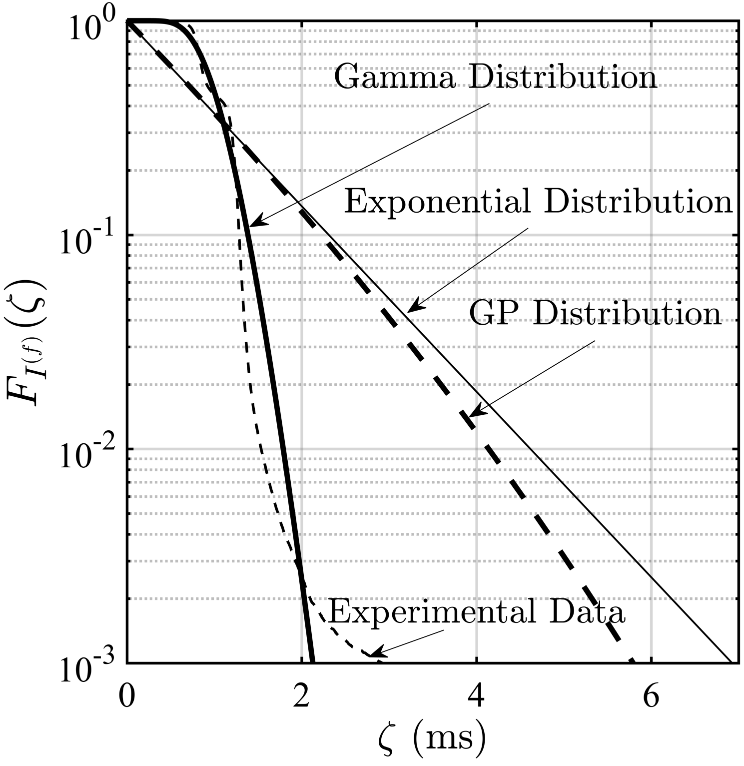
  $s_i^\delta \leftarrow \frac{s_j - s_{j-1}}{t_j - t_{j-1}}(t_i^\delta - t_{j-1}) + s_{j-1}, \forall j : t_{j-1} < t_i^\delta < t_j$

end for

return $\mathcal{T}^\delta, \mathcal{S}^\delta$

Haptic Traffic: Packet Interarrival Times





Haptic Traffic: Packet Interarrival Times

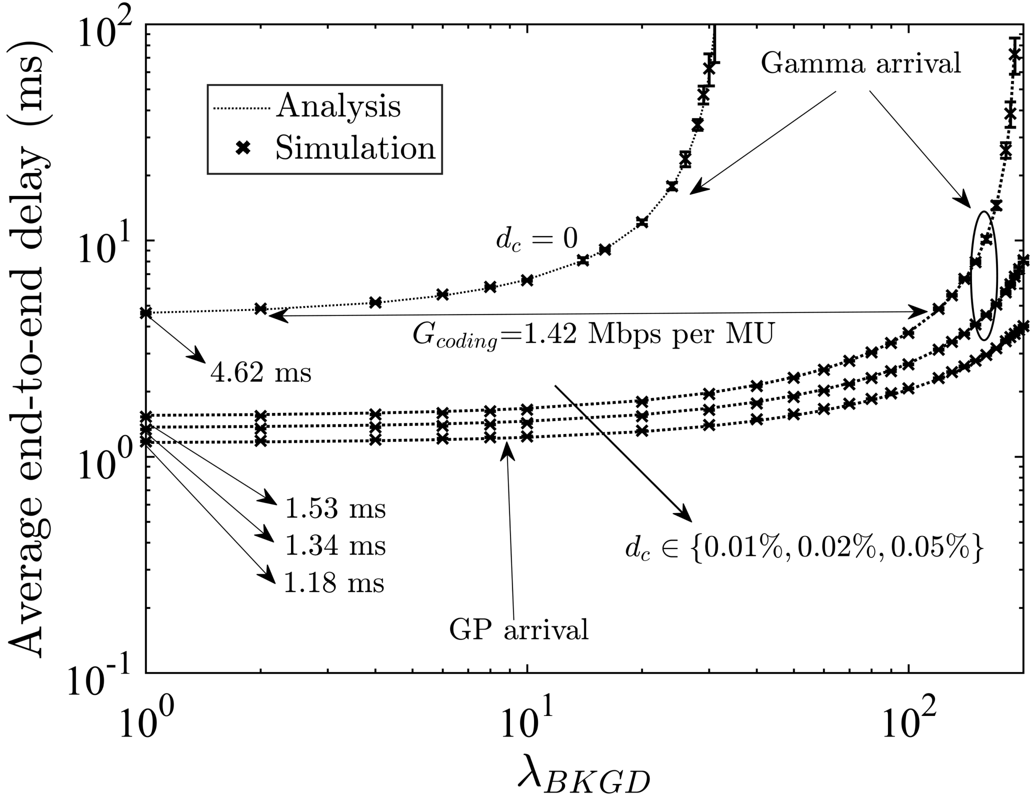
	Without Deadband Coding	With Deadband Coding
Command path	**Gamma**	**Gamma** ($\forall d_c < 0.05\%$) **GP** ($\forall d_c \geq 0.05\%$)
Feedback path	**Gamma**	**Gamma** ($\forall d_f < 15\%$) **Poisson** ($\forall d_f \geq 15\%$)

(a)

	Without Deadband Coding	With Deadband Coding
Command path	**Deterministic**	**GP**
Feedback path	**Deterministic**	**GP**

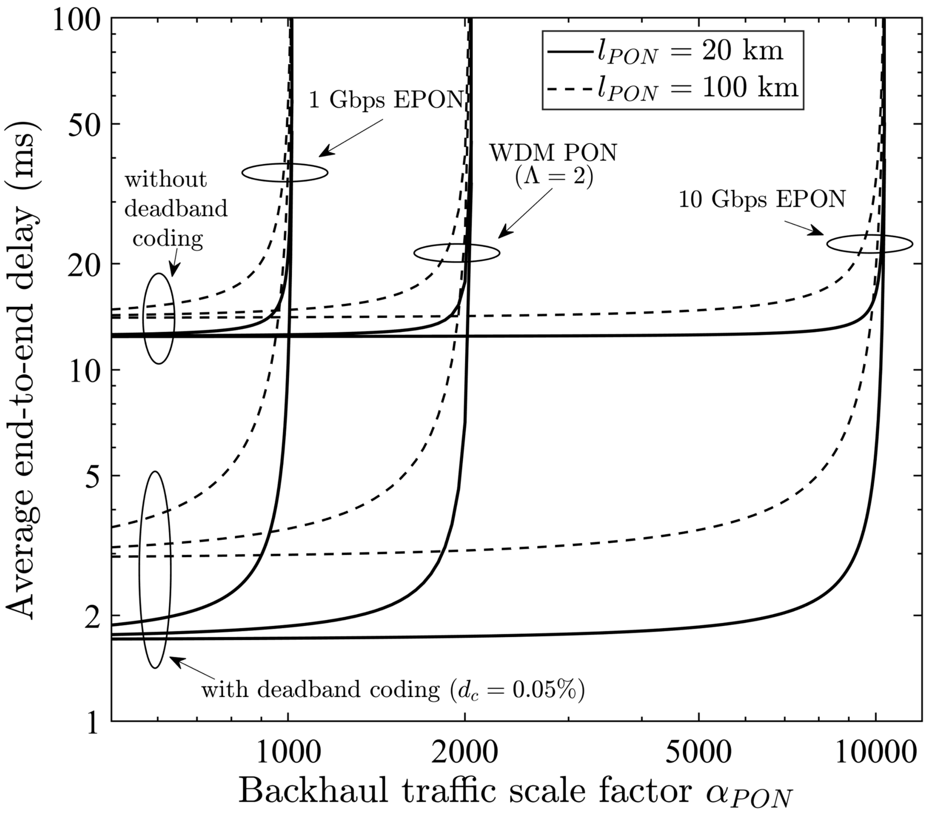
(b)

Haptic Trace Driven Simulations



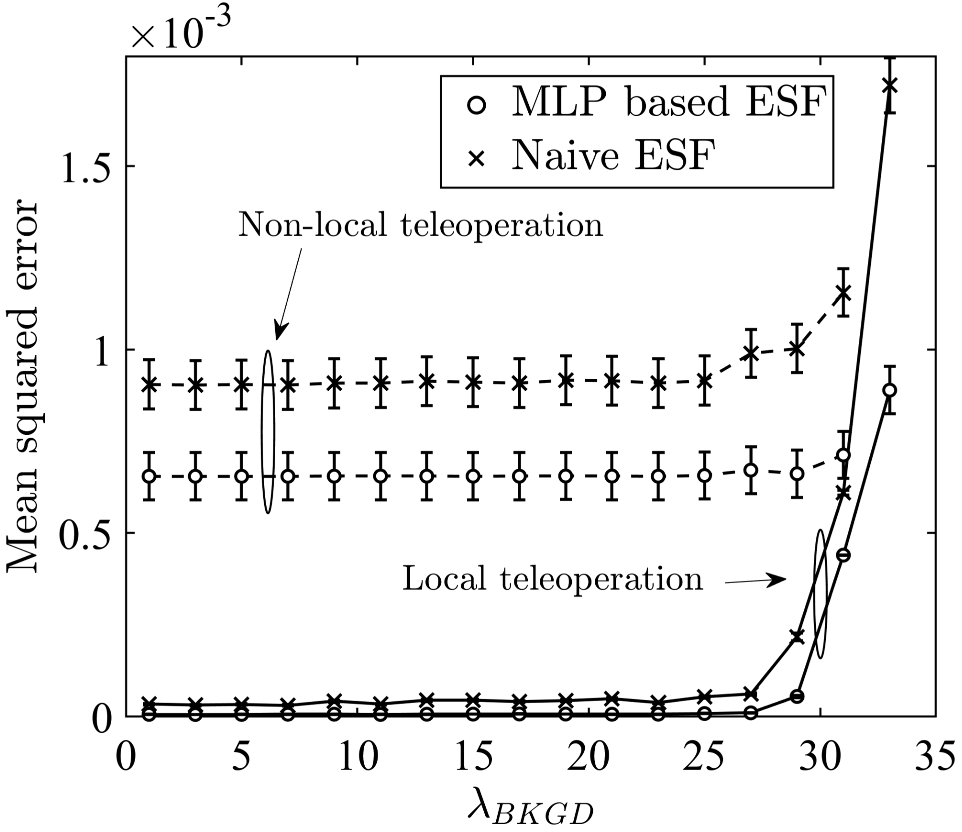
Local teleoperation w/ and w/o **deadband coding**

NG-PON Backhaul



Non-local teleoperation across different **NG-PON backhaul infra-structures**

ESF: Forecasting Accuracy



Haptic traces used to train MLP based ESF to perceive remote task environment in **real-time at 1-ms granularity**

Intelligent Machines: Classification

Task Type	Human Support	Repetitive Task Automation	Context Awareness and Learning	Self-Aware Intelligence
Analyze numbers	Business intelligence, data visualization, hypothesis-driven analytics	Operational analytics, scoring, model management	Machine learning, neural nets	Not yet
Digest words, images	Character and speech recognition	Image recognition, machine vision	Watson, natural language processing	Not yet
Perform digital tasks (admin and decisions)	Business process management	Rules engines, robotic process automation	Not yet	Not yet
Perform physical tasks	Remote operation	Industrial robotics, collaborative robotics	Fully autonomous robots, vehicles	Not yet

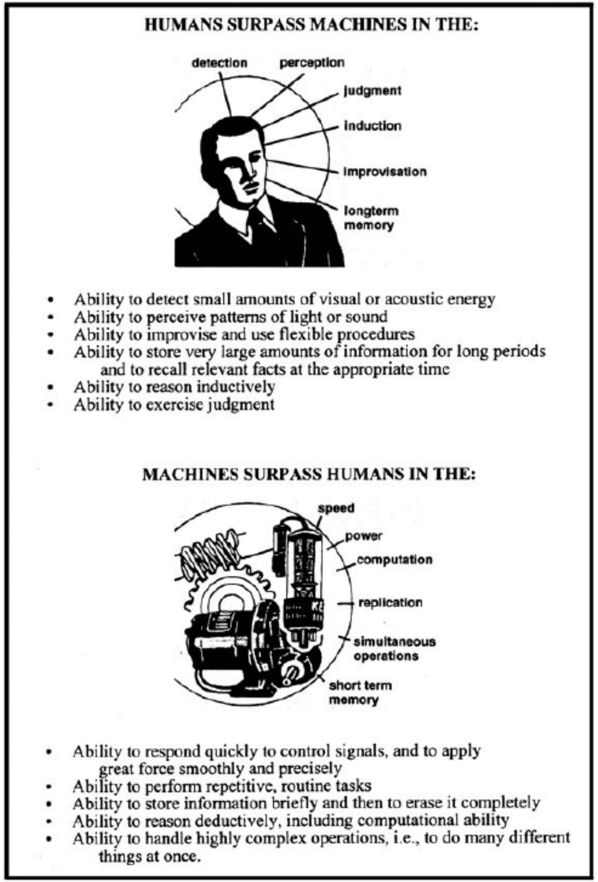
Ability to **act** (vertical)
vs.
Ability to **learn** (horizontal)

T. H. Davenport and J. Kirby, "Only Humans Need Apply: Winners and Losers in the Age of Smart Machines," HarperBusiness, May 2016.

HABA/MABA

- Traditional **humans-are-better-at/machines-are-better-at (HABA/MABA)** design approach

- Only divides up work between humans and machines



HUMANS SURPASS MACHINES IN THE:

- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
- Ability to reason inductively
- Ability to exercise judgment

MACHINES SURPASS HUMANS IN THE:

- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle highly complex operations, i.e., to do many different things at once.

"Human Engineering for an Effective Air Navigation and Traffic Control System," *National Academy of Sciences*, 1951.

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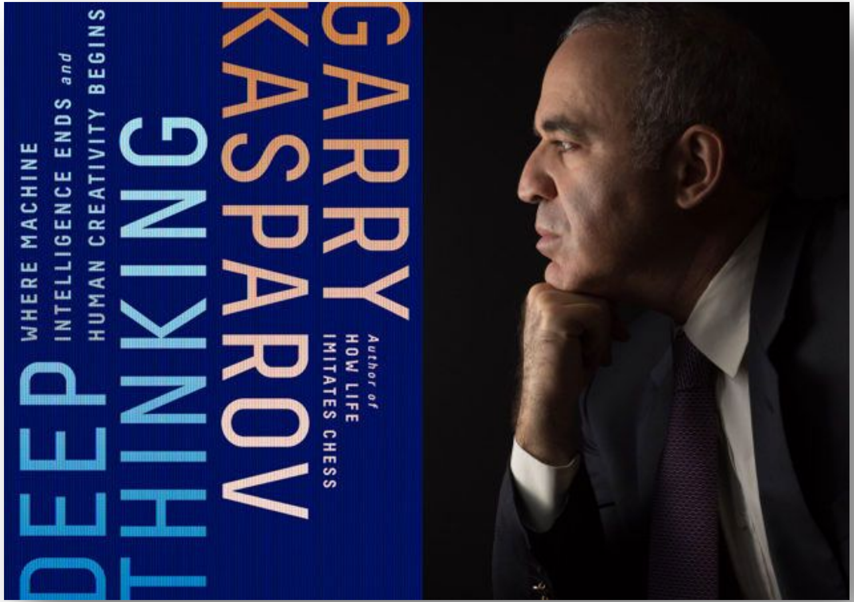
Human-Machine Collaboration



Weak human + Machine + Better process

superior to

Strong human + Machine + Inferior process

A **clever process** beats superior knowledge & superior technology

From AI to IA (Intelligence Amplification)

Human-Agent-Robot Teamwork (HART)

Basic Idea: “Keep Human in the Loop”

- Treating human as a “member” of a team of intelligent machines for a race with (rather than against) machines

Goals

- Design of **human-machine coordination processes**
- Drive **symbiotic human-robot development** in search for synergies
- Enabling **automation and/or augmentation** of physical and cognitive human tasks

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Physical Task Allocation Using Self-Awareness

Given:

- J_i: Task i, $(i = 1, 2, ...)$.
- t_i^a: Arrival time of task demand i.
- w_i: Workload brought in by task i.
- l_i^{task}: Location of task i.
- S_{UO}^A: Set of available user-owned robots.
- S_{UO}^B: Set of busy user-owned robots.
- S_{NO}^A: Set of available network-owned robots.
- S_{NO}^B: Set of busy network-owned robots.
- S: Set of all user- and network-owned robots.
- N: Total number of robots.
- l_j^r: Location of robot j.
- t_j^{av}: Next available time of robot j.
- v_j: Speed of robot j.
- C_j: Task processing capacity of robot j.
- D: Maximum scheduling deadline.
- $d(l_j^r, l_i^{task})$: Euclidean distance between task i and robot j.

Decision variables:

- X_i^j: A binary variable equal to 1 if task i is assigned to robot j.

Objective:

$$\min \sum_{j=1}^{N} X_i^j \left(\overbrace{\max\left(t_j^{av} - t_i^a, 0\right)}^{\text{scheduling delay}} + \overbrace{\frac{d(l_j^r, l_i^{task})}{v_j}}^{\text{traversing time}} + \overbrace{\frac{C_j}{w_i}}^{\text{execution time}} \right),$$

subject to

$$\sum_{j \in S_{UO}^A \cup S_{UO}^B} \left(t_j^{av} - t_i^a\right) X_i^j < D,$$

$$\sum_{j=1}^{N} X_i^j = 1,$$

$$X_i^j \in \{0, 1\}.$$

Algorithm 1 Self-Aware Multi-Robot Task Coordination

Input: $J_i, w_i, t_i^a, S_{UO}^A, S_{UO}^B, S_{NO}^A, S_{NO}^B, S, l_j^r, t_j^{av}, C_j, v_j, D$
Output: $X_i^j, t_j^{av}, l_j^r, \forall j = 1, 2, ..., N$

if $S_{UO}^A \neq \emptyset$ **then**
  $j^* \leftarrow \underset{j \in S_{UO}^A}{\operatorname{argmin}}\, d\left(l_j^r, l_i^{task}\right)$
else
  if $S_{UO}^B \neq \emptyset$ **then**
    $W_{min} \leftarrow \min_{j \in S_{UO}^B}(t_j^{av} - t_i^a)$
    if $W_{min} < D$ **then**
      $j^* \leftarrow \underset{j \in S_{UO}^B}{\operatorname{argmin}}(t_j^{av} - t_i^a)$
    else
      if $S_{NO}^A \neq \emptyset$ **then**
        $j^* \leftarrow \underset{j \in S_{NO}^A}{\operatorname{argmin}}\, d\left(l_j^r, l_i^{task}\right)$
      else
        $j^* \leftarrow \underset{j \in S}{\operatorname{argmin}}(t_j^{av} - t_i^a)$
      end if
    end if
  end if
end if
$X_i^{j^*} \leftarrow 1$
$t_{j^*}^{av} \leftarrow t_{j^*}^{av} + \max\left(t_{j^*}^{av} - t_i^a, 0\right) + \frac{d(l_{j^*}^r, l_i^{task})}{v_{j^*}} + \frac{C_{j^*}}{w_i}$
return $X_i^j, t_j^{av}, l_j^r, \forall j = 1, 2, ..., N$

HART-centric task coordination based on **shared use of user- and network-owned robots**

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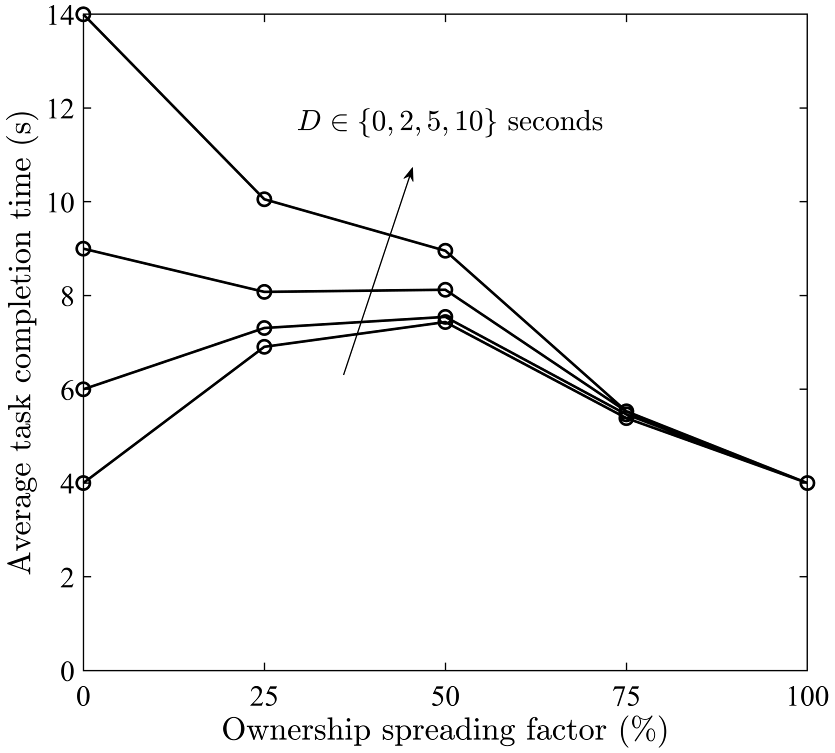
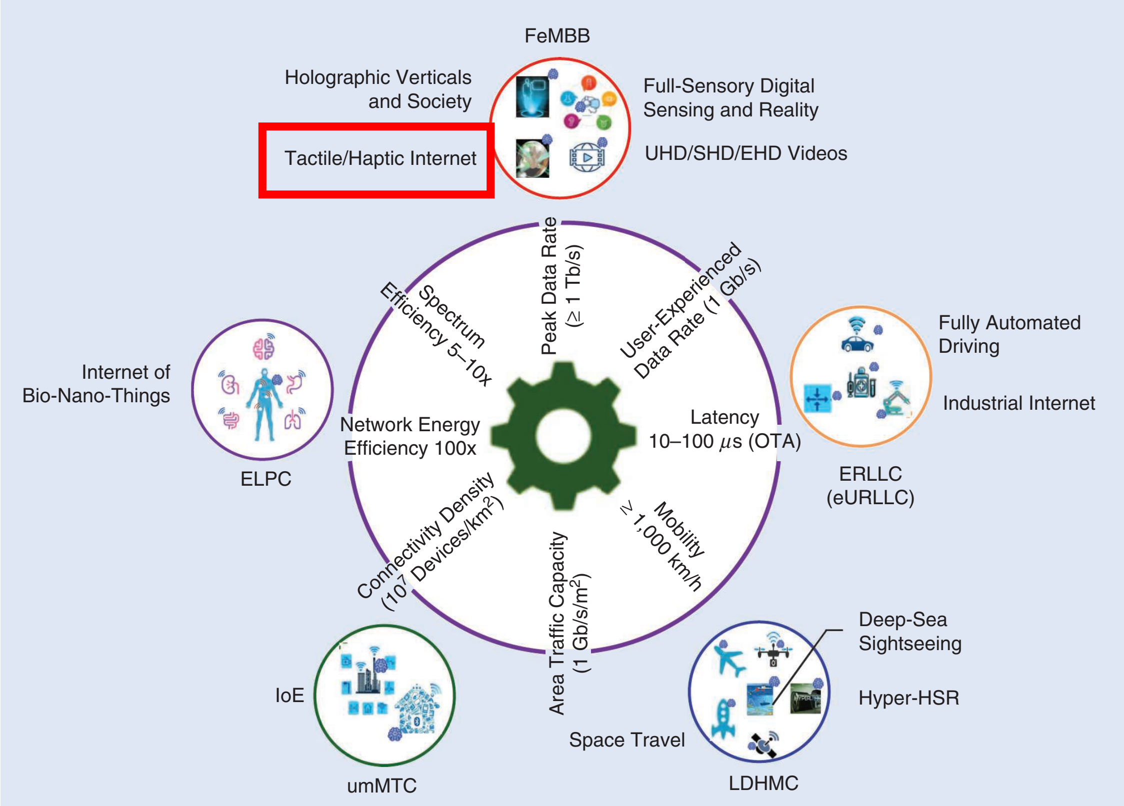
Spreading Ownership



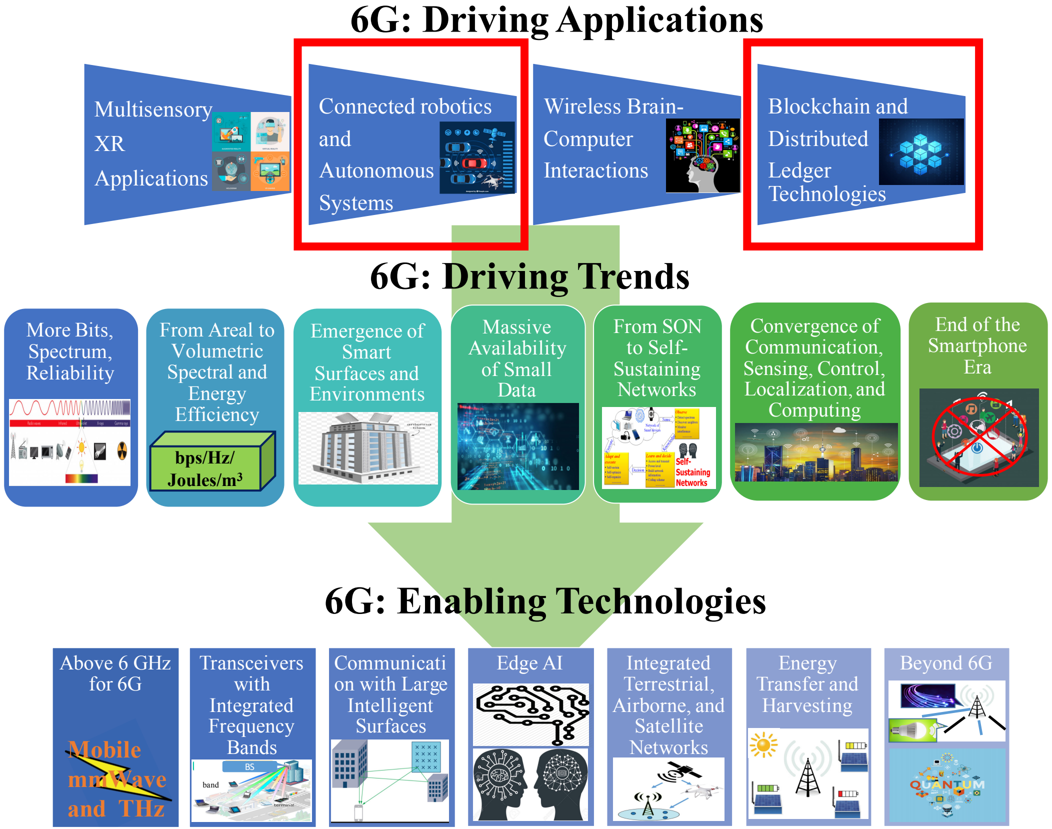
Minimizing completion time of physical tasks by **spreading ownership of robots across MUs**

Tactile Internet & 6G



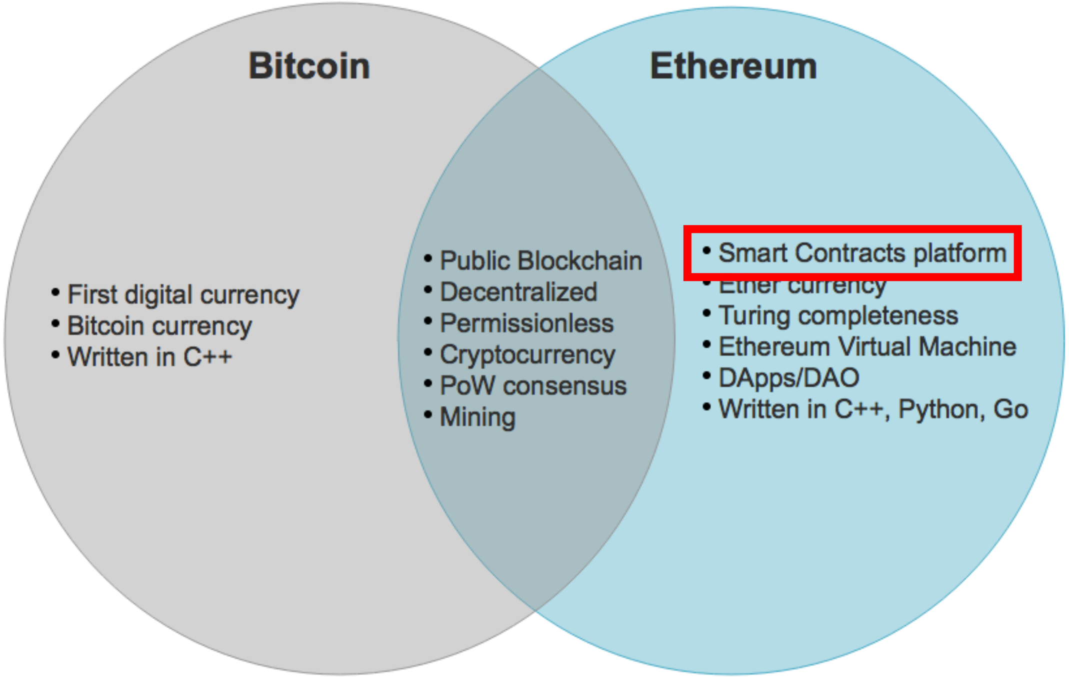
Z. Zhang, Y. Xiao, Z. Ma, M. Xiao, Z. Ding, X. Lei, G. K. Karagiannidis, and P. Fan, “6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies,” IEEE Vehicular Technology Magazine, vol. 14, no. 3, pp. 28-41, Sep. 2019.

6G: Convergence of Technologies



W. Saad, M. Bennis, and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," IEEE Network, IEEEXplore Early Access

Decentralization via Blockchain



Decentralized blockchain technologies used to realize **blockchain IoT (BIoT)**

Blockchain IoT (BIoT)

Smart Contracts

ACC Framework

- **Access control contract (ACC)** maintains misbehavior list for each BIoT resource & its penalty (e.g., blocking access for certain time period)
- **Judge contract (JC)** Implements certain misbehavior judging method & returns decision to ACC for executing penalty

Architectural Styles

Decentralized edge computing

- **Fully centralized** (cloud w/o blockchain)
- **Pseudo distributed** (blockchain physically located in cloud)
- **Distributed** (things directly controlled by smart contracts)
- **Fully distributed** (blockchain deployed on end-user devices): *Superior robustness & security*

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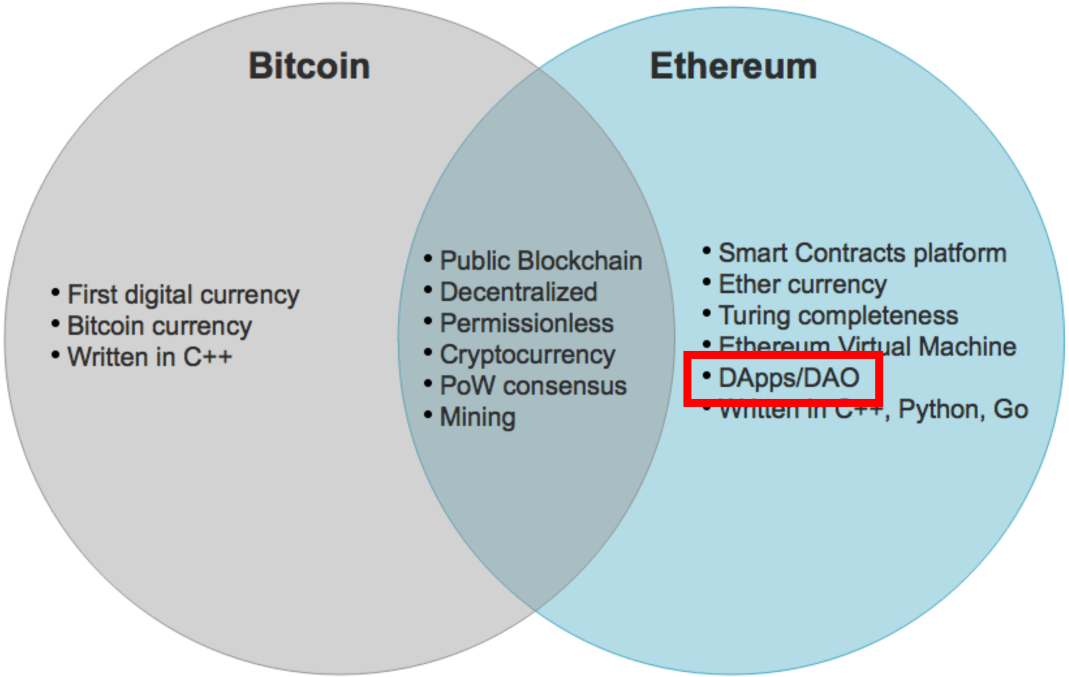
Decentralization via Blockchain



Decentralized blockchain technologies used to realize **blockchain IoT (BIoT)**

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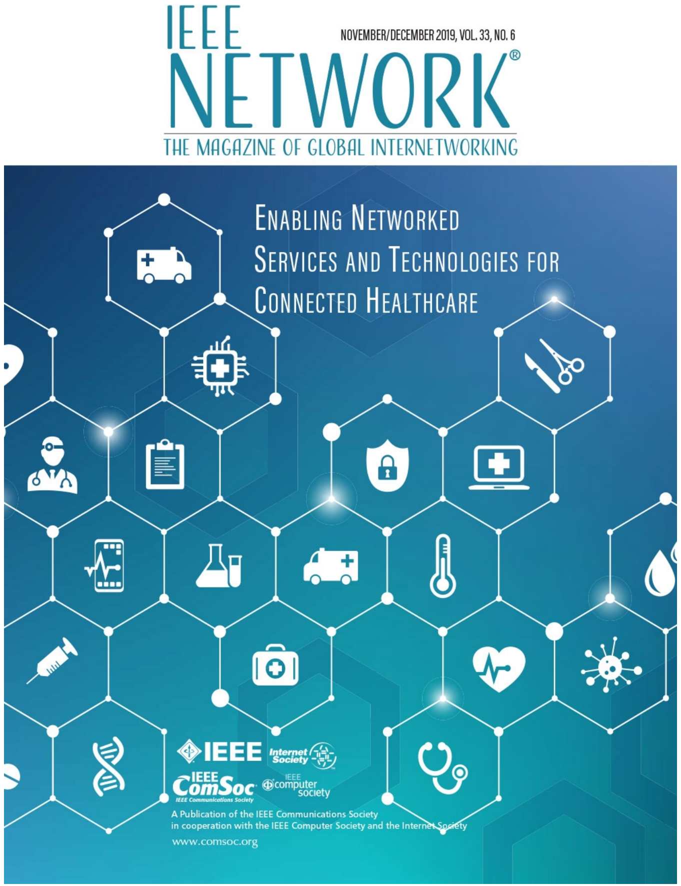
“The Way of The DAO”

A. Beniiche, A. Ebrahimzadeh, and M. Maier

“The Way of The DAO: Towards Decentralizing the Tactile Internet”

IEEE Network, submitted January 2020



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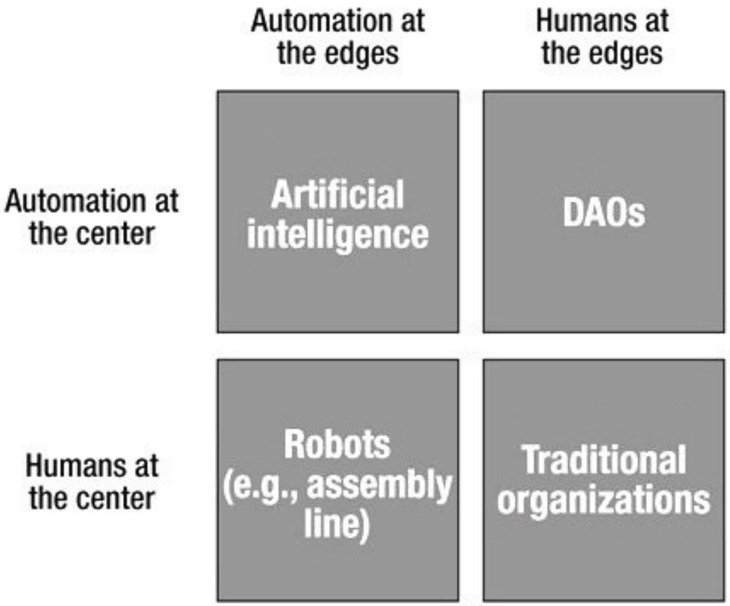
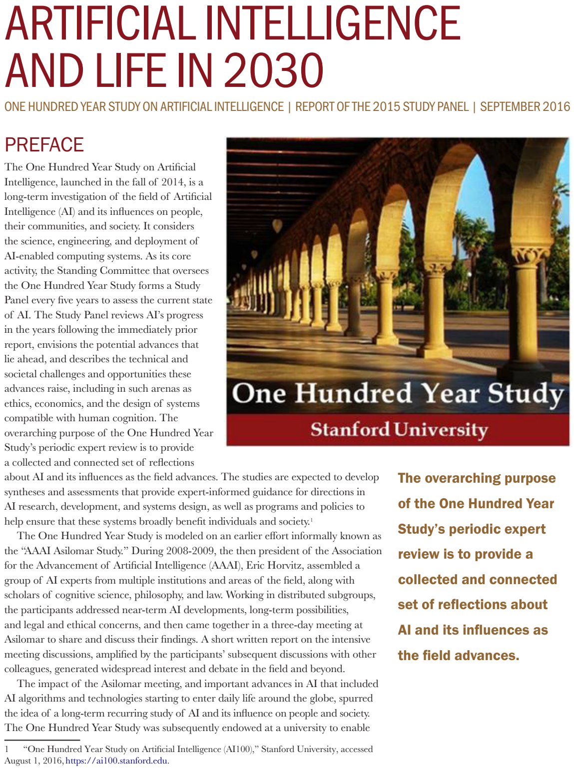
Ethereum: DAOs vs. AI & Robots



Decentralized Autonomous Organizations (DAOs)

- Salient feature of Ethereum
- Open-source, distributed software platform that executes smart contracts
- Unlike autonomous AI based agents, DAOs by design heavily rely on involvement from humans at the edges (**"crowdsourcing"**)

Stanford University: “AI and Life in 2030”



ARTIFICIAL INTELLIGENCE AND LIFE IN 2030

ONE HUNDRED YEAR STUDY ON ARTIFICIAL INTELLIGENCE | REPORT OF THE 2015 STUDY PANEL | SEPTEMBER 2016

PREFACE

One Hundred Year Study
Stanford University

The One Hundred Year Study on Artificial Intelligence, launched in the fall of 2014, is a long-term investigation of the field of Artificial Intelligence (AI) and its influences on people, their communities, and society. It considers the science, engineering, and deployment of AI-enabled computing systems. As its core activity, the Standing Committee that oversees the One Hundred Year Study forms a Study Panel every five years to assess the current state of AI. The Study Panel reviews AI's progress in the years following the immediately prior report, envisions the potential advances that lie ahead, and describes the technical and societal challenges and opportunities these advances raise, including in such arenas as ethics, economics, and the design of systems compatible with human cognition. The overarching purpose of the One Hundred Year Study's periodic expert review is to provide a collected and connected set of reflections about AI and its influences as the field advances. The studies are expected to develop syntheses and assessments that provide expert-informed guidance for directions in AI research, development, and systems design, as well as programs and policies to help ensure that these systems broadly benefit individuals and society.[1]

The One Hundred Year Study is modeled on an earlier effort informally known as the "AAAI Asilomar Study." During 2008-2009, the then president of the Association for the Advancement of Artificial Intelligence (AAAI), Eric Horvitz, assembled a group of AI experts from multiple institutions and areas of the field, along with scholars of cognitive science, philosophy, and law. Working in distributed subgroups, the participants addressed near-term AI developments, long-term possibilities, and legal and ethical concerns, and then came together in a three-day meeting at Asilomar to share and discuss their findings. A short written report on the intensive meeting discussions, amplified by the participants' subsequent discussions with other colleagues, generated widespread interest and debate in the field and beyond.

The impact of the Asilomar meeting, and important advances in AI that included AI algorithms and technologies starting to enter daily life around the globe, spurred the idea of a long-term recurring study of AI and its influence on people and society. The One Hundred Year Study was subsequently endowed at a university to enable

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1 "One Hundred Year Study on Artificial Intelligence (AI100)," Stanford University, accessed August 1, 2016, https://ai100.stanford.edu.

- AI likely to replace **tasks** rather than jobs in near term
- Importance of **crowdsourcing of human skills** to solve problems that machines alone cannot solve well

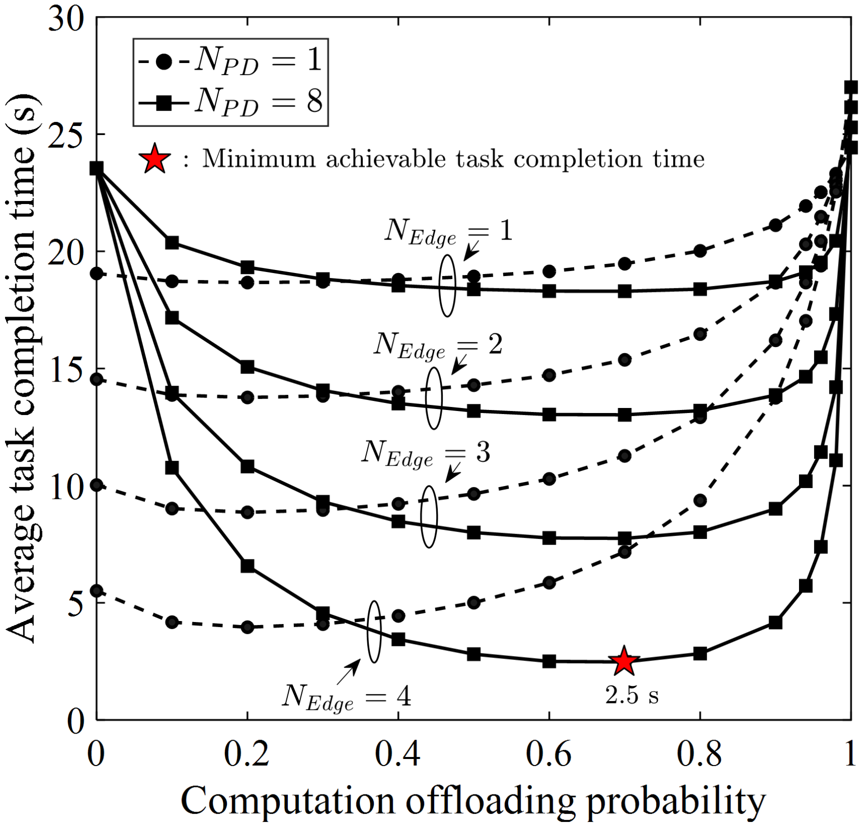
INRS

Decentralizing the Tactile Internet

Goal:

“Search for **synergies** between HART membership and complementary strengths of the DAO, AI, and robots to enable **local human-machine coactivity clusters** via decentralizing the Tactile Internet”

MEC: Partially vs. Fully Decentralized

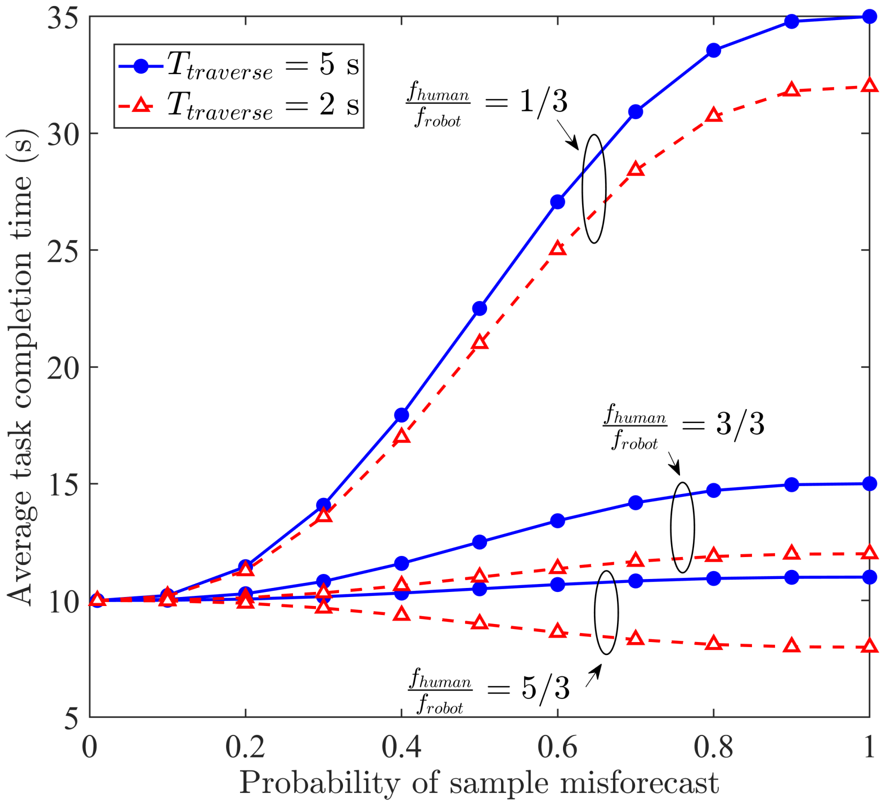


- $1 \leq N_{Edge} \leq 4$ MEC servers
- **Partially/fully decentralized** end-users control their computation offloading probability for **local computation** on smartphones/user-owned robots

$$1 \leq N_{PD} \leq 8$$

- Remaining $8 - N_{PD}$ end-users rely on **edge computing** only

Crowdsourcing: Human Assistance of Robots



Smart Contracts

Help establish/maintain trusted human-agent-robot teamwork (HART) membership

Crowdsourcing

Nearby HOs help finalize physical tasks when 3 ouf of 5 haptic feedback samples are misforecast

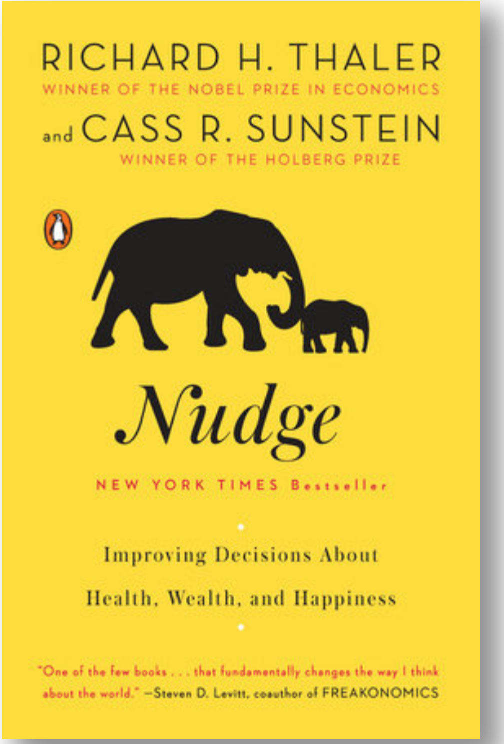
Nudge: Cognitive Assistance of Humans

- **Definition of nudge:**

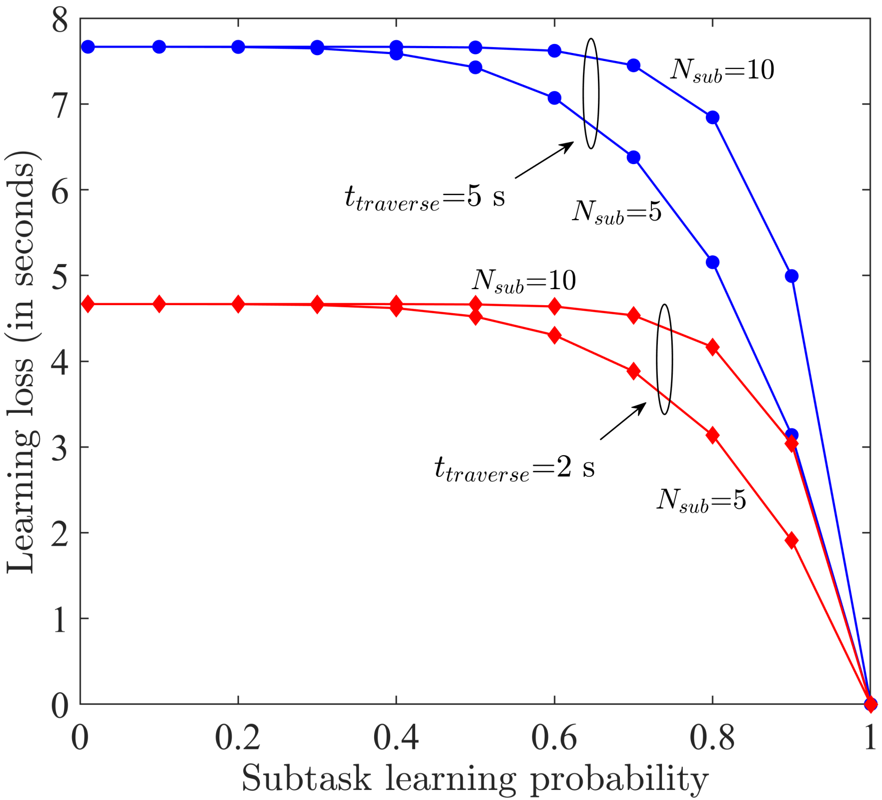
  Any aspect of a choice architecture that changes people's behaviour in a predictable way

- A nudge can **steer people as opposed to steer objects**, as done in conventional Tactile Internet

- Used to **enhance human capabilities of unskilled crowd members**



Nudging via Smart Contract



Algorithm 1 Nudge Contract

Given: Set $U = \{h_1, h_2, ..., h_n\}$ of n DAO members, capability vector $\mathbf{C} = [c_1, c_2, ..., c_n]$, distance vector $\mathbf{D} = [d_1, d_2, ..., d_n]$, interrupted task $\mathbf{T}$, required number D of actions to execute the interrupted task, interrupted robot r_0, capability requirement c_0 of the interrupted task

Decompose the given interrupted task $\mathbf{T}$ into N_{sub} subtasks

for $i = 1$ *to* n **do**

  if $c_i \geq c_0$ **then**

    $S \leftarrow h_i$

  end

end

$h^* \leftarrow \arg\min_{d_i}\{S\}$

Create a secure blockchain transaction between h^* and interrupted robot r_0

Send the learning instructions from h^* to r_0 through the established transaction

Use the multi-arm bandit selection strategy in [15] to help the robot learn the given set of subtasks

if *all N_{sub} subtasks are learned successfully* **then**

  learning process is successfully accomplished

  r_0 can execute the interrupted task $\mathbf{T}$ with the capability of h^*

  else

  Learning process is failed

  DAO member h^* traverses to the interruption point to execute the task $\mathbf{T}$

end

Reward the skilled DAO member h^* via blockchain smart contract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