NEST
Research Group - ENSEM

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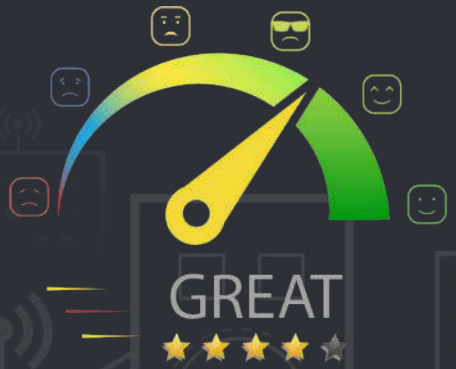
# Learn to Satisfy:
## QoS Self-Provisioning for 5G and Beyond




**Essaid Sabir**

NEST ENSEM, Hassan II University of Casa, Morocco

Dept. of Computer Science, UQAM, Montréal, Canada

LATECE Seminars

October 07th, 2020

# Agenda

A couple of Words on 5G and SONs

Wireless Artificial Intelligence

Satisfaction Equilibrium

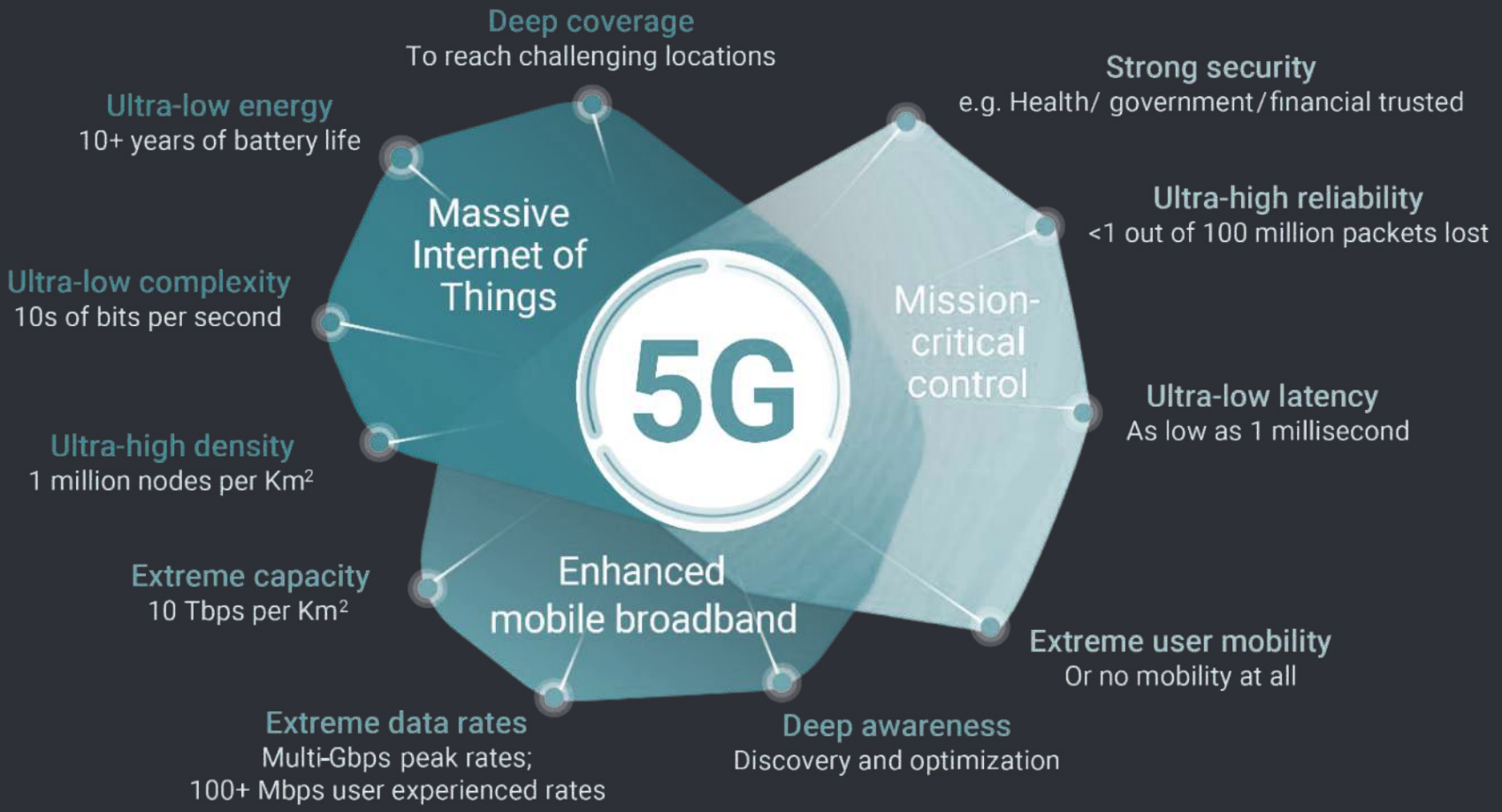
Some Satisfaction Games in Wireless Networks

Summary

# 1 A Short Overview on 5G

# A Short Overview on 5G and SONs

## ⌘ 5G Use-Cases



# A Short Overview on 5G and SONs

⌘ 5G Enabling Technologies

- Densification & Massive MIMO
- Full Duplex Transmissions
- mmWave Communications
- D2D Communications
- (Re)Programmable Infrastructure: SDN, NFV & Slicing
- Self-Organized Networks

# A Short Overview on 5G and SONs

⌘ The need to decentralize decision-making

- Legacy networks are mostly centralized !
- A connection density of 1M/Km² is expected for 5G and beyond!
- Computer networks and Telecom networks convergence
  ➔ High number of heterogeneous technologies co-exist!
- **Data Tsunami:**
  + Social networks generate tremendous traffic
  + New content classes (mobile video is the 4G killer APP)
  + New services (AR/VR, IoT, URLLC, …)


Dimension curse ➔ Scalability !

Need to distribute decision-making among network entities !!

Operators won't be happy… who cares !!

# A Short Overview on 5G and SONs

⌘ Some benefits of decentralizing decision-making

- Fully intelligent networks could be built
- Scalable systems
- Seamless access and ubiquitous connectivity: plug-&-play fashion!
- No more (heavy) signaling
- Efficient spectrum/resource usage/sharing
- Etc.

# 2 Wireless AI

# Wireless AI

⌘ Some Definitions

**Intelligence** is the ability to learn, understand, and make judgments or have opinions that are based on reason (Cambridge dictionary)

**Artificial Intelligence** is the study of how to produce machines that have some of the qualities that the human mind has, such as the ability to understand language, recognize pictures, solve problems, and learn (Cambridge dictionary)

**Wireless Artificial Intelligence** is a “new” paradigm suggesting to bring AI in wireless networking

# Wireless AI

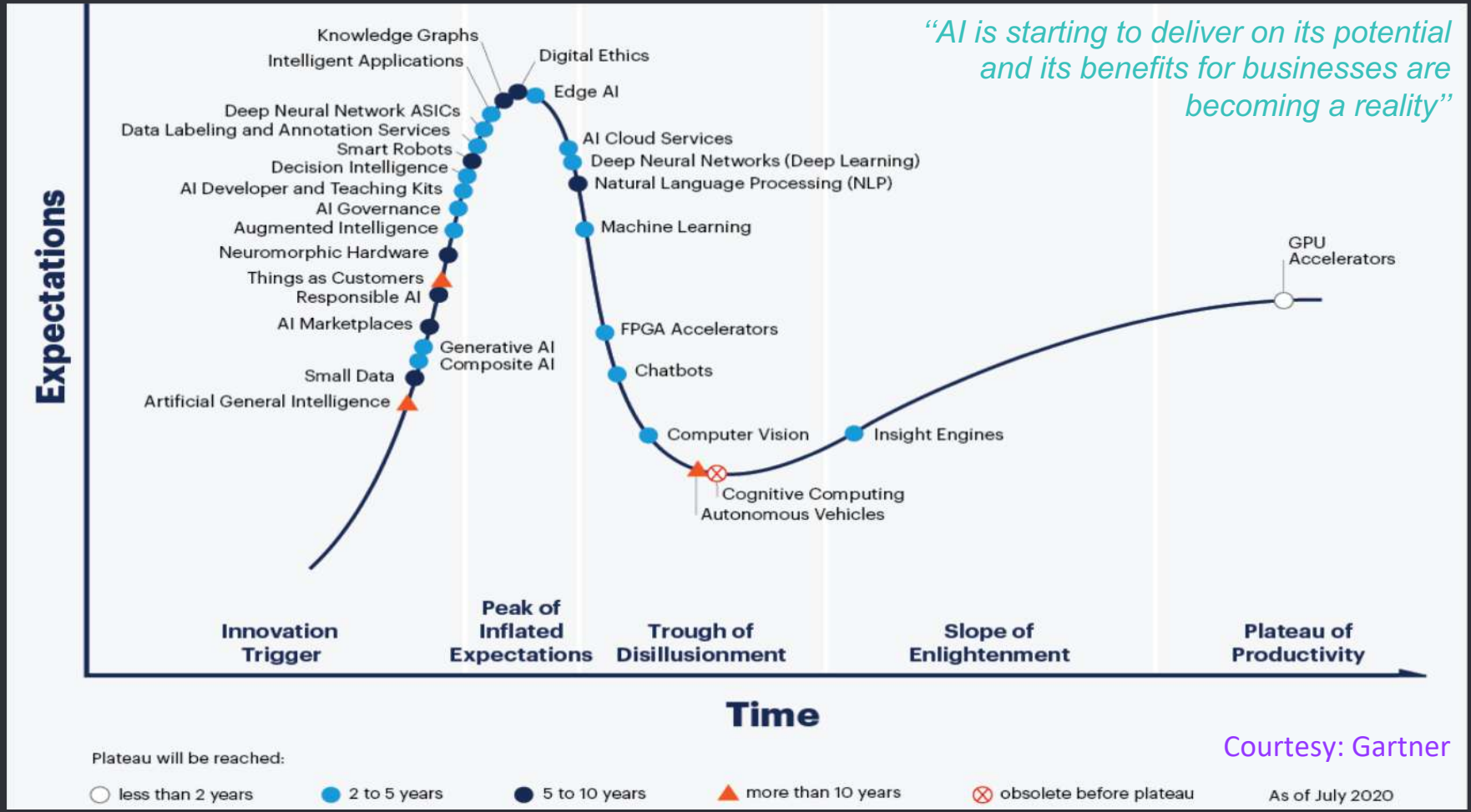
⌘ Gartner's Top 10 Strategic Technology Trends for 2020

| People-Centric | Smart Spaces |
| --- | --- |
| Hyperautomation | Empowered Edge |
| Multiexperience | Distributed Cloud |
| Democratization | Autonomous Things |
| Human Augmentation | Practical Blockchain |
| Transparency and Traceability | AI Security |

Courtesy: Gartner

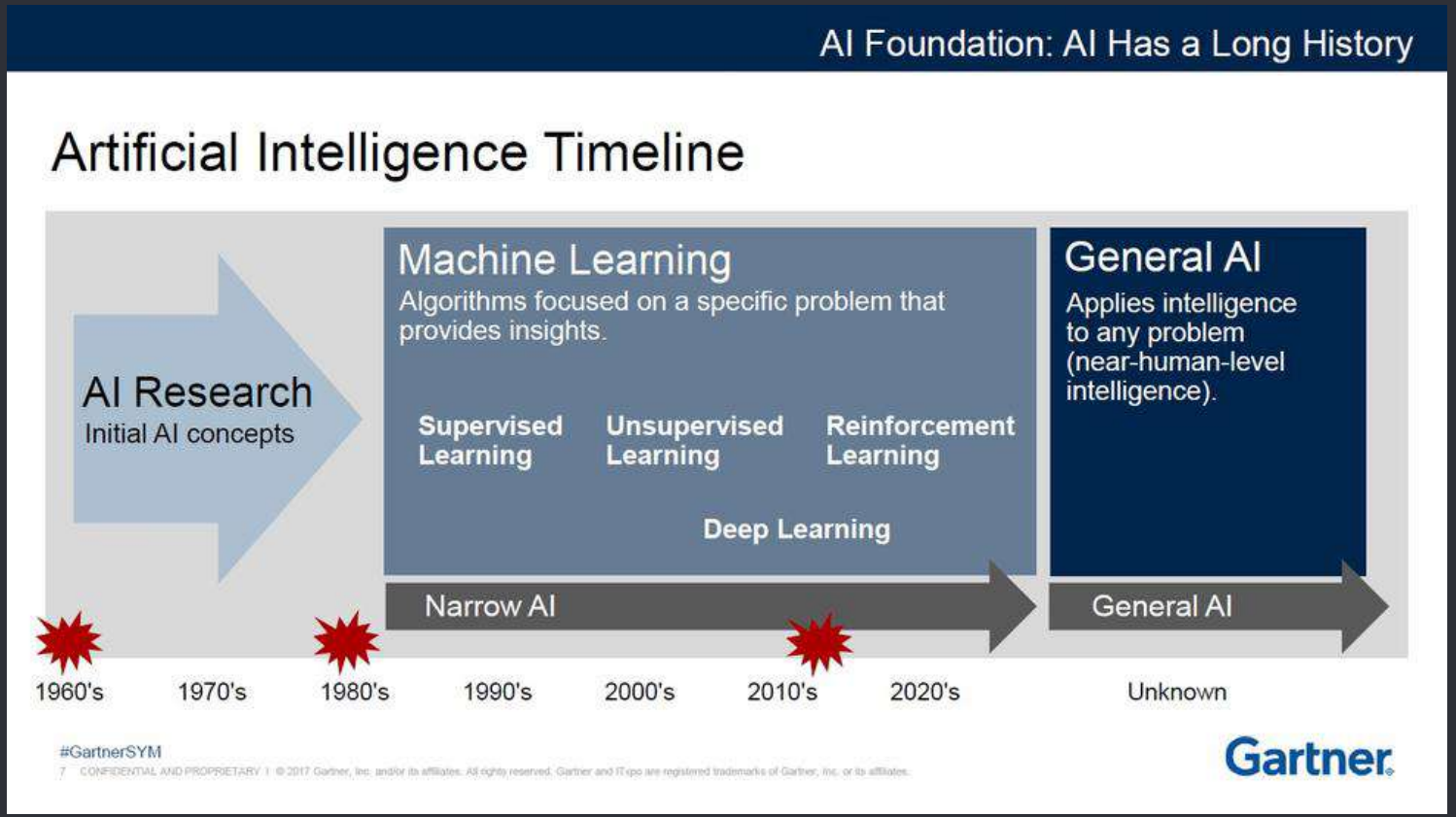
# Wireless AI

## ⌘ Gartner Hype Cycle for AI 2020



# Wireless AI

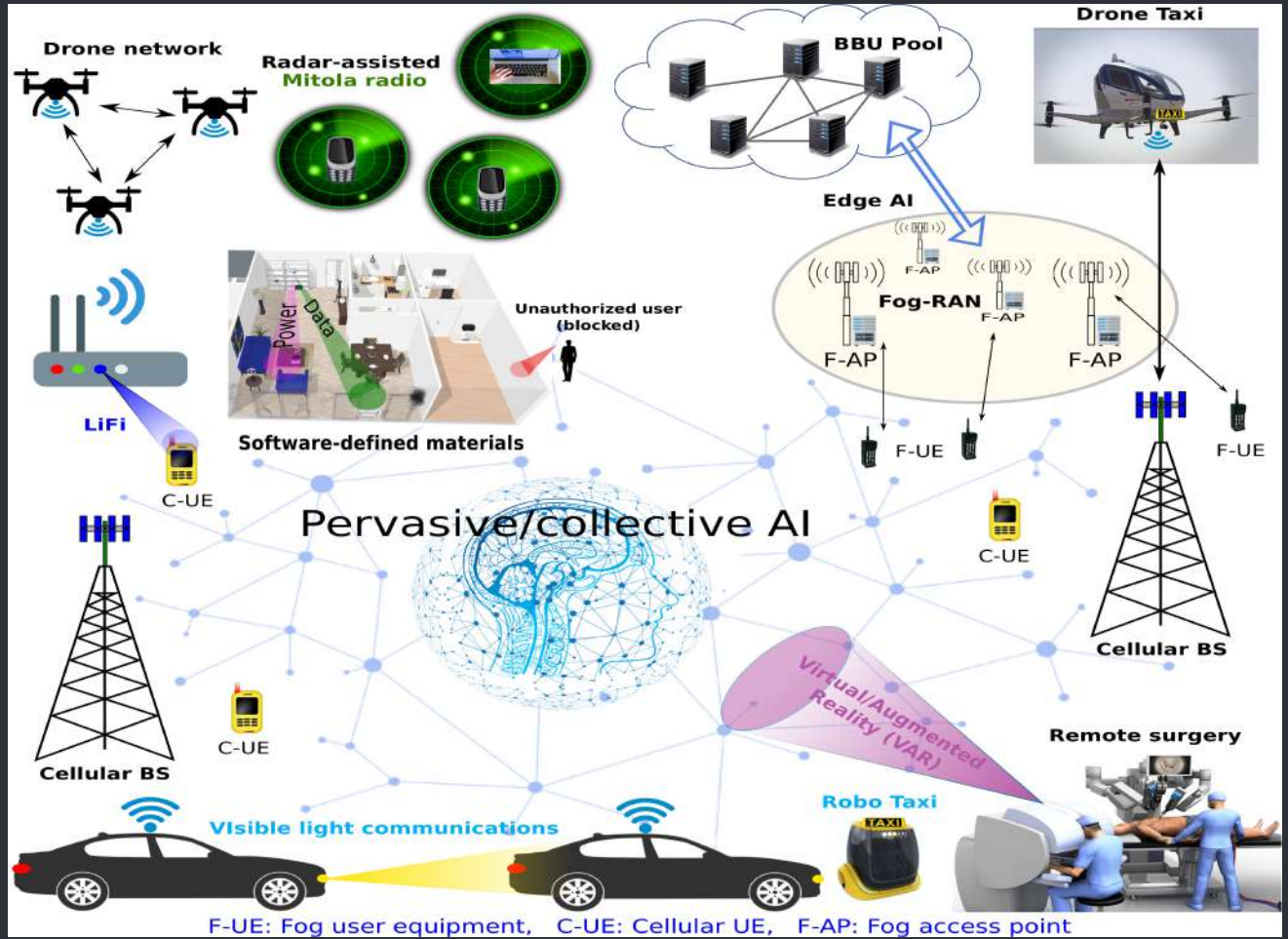
⌘ AI Foundation




Courtesy: Gartner

# Wireless AI

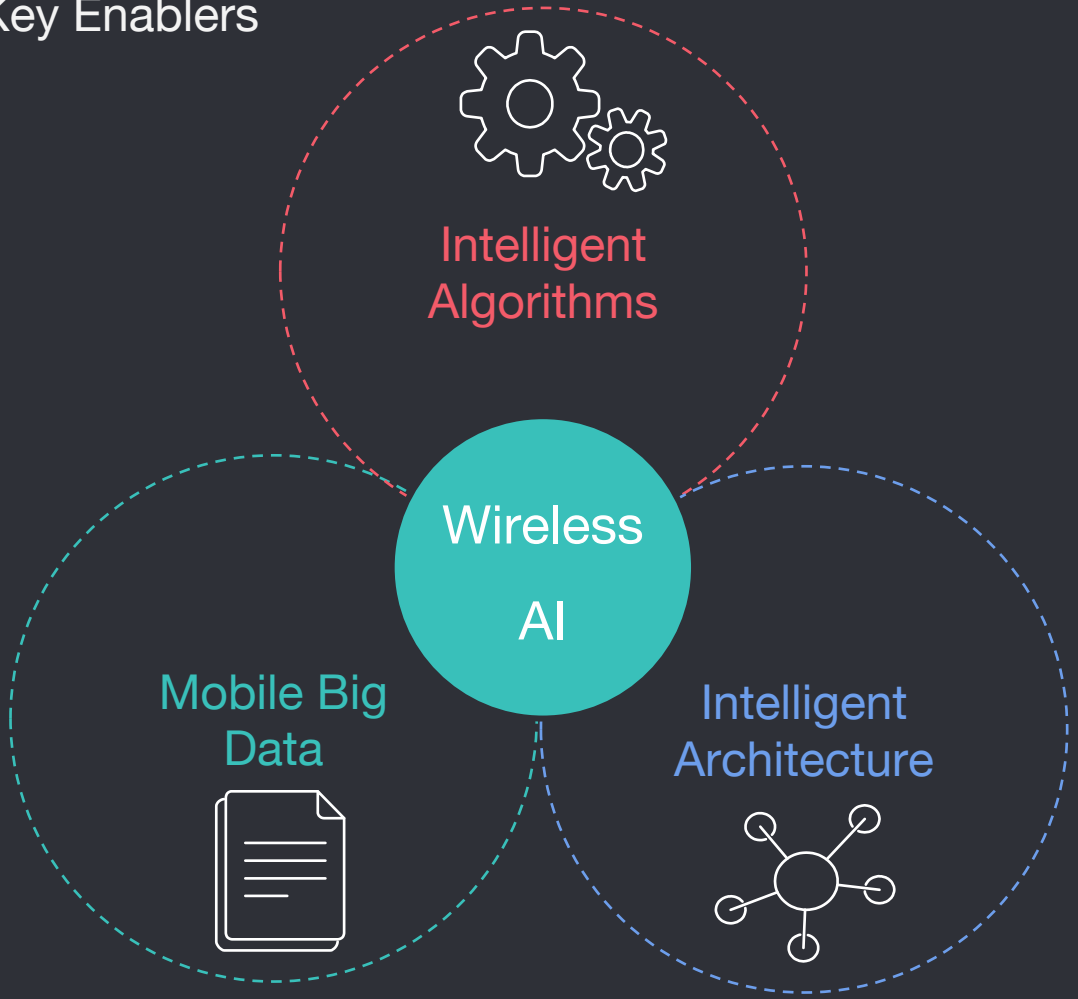
## ⌘ Wireless AI: The Full Picture




F. Tariq, M.R. A. Khandaker, K. Wong, M.Imran, M.Bennis, M.Debbah, **"A Speculative Study on 6G"**. IEEE Commag, 2020

# Wireless AI

⌘ Wireless AI Key Enablers



# Wireless AI

## ⌘ Design Considerations & Issues

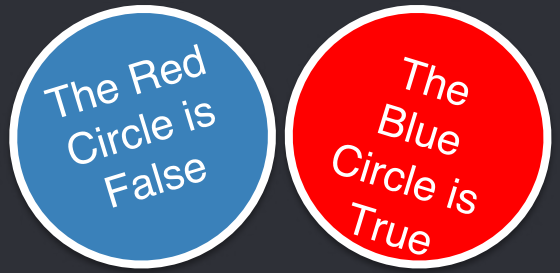
- **Issues related to the architecture :** environment, target application, time scale, federation/coordination (if any), etc.
- **Issues related to the learning algorithm :** convergence, accuracy, recoverability, scalability, robustness against uncertainty, etc.
- **Issues related to Data :** availability, heterogeneity, quality/correctness, freshness, etc.
- **Issues related to learning automata :** role, rationality, Human Vs Machine (AV), selfishness, incentive, cheating, etc.

# Wireless AI

⌘ Side Effects

- Loss of control over machines
- Paradoxical situations (desirable ?!)
  - Aggressive behaviour (e.g., transmit rate, transmit power, etc.)
  - Abuse of power/hierarchy
  - Information manipulation
  - Loss of efficiency (how much ?)
  - Etc.






$$\frac{1}{3} = 0{,}3333\cdots$$

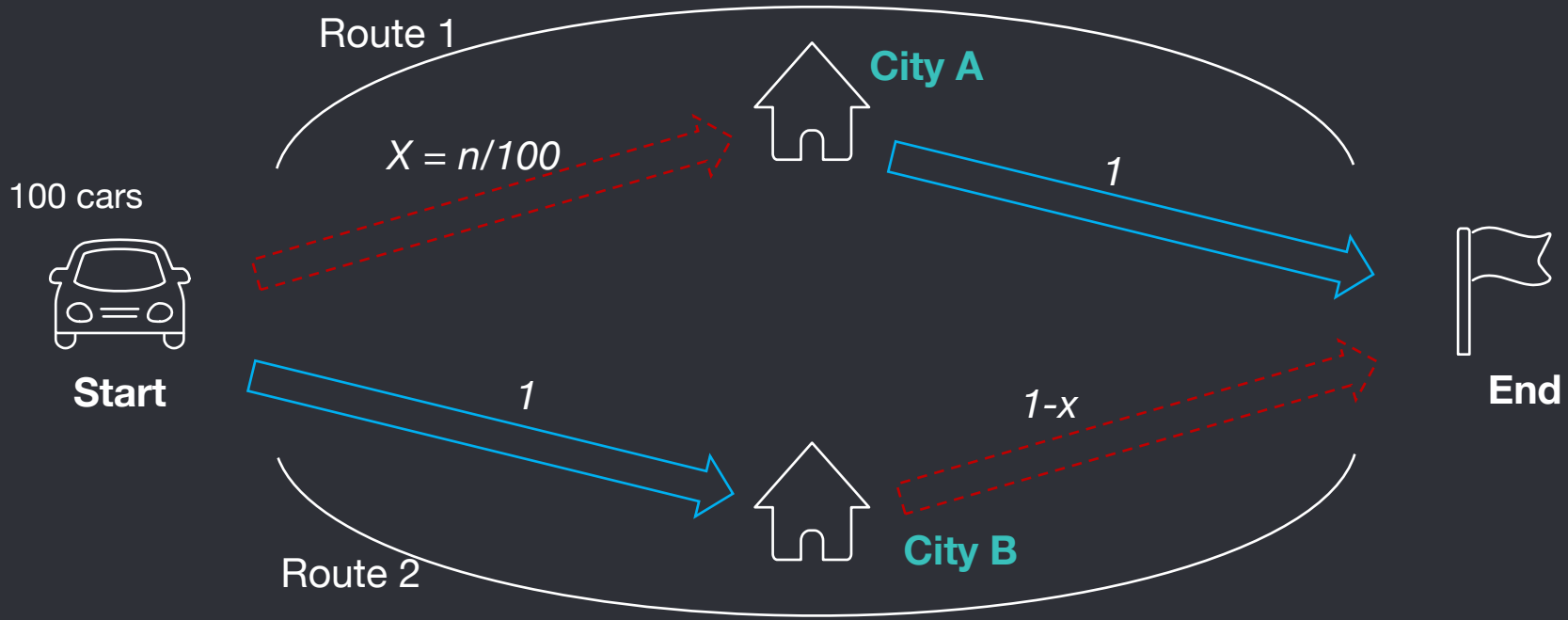
$$3 \times \frac{1}{3} = 3 \times 0{,}3333\cdots$$

$$1 = 0{,}9999\cdots \quad \text{QED !!}$$

# Wireless AI

⌘ Routing Game (example)

Travel time : 1,5 H

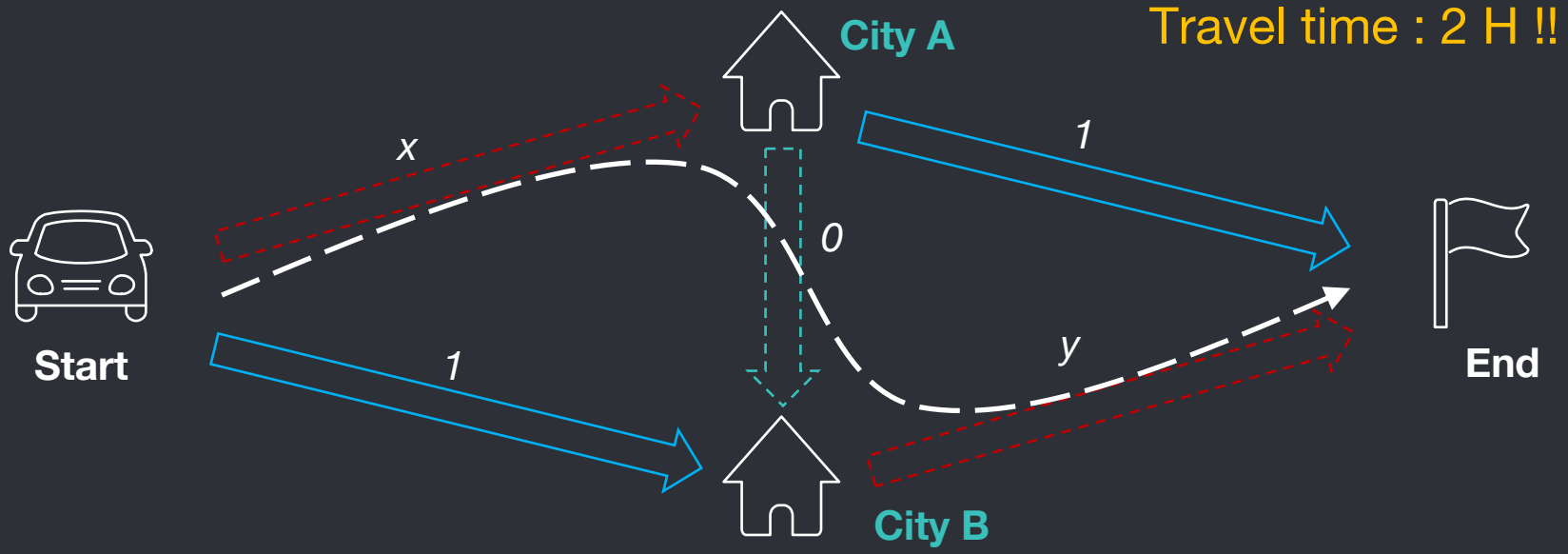



What is the equilibrium traffic flow on each route?

# Wireless AI

⌘ Routing Game: Braess Paradox

A free Highway as a present for Thanksgiving!




What is the new equilibrium traffic flow on each route?

# Wireless AI

⌘ Braess Paradox: True Story

Introduced by Pr. Dietrich Braess (1968)

New York (New York Times, December 25th, 1990)

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The New York Times

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY

Search Health


## What if They Closed 42d Street and Nobody Noticed?

By GINA KOLATA
Published: December 25, 1990

Similar observation in Boston, London, Stuttgart, Seoul, San Diego, etc.

# Wireless AI

⌘ Braess Paradox: Some Identified Examples in Networking

- Random access
- Power control
- Information game (e.g., Fake News)
- Social Networking: More is Less!
- The removal of one player can sometimes improve a team's performance: Less is Better!
- etc.

# 3 Satisfaction Equilibrium

# Satisfaction Equilibrium

⌘ Non-Cooperative Game

A non-cooperative game is defined by the following:

- A set of players $N = \{1,...,n\}$
- A set of actions $A_i = \{a_{1,1}, a_{1,2}, \ldots, a_{1,ni}\}$ for each player $i$
- The decision-making sequence
- A utility function $U_i$ (function of made decisions) for each player $i$
- The information available to each player. It can be perfect/imperfect and/or complete/incomplete

# Satisfaction Equilibrium

⌘ Non-Cooperative Game: Nash Equilibrium

**Definition.** *A a Nash equilibrium is a strategy profile where no player has incentive to unilaterally change his strategy.*

**Theorem 1 (John F. Nash).** *Every finite game has a mixed strategy Nash equilibrium.*

**Theorem 2 (Debreu, Glicksberg, Fan).** *Consider a strategic form game such that for each player*

① *the strategy space is compact and convex;*

② *the utility function $U_i(s_i, s_{-i})$ is continuous in $s_i$;*

③ *$U_i(s_i, s_{-i})$ is continuous and quasi-concave in $s_i$ ,*

➔ *Then a pure strategy Nash equilibrium exists.*

# Satisfaction Equilibrium

⌘ Non-Cooperative Game: Satisfaction Equilibrium

Consider the game $\mathcal{G} = \{\mathcal{U}, \{\mathcal{P}^i\}_{i\in\mathcal{U}}, \{U_i\}_{i\in\mathcal{U}}, \{\theta\}_{i\in\mathcal{U}}\}$.

**Definition.** A strategy profile $\boldsymbol{P}^+$ is a satisfaction equilibrium of the game $\mathcal{G}$, if

$$\forall i \in \mathcal{U},\ P_i^+ \in f_i(\boldsymbol{P}_{-i}^+),\ \textit{i.e.,}\ U_i(P_i^+, \boldsymbol{P}_{-i}^+) \geq \theta_i.$$

Where $f_i(.)$ is a correspondence function providing a subset of strategies yielding a utility higher than the demand.

# Satisfaction Equilibrium

⌘ Non-Cooperative Game: Satisfaction Equilibrium

Consider the following prisoners dilemma game:

| | | Bob | |
|---|---|---|---|
| | | C | D |
| Alice | C | -5, -5 | 0, -10 |
| | D | -10, 0 | -1, -1 |

OK if arrested a duration less than or equal 5 years !

| | | Bob | |
|---|---|---|---|
| | | C | D |
| Alice | C | 1, 1 | 1, 0 |
| | D | 0, 1 | 1, 1 |

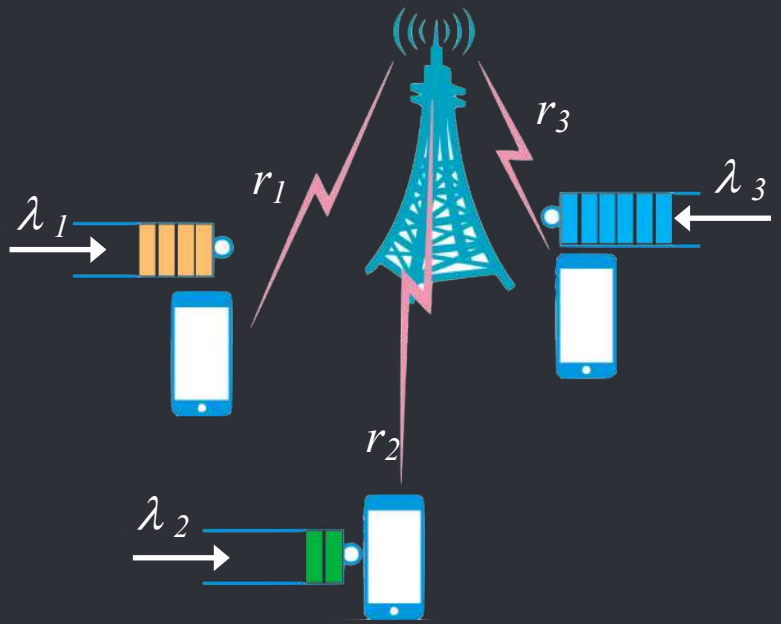
A unique NE !
➔ (C, C) with payoffs (-5, -5)

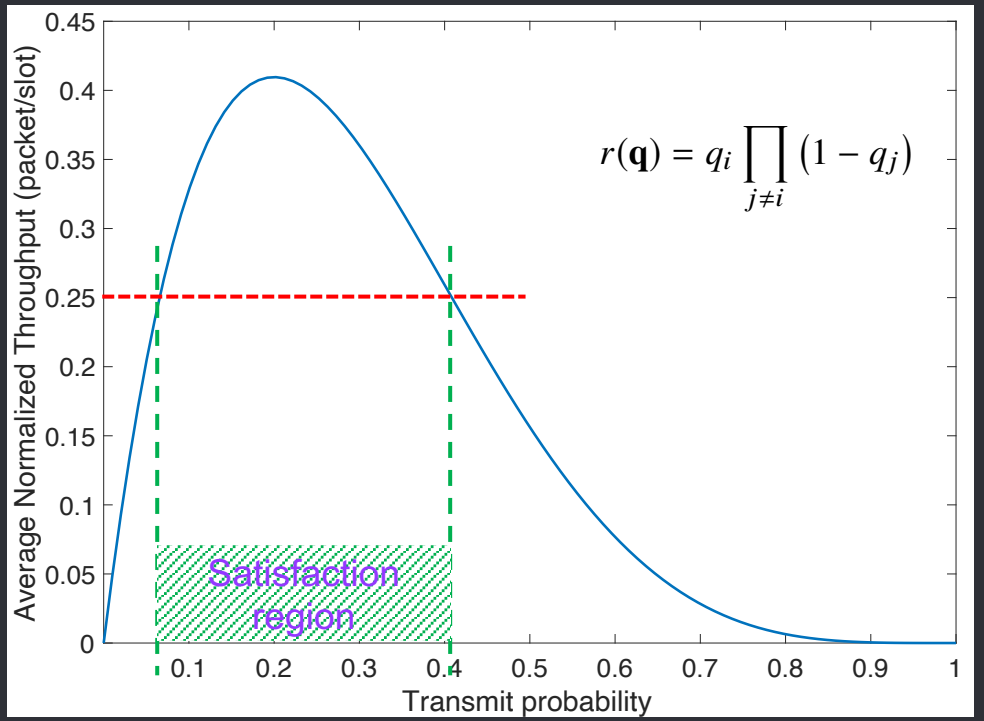
Two SE(NE) !
➔ (C, C) with payoffs (-5, -5)
&
➔ (D, D) with payoffs (-1, -1)

# 4 Satisfaction Games in Wireless Networks

# Some Satisfaction Games in Wireless Networks

⌘ Satisfactory Slotted Aloha for IoT standard (LoRa, Sigfox, etc.)




E. Sabir, Rachid EL-Azouzi, Kavitha Verraruna, Yezekael Hayel, El-Houssine Bouyakhf, ‘‘Constrained Nash Equilibrium Throughput in Non-Saturated Wireless Collision Channel’’. ACM Valuetools 2009.

# Some Satisfaction Games in Wireless Networks

⌘ Satisfactory Slotted Aloha for IoT standard (LoRa, Sigfox, etc.)

**Algorithm 1 :** Fully Distributed Throughput Predicting Algorithm (FDTPA)

**Initialization:**

Each node $i$ picks randomly an initial value $r_i^0$

**Learning pattern:**

**for** each node $i \in 1, 2, ..., m$ **do**

$r_i^{t+1} := r_i^t + \epsilon_i^t \left(\mathbb{1}_{success}^t - r_i^t\right)$

$q_i^{t+1} := q_i^t + \eta_i^{t+1} \left(r_i^{t+1} - \lambda_i\right)$

**end for**



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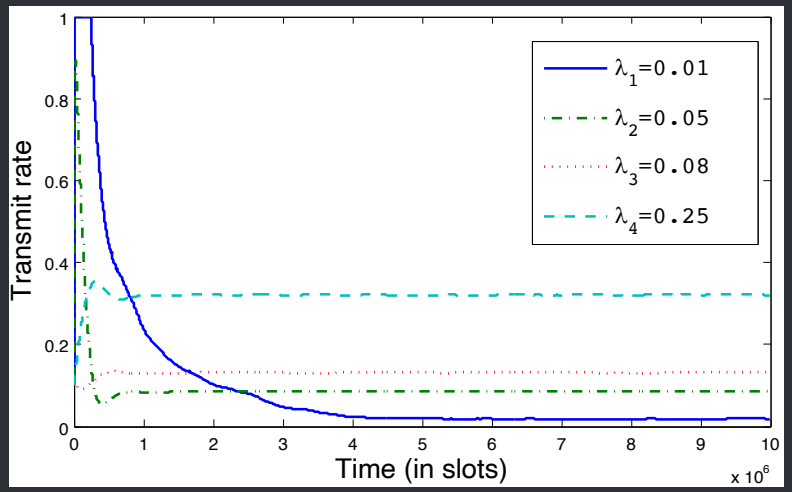
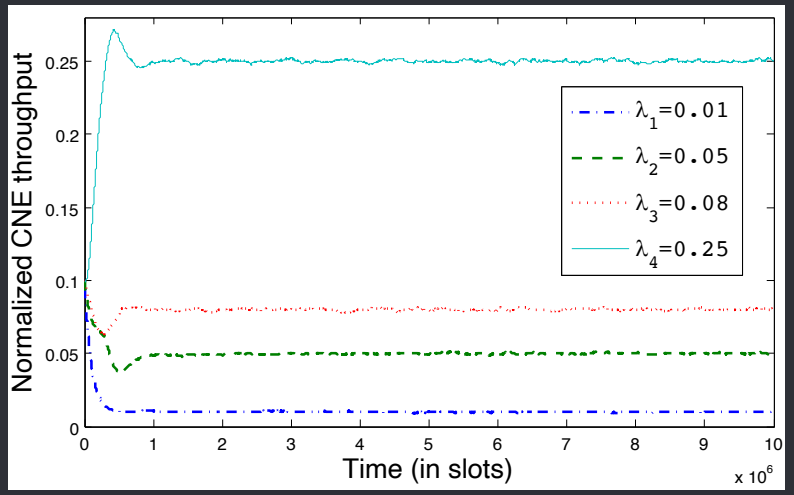
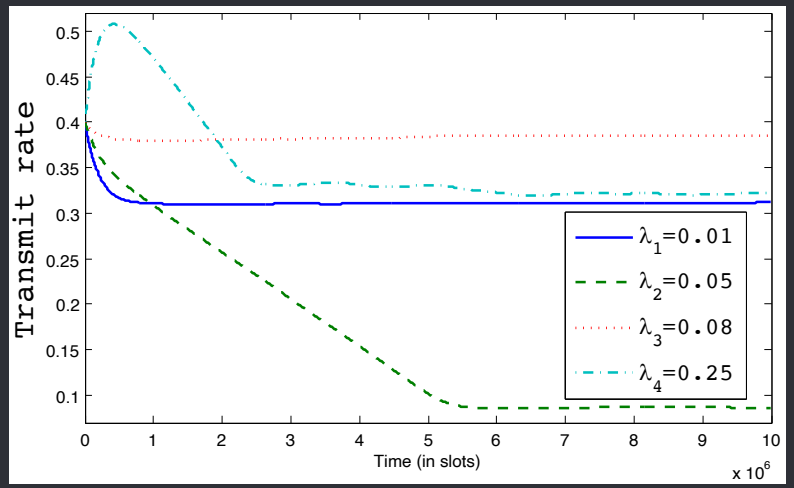
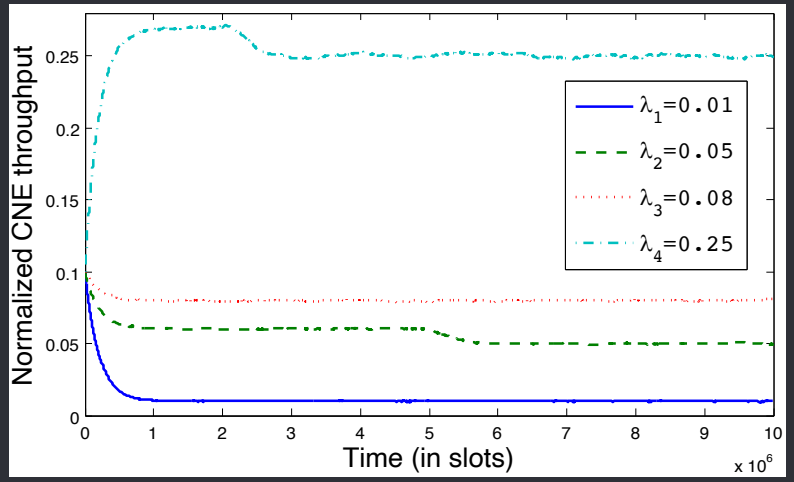


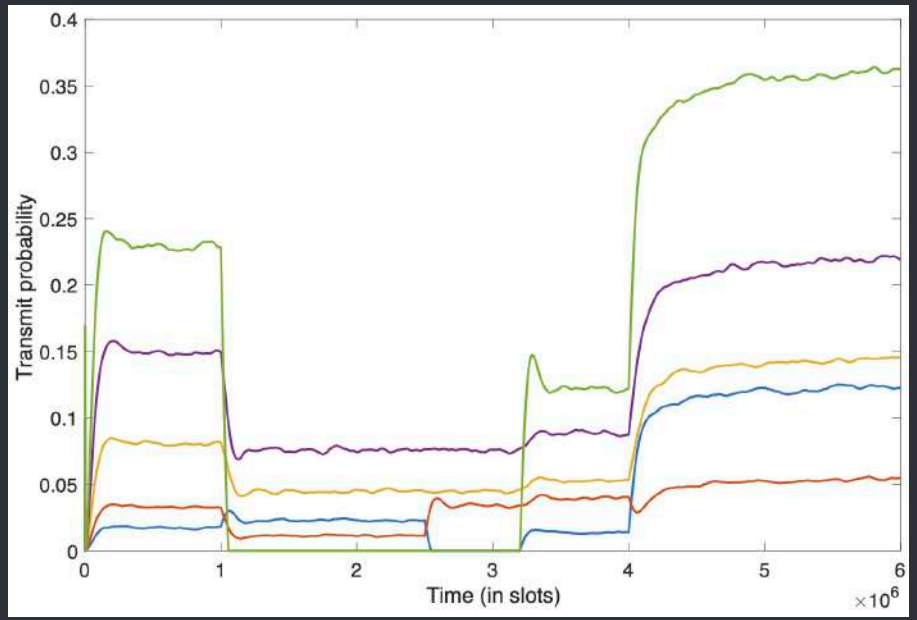



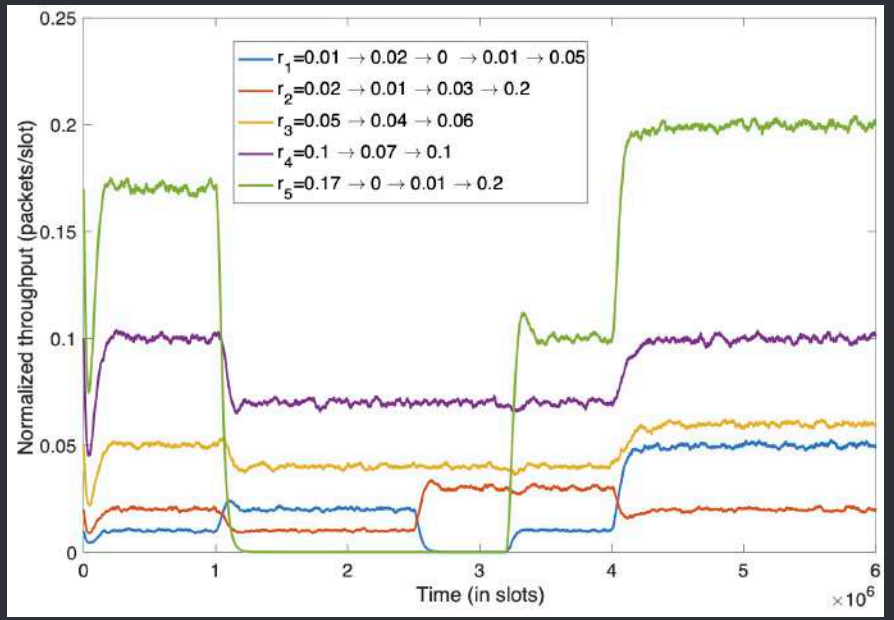



# Some Satisfaction Games in Wireless Networks

⌘ Satisfactory Slotted Aloha for IoT standard (LoRa, Sigfox, etc.)

Re-convergence of FDTPA

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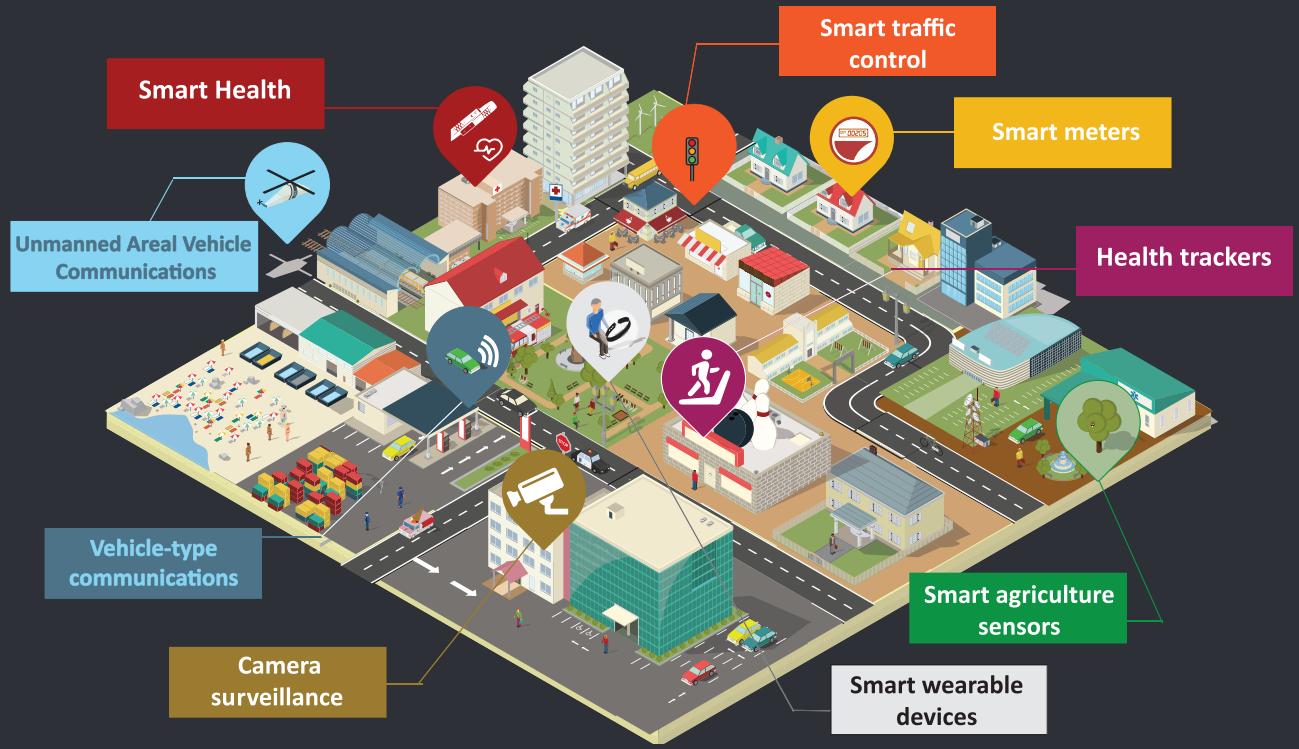
# Some Satisfaction Games in Wireless Networks

## ⌘ Turning Power onto QoS in 5G Networks

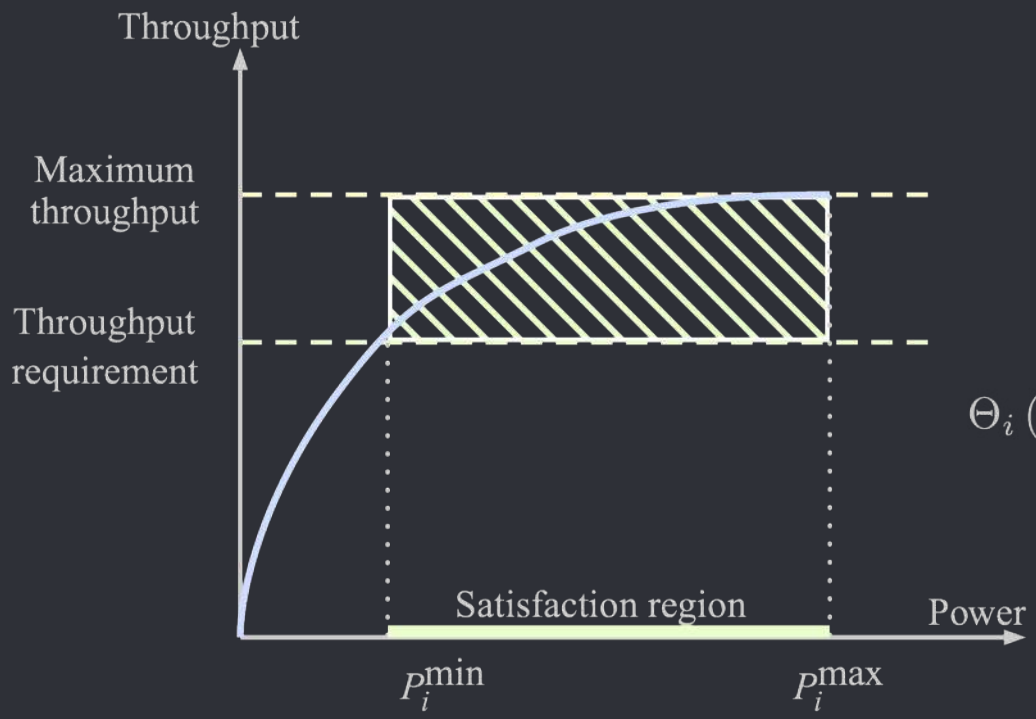



H. El Hammouti, E. Sabir, H. Tembine, ``A fully distributed satisfactory power control for QoS self-provisioning in 5G networks''. IEEE CCNC 2017

H. El Hammouti, E. Sabir, H. Tembine, ``A Satisfactory Power Control for 5G Self-Organizing Networks''. arXiv:1606.07904v1

# Some Satisfaction Games in Wireless Networks

⌘ Turning Power onto QoS in 5G and IoT




$$\Theta_i(\mathbf{P}) = \log\left(1 + \frac{p_i \cdot h_i}{\sigma^2 + \sum_{j \neq i} p_j \cdot h_j}\right)$$

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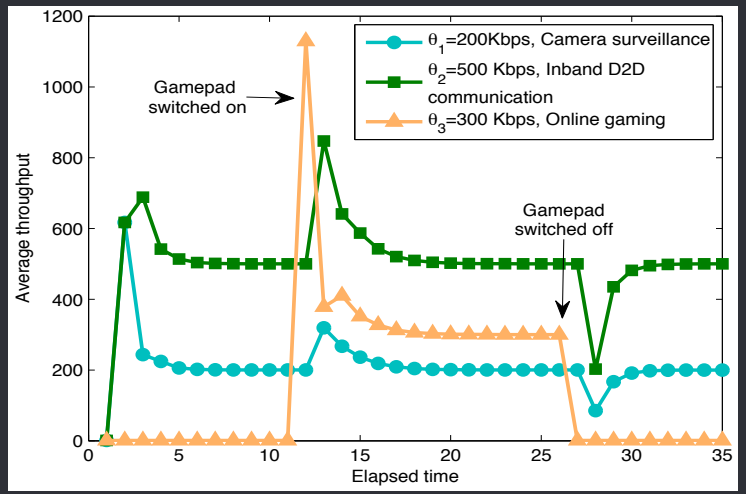
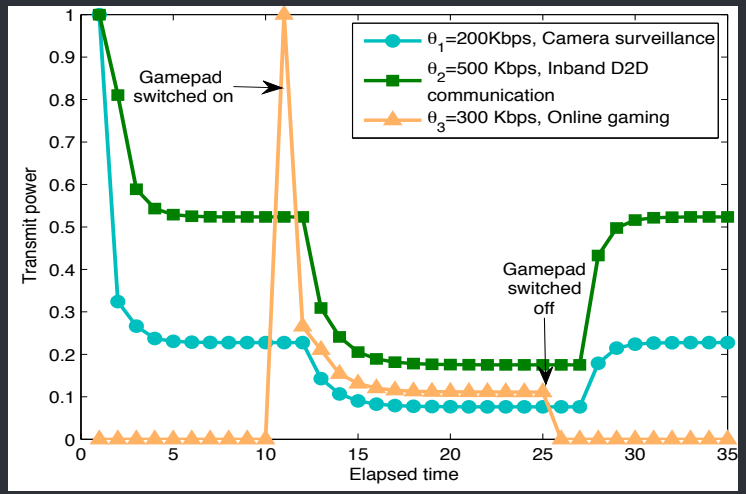
# Some Satisfaction Games in Wireless Networks

⌘ Turning Power onto QoS in 5G and IoT

**Algorithm 1** Banach-Picard algorithm

1: **Parameters initialization**
Each node picks randomly a transmit power with initial probabilities $p_i^0$
2: **repeat**
3: **Learning pattern**
4: **for** Each node $i$ **do**
Observes the value of its instantaneous throughput $r_i^t(p_i^t, \mathbf{P}_{-i})$
Updates its power as follows:
$p_i^{t+1} \leftarrow p_i^t \frac{\theta_i}{r_i^t}$
5: **until** The stopping criterion

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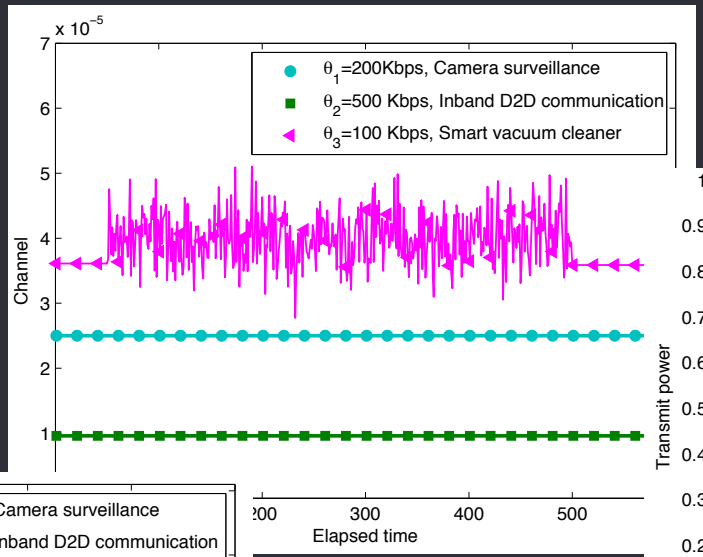


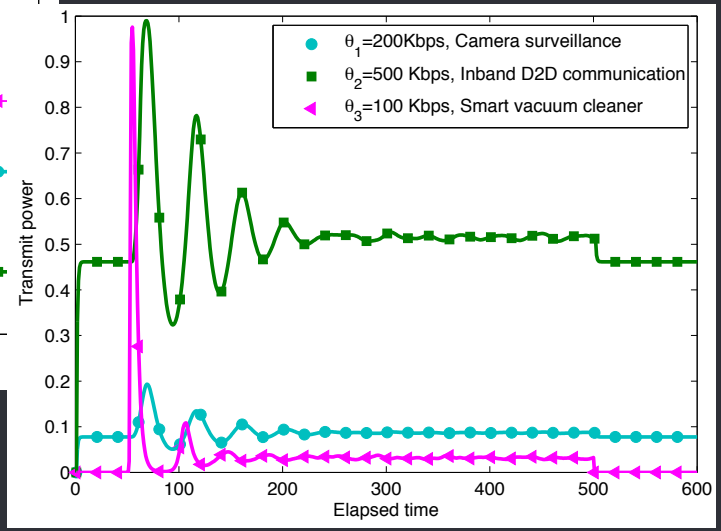


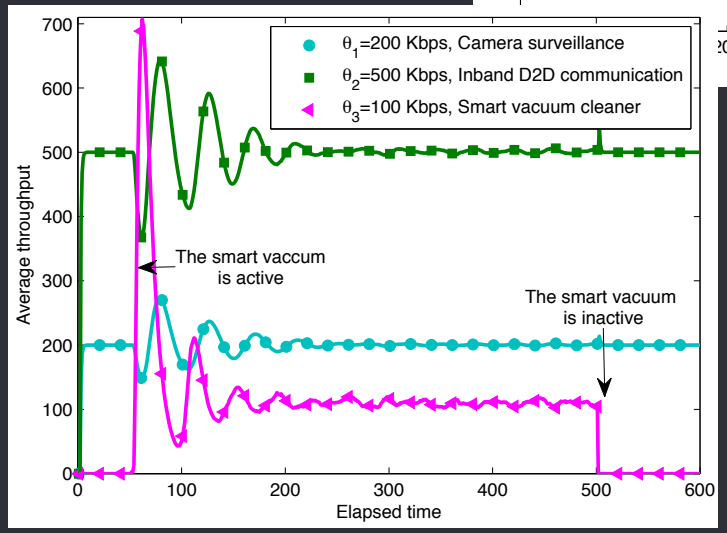


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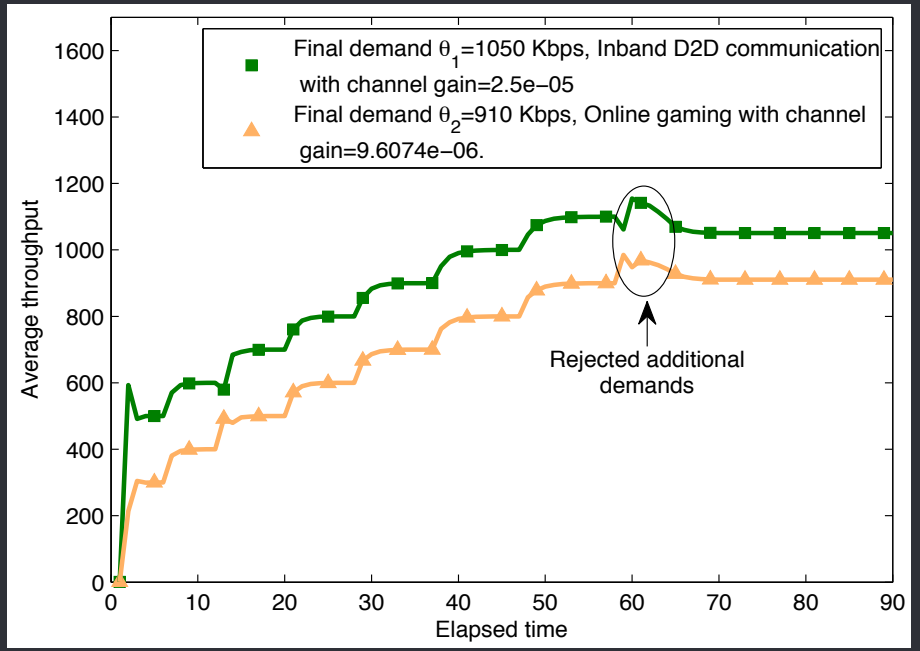
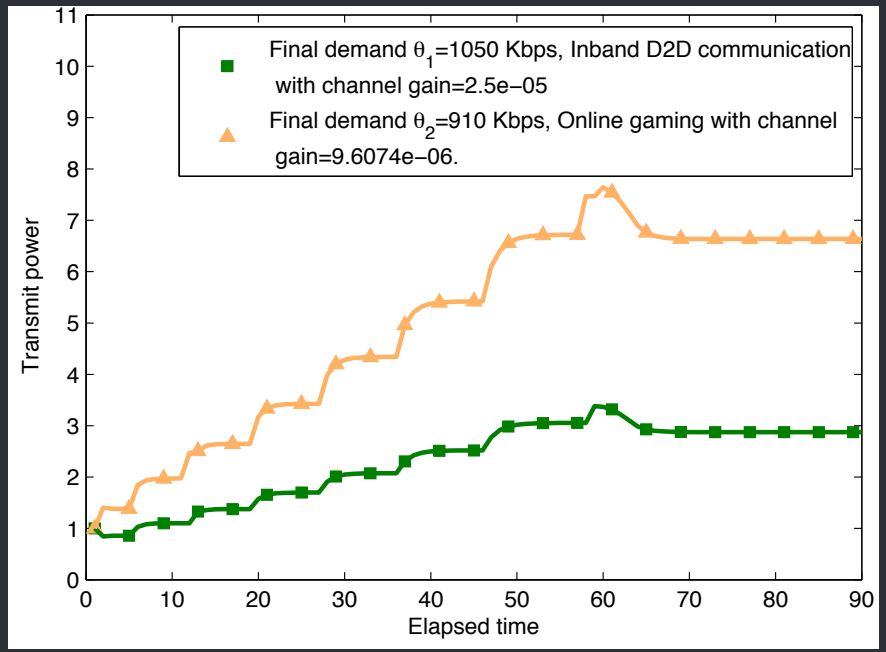
# Some Satisfaction Games in Wireless Networks

⌘ Capacity Discovery!

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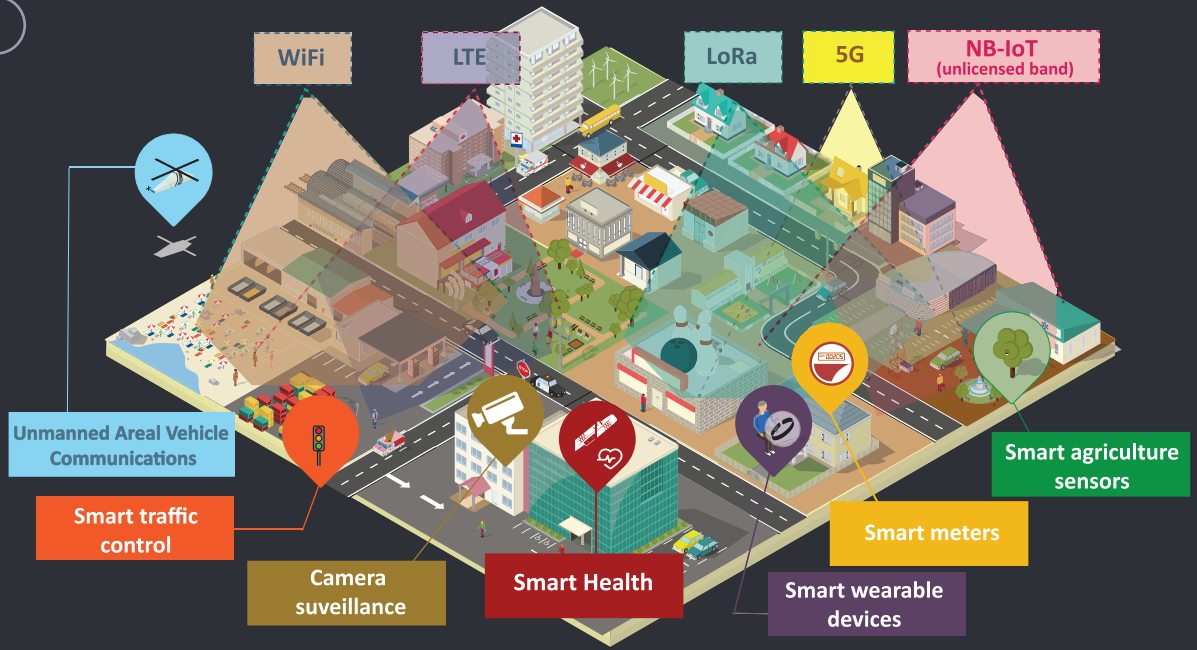
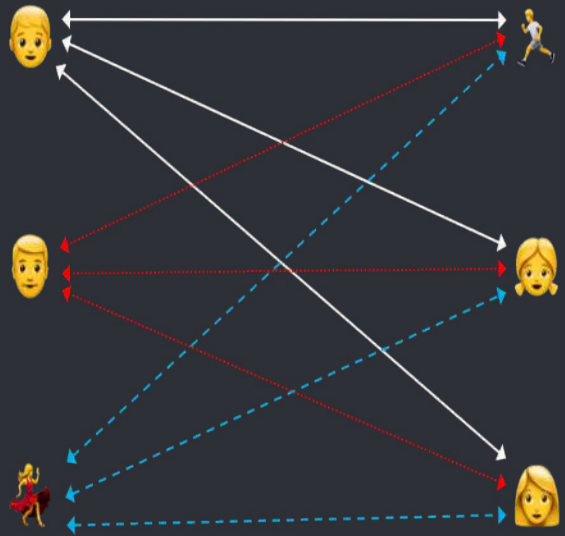
# Some Satisfaction Games in Wireless Networks

## ⌘ RAT Assignment for IoT



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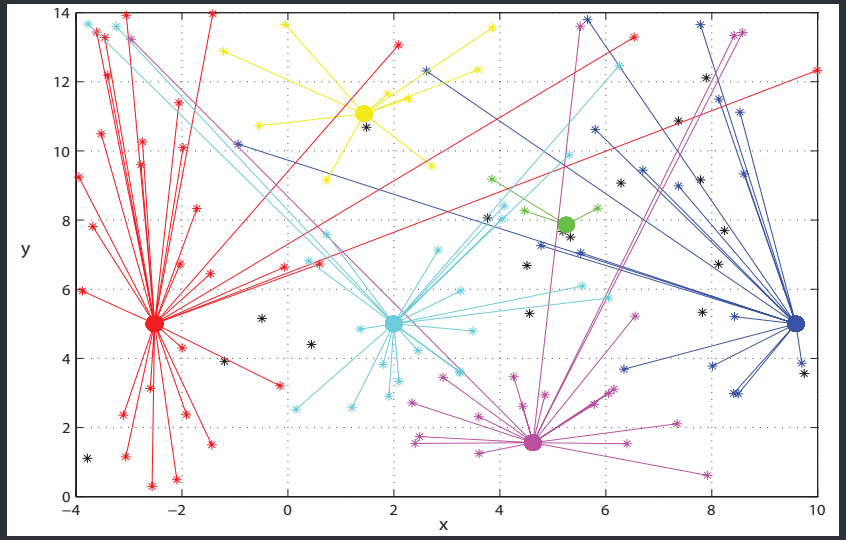
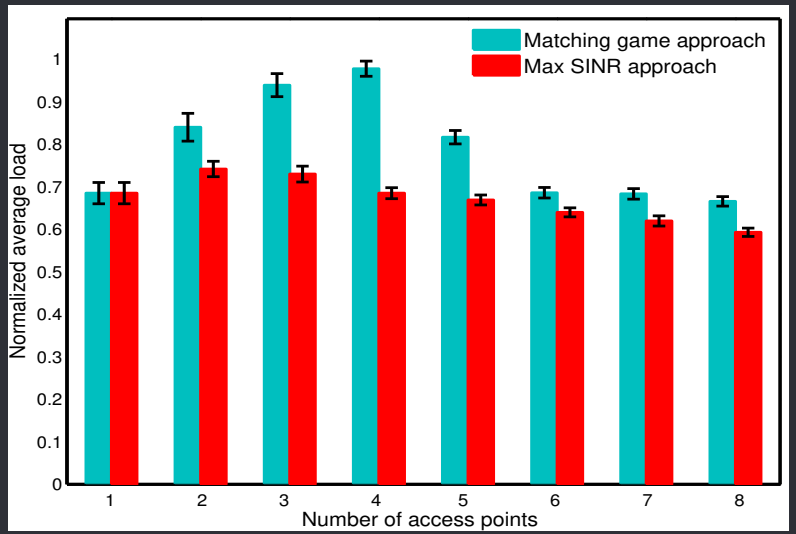
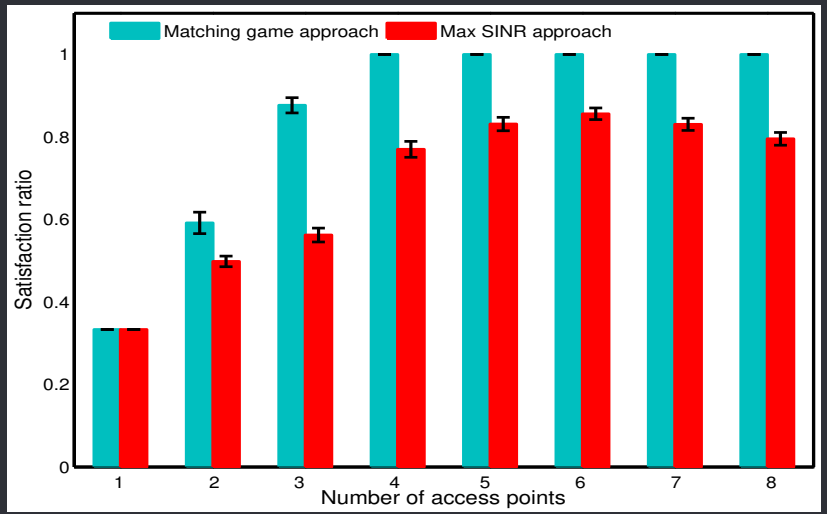
# Some Satisfaction Games in Wireless Networks

⌘ RAT Assignment for IoT

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# 5 Summary

# Summary

⌘ Concluding Remarks

- AI/ML/DL is quite attractive to enable ambient intelligence

  ➔ Scalability and convergence are still to be solved

- Need to consider cross-layer optimization for efficient SE

  ➔ Hardware and software co-design is a must

- AI is speculated to be the next big game changer

- One thing is ~~almost~~ sure, 6G is ~~likely~~ to be AI-driven

# A Short Overview on 5G and SONs

⌘ Some Use-Cases where SE might be useful

- Ultra Reliable Low Latency Communications
- Haptic communications, VR/AR and Tactile Internet
- Cognitive Radio, Flexible Radio & SDN
- Nomadic Infrastructure (e.g., UAV, Under-Water Networks, …)
- Industrial Internet of Things (IIoT)
- Etc.

Join us in Marrakesh on May 19-22, 2021 !

Submission deadline: January 20th, 2021

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Ubiquitous Networking

UNet21

# Thank You!

LATECE Seminars

Essaid Sabir

sabir.essaid@uqam.ca