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Machine learning for a 5G future

SMART USAGE OF MULTIPLE RAT IN IoT-ORIENTED 5G NETWORKS: A REINFORCEMENT LEARNING APPROACH

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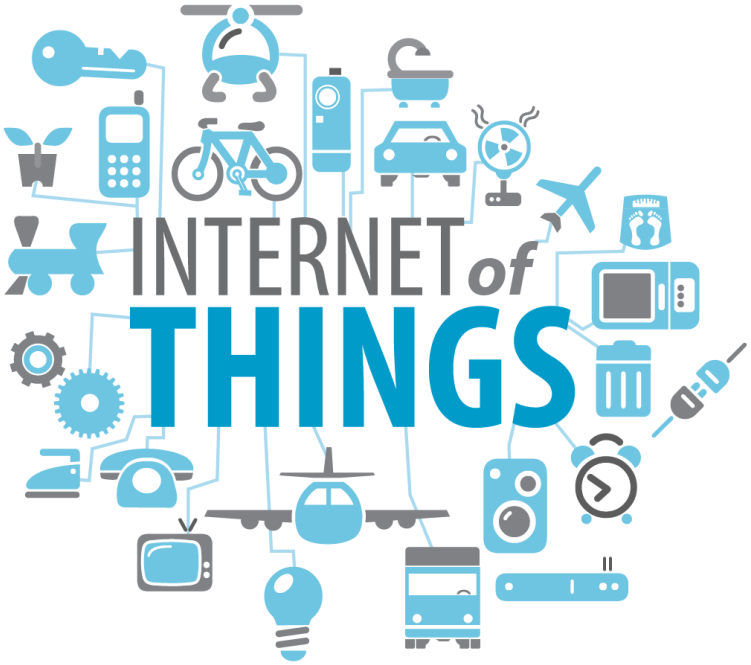
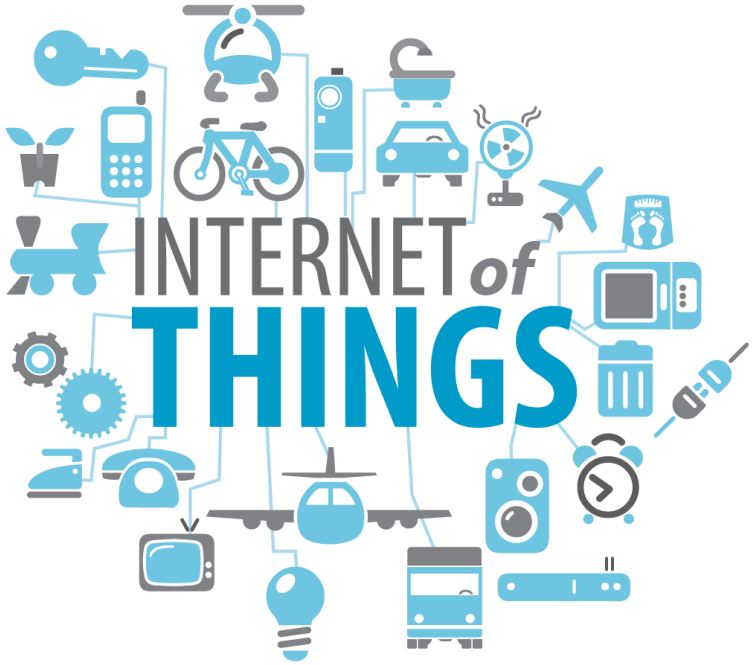
What is the Internet of Things (IoT)?

- Is the network of physical objects
- Objects endowed with communication, sensing and processing capabilities
- Gives rise to: Smart Cities, Smart Industries…



What are the challenges of IoT?

- Dramatic increase in generated traffic
- Leads to congestion of the EM spectrum
- Particular characteristics of traffic patterns
- Possible solution multiple Radio Access Technologies (RATs):
  - Different advantages and disadvantages
  - Reduce congestion



5G LoRa Wi Fi Bluetooth

Which RAT should be used?

Cellular Technologies:

+ Global coverage
+ Long range
- Operational Costs
- Oriented for data streams

LPWAN:

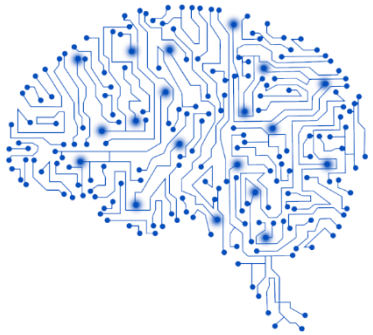
+ Long range
+ Low-power consumption
+ Use of unlicensed ISM bands
- Very low data rate

Short-range Technologies:

+ Low-power consumption
+ Use of unlicensed ISM bands
- Very short range

What do we propose?

- Let IoT devices use multiple RATs
- Solve the problem of deciding which RAT to use with Machine Learning
  - Consider the potential limitations of each technology
  - Maximize prioritized throughput



Mathematical model of RATs and IoT nodes

- IoT nodes generate events of different priorities (G) and length (L)
- Events are generated at a rate of λ (pkt/s)
- These events are transmitted using any of the N available RATs $(a_1, a_2, \dots a_N)$ or simply discarded (a_0)
- Each RAT:
  - Presents an usage limitation $(u_1^{MAX}, u_2^{MAX}, \dots u_N^{MAX})$ in terms of $/bits/pkts per day
  - Entails a power consumption $(c_1, c_2, \dots c_N)$ (joules)
  - Has its own infinite queue to buffer packets $(o_1, o_2, \dots o_N)$
- IoT nodes are fitted with batteries of b joules

Reinforcement Learning (RL) approach

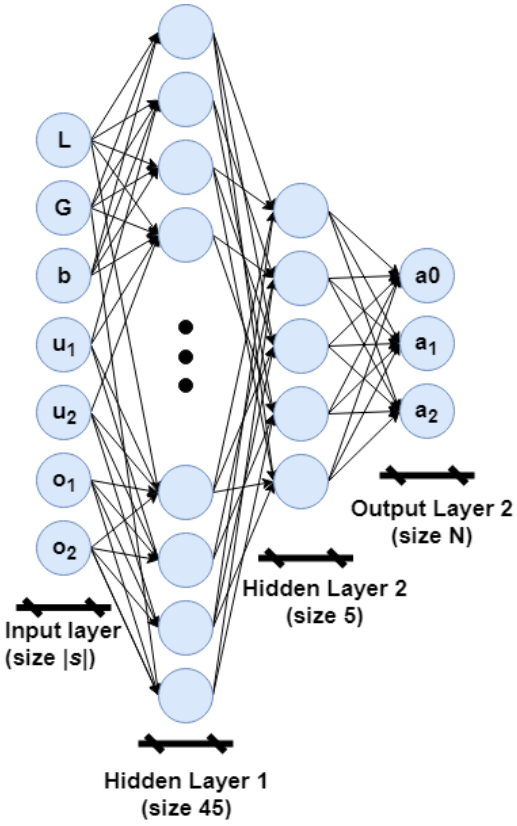
- **Objective**: determining which RAT should be used by an IoT device in any given situation so as to **optimize the prioritized throughput**.

- **RL jargon**: determining the optimal action a to take given a state s so as to **maximize the accumulation of rewards** R by the end of the day
  - Where s is a complete description of the state of the IoT node (composed of $L, G, b, u_1, u_2, \ldots u_N, o_1, o_2, \ldots, o_N$)
  - And $R = G\frac{L}{delay(a_i)}$ to indirectly maximize prioritized throughput

- **Result**: a policy. Which is the RL entity that prescribes actions for states.

Reinforcement Learning (RL) algorithm

- **Objective**: to derive a policy that determines the optimal action for each state
- Such a policy is modeled with an Artificial Neural Network (ANN)
- The ANN is fed with the state s of the node and outputs the optimal action a



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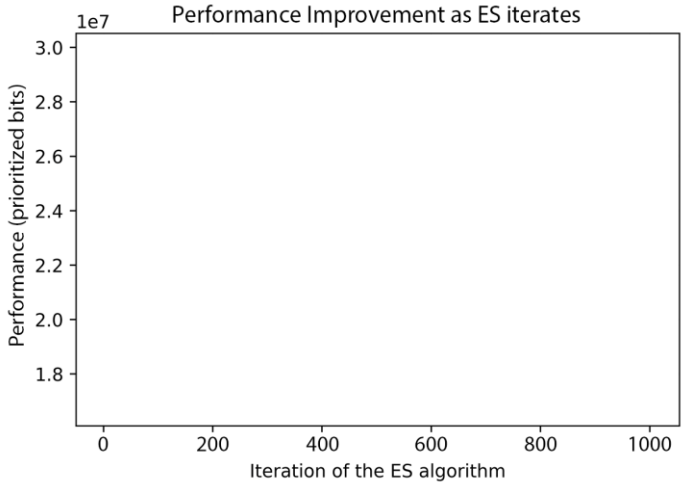
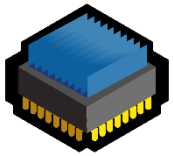
- We employ the algorithm known as Evolution Strategies [1] to *evolve* the ANN (1000 iterations)



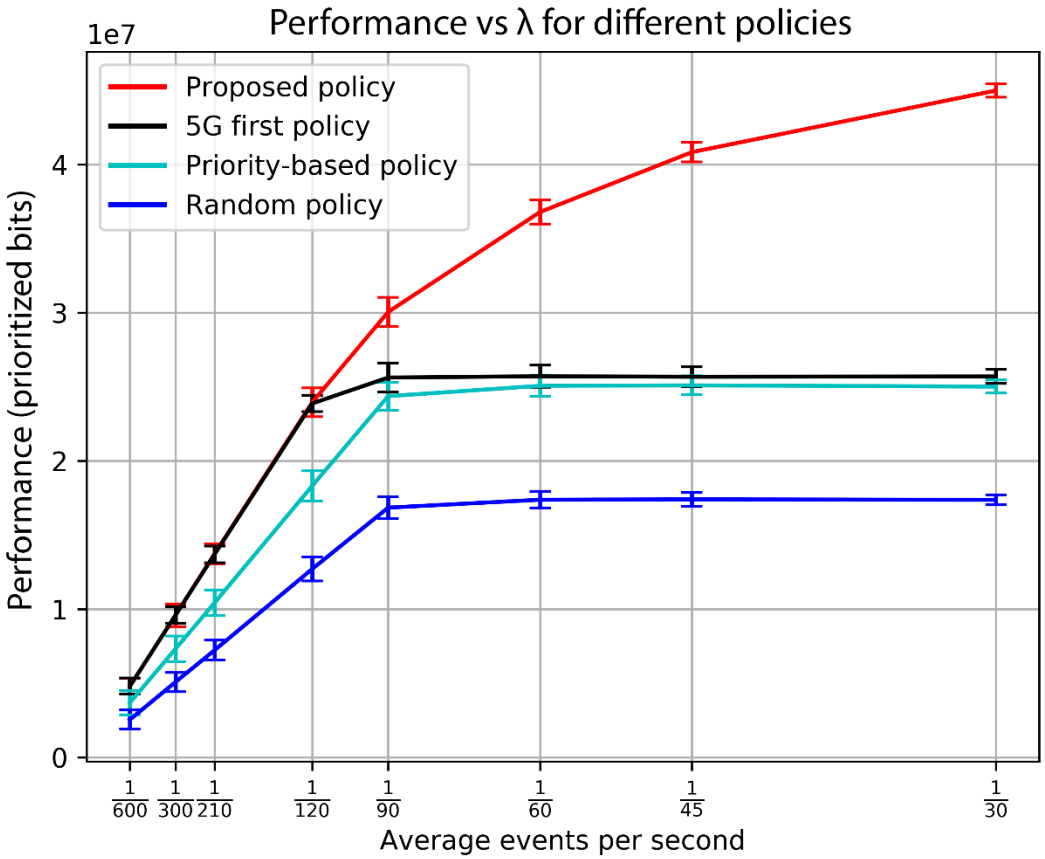
[1] T. Salimans, J. Ho, X. Chen, S. Sidor, and I. Sutskever, “Evolution Strategies as a Scalable Alternative to Reinforcement Learning,” ArXiv e-prints, Mar. 2017.

Simulations and results (Settings)

- We simulate an IoT network in a Smart City with two RATs:
  - **5G:** Spectrum renting scheme (100kbps), usage limitation (1Mb/day)
  - **LoRa:** Spreading Factor 7 (2.43Kbps)
- IoT nodes:
  - Generate packets with priorities: $\mathrm{G} = U(0,1)$
  - Generate packets of varying length: $\mathrm{L} = U(30,200)$ bytes
  - Designed to last for 3 years with 2AA batteries
  - Packet generation rates studied: from $\lambda = \frac{1}{600}$ to $\lambda = \frac{1}{30}$ packets/s
- 3 Alternative policies:
  - 5G first
  - Priority-based policy
  - Random



Simulations and results (Results)



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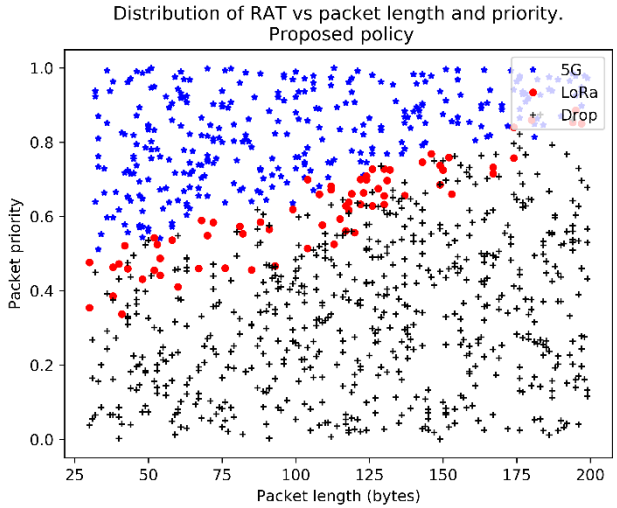
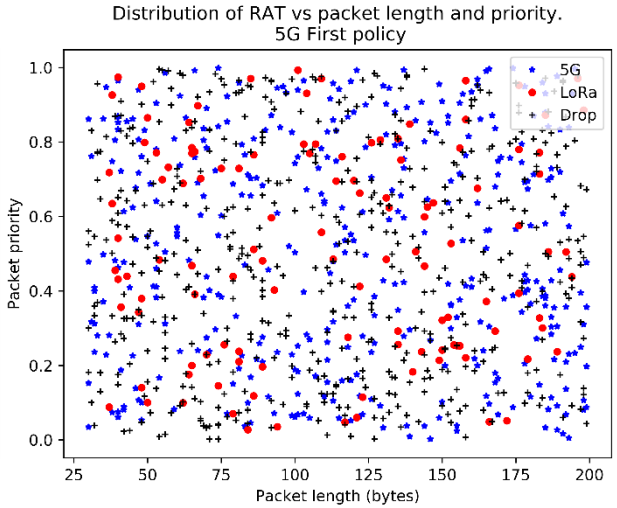
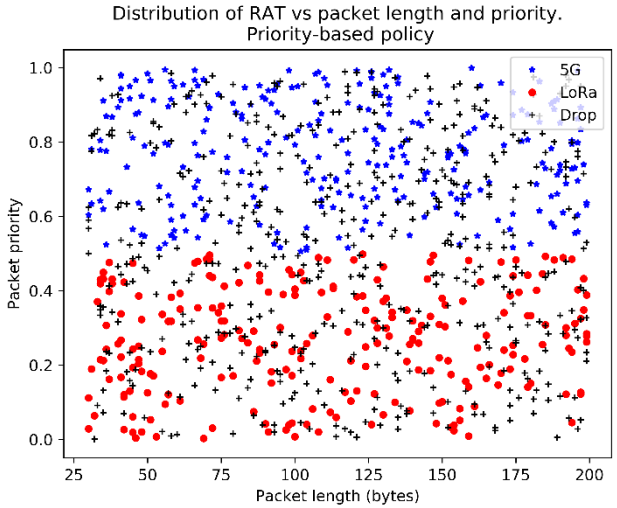
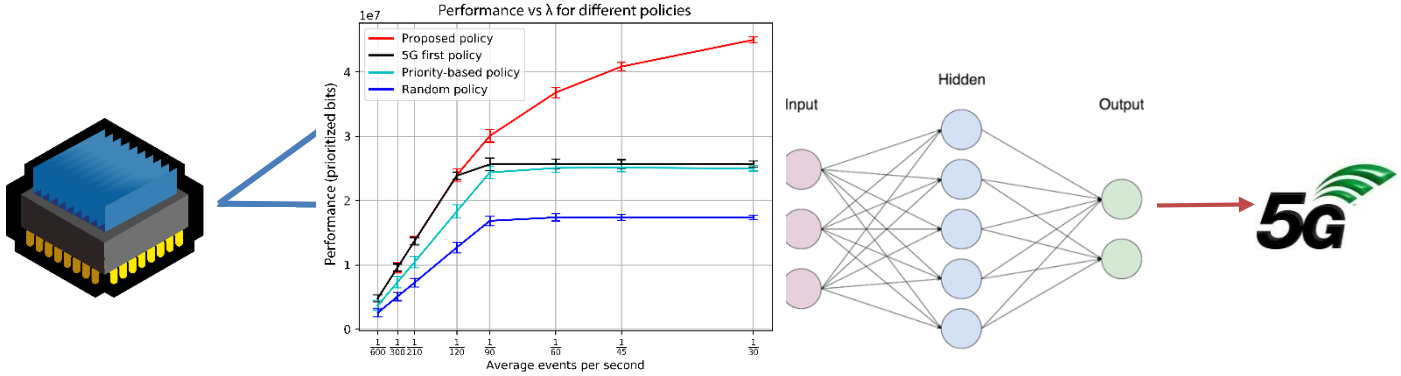






Conclusions

- **IoT** nodes deployed in Smart Cities/Industries may **benefit** from **multiple RAT**
- Solve the problem of **deciding** which **RAT** to use with **Machine Learning**
- Such a task is **mathematically modeled** as a formal **RL problem**
- **Evolution Strategies** to solve the RL problem is applied
- A particular scenario with **5G** and **LoRa** (intrinsic limitations) is studied
- The proposed solution and 3 alternative policies are **simulated**
- The **superior performance of RL-based** policies for RAT selection **is shown**



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Any questions?

Thank you