Title of the these

Aghiles DJOUDI

PhD student
LIGM/ESIEE Paris & ECE Research Lab Paris

January 3, 2020

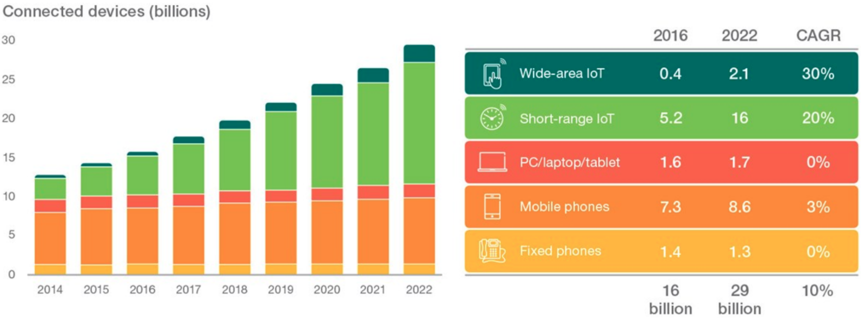
Outline

1. IoT Devices
2. IoT Applications
3. IoT Wireless Communications

Outline

Massive IoT devices

IoT devices are useless without a good communication capability



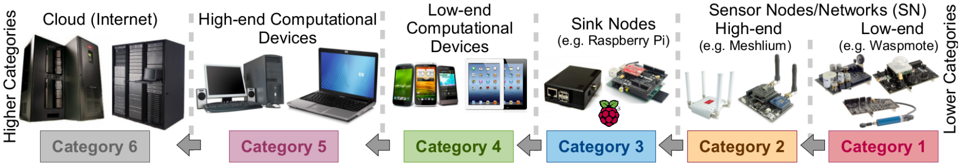


Figure 1. IoT devices [1].

Outline

Applications diversification

Each application has its own communication requirements

Challenges/Applications	Grids	EHealth	Transport	Cities	**Building**
Resources constraints	✗	✓	✗	-	✗
Mobility	✗	-	✓	✓	✗
Heterogeneity	-	-	-	✓	✗
Scalability	✓	-	✓	✓	-
QoS constraints	-	-	✓	✓	✓
Data management	-	✗	✓	✓	-
Lack of Standardization	-	-	-	-	✓
Amount of attacks	✗	✗	✓	✓	✓
Safety	-	✓	✓	-	✓

Table 1. Main IoT challenges [2] [3]

Figure 2. IoT Applications.

IoT platforms

IoT platforms is a chain of communication process

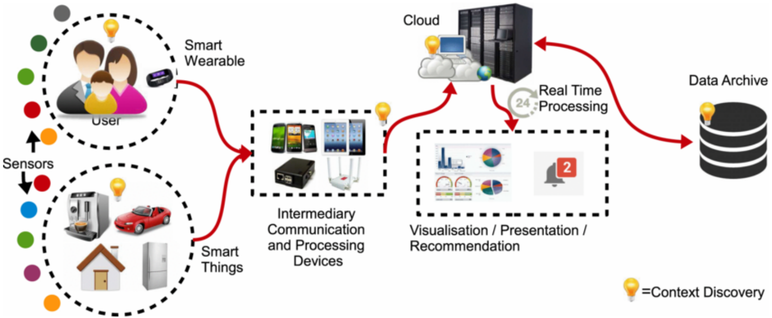


Figure 3. IoT platform.

Figure 4. IoT challenges.

Applications diversification

Requirements

Use Case	Packet rate [pkt/day]	Min success rate [Ps,min]	Payload Size [Byte]
Wearables	10	90	
Smoke Detectors	2	90	
Smart Grid	10	90	10-20
White Goods	3	90	
Waste Management	24	90	
VIP/Pet Tracking	48	90	
Smart Bicycle	192	90	
Animal Tracking	100	90	
Environmental Monitoring	5	90	
Asset Tracking	100	90	50
Smart Parking	60	90	
Alarms/Actuators	5	90	
Home Automation	5	90	
Machinery Control	100	90	
Water/Gas Metering	8	90	
Environmental Data Collection	24	90	
Medical Assisted Living	8	90	
Micro-generation	2	90	
Safety Monitoring	2	90	100-200
Propane Tank Monitoring	2	90	
Stationary Monitoring	4	90	
Urban Lighting	5	90	
Vending Machines Payment	100	90	
Vending Machines General	1	90	1K

Table 2. Application requirements for the use cases of interest [4] [3] [5]

Outline

IoT wireless communication

Wireless communication performance need to be evaluated to match applications requirements

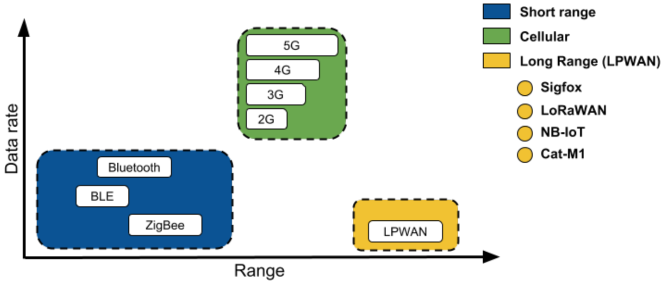


Figure 5. Short range, Cellular and Long range networks.

Outline

Wireless communication

Exp: LPWAN in a new technology that satisfy IoT applications requirements

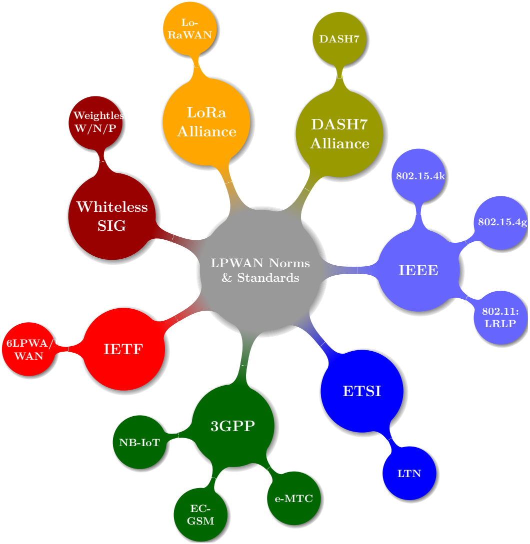


Figure 6. Wireless communication diversity.

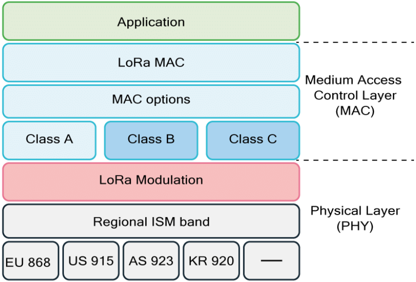


Figure 7. LoRa and LoRaWan stack.

LoRa modulation

Physical layer [6]

$$\textbf{LoRa} = \frac{2^{SF}}{BW}\left((NP + 4.25) + \left(SW + \max\left(\left\lceil \frac{8PS - 4SF + 28 + 16CRC - 20IH}{4(SF - 2DE)} \right\rceil (CR + 4), 0\right)\right)\right) \quad (1)$$

$$\textbf{GFSK} = \frac{8}{DR}(NP + SW + PL + 2CRC) \quad (2)$$

Where:

- NP = 8, if LoRa . 5, if GFSK
- SW = 8, if LoRa . 3, if GFSK
- CRC = 0 if downlink packet. 1 if uplink packet
- IH = 0 if header. 1 if no header present
- DE = 1 if data rate optimization. 0 if not

- Payload size (*PS*) = PHY_Payload bytes
- Spreading Factor (*SF*) = 7, 8, 9, 10, 11, 12
- Bandwidth (*BW*) = 125kHz, 250kHz, where BW is the bandwidth
- Coding Rate (*CR*) = Indicates the Coding Rate

LoRa parameters selection

How to select the optimal configuration

- Parameters
  - BW
  - SF
  - CR
  - Transmission Power (P^{tx})
  - PS
- Metrics
  - Signal Noise Rate (SNR)
  - Data Rate (DR)
  - Air Time (AT)
  - PS_{max}
  - Receiver Sensitivity (S_{rx})

Setting	Values	Rewards	Costs
BW	7.8 ➠ $500kHz$	DR	S_{rx}, Range
SF	2^6 ➠ 2^{12}	S_{rx}, Range	DR, SNR, PS_{max}, P^{tx}
CR	$4/5$ ➠ $4/8$	Resilience	PS_{max}, P^{tx}, AT
P^{tx}	-4 ➠ $20dBm$	SNR	P^{tx}
PS	59 ➠ $230B$	PS	P^{tx}, AT

Table 3. LoRa parameters selection [7]

Multi criteria decision making

Layer	Maximize (Reward)	Minimize (Cost)
Application	Sec security	Service Cost (*SC*)
Network	Range Packet delivery ratio (*PDR*) *PS* *DR*	Jitter (*Jit*) Traffic congestion (*TC*) Round-Trip Delay (*RTD*) Packet Error Rate (*PER*) Time Complexity (O_{time}) Space Complexity (O_{space})
Radio	Mobility (*Mob*) Symbol Rate (*SR*) Bit Rate (*BR*) Sensitivity (*Sen*) Received Signal Strength Indication (*RSSI*) Signal-to-interference & noise ratio (*SINR*) *SNR* Signal-to-Interference Ratio (*SIR*)	Bit Error Rate (*BER*) P^{tx} Co-channel Interference (*CCI*) Duty cycle (*DC*) Time on Air (*ToA*) Path loss (*PL*)

Table 4. Network selection inputs and classification of parameters [8] [9]

Multi criteria decision making

$$SNR_{\mathbf{[dB]}} = 20.log(\frac{S}{N}) \tag{3}$$

$$RSSI = Tx_{power} \cdot \frac{Rayleigh_{power}}{PL} \tag{4}$$

$$SR_{\mathbf{[sps]}} = \frac{BW}{2^{SF}} \tag{5}$$

$$BR_{\mathbf{[bps]}} = SF * \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}} \tag{6}$$

$$PL = |RSSI| + SNR + P_{TX} + G_{RX} \tag{7}$$

$$Sen_{\mathbf{[dBm]}} = -174 + 10\log_{10} BW + NF + SNR \tag{8}$$

$$PER_{\mathbf{[pps]}} = 1 - (1 - BER)^{n_{bits}} \tag{9}$$

$$BER_{\mathbf{[bps]}} = \frac{8}{15} \cdot \frac{1}{16} \cdot \sum k = 216 - 1^{k} (\frac{16}{k}) e^{20.SINR(\frac{1}{k} - 1)} \tag{10}$$

$$ToA_{\mathbf{s}} = \frac{2^{SF}}{BW_{[Hz]}} \tag{11}$$

$$PER_{\mathbf{[pps]}} = 1 - (1 - BER)^{n_{bits}} \tag{12}$$

(13)

Multi criteria decision making

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(p_i - r_i)^2 \tag{14}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(p_i - r_i)^2} \tag{15}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|p_i - r_i\right| \tag{16}$$

$$Recall = \frac{TP}{TP + FN} \tag{17}$$

$$Precision = \frac{TP}{TP + FP} \tag{18}$$

$$F1\_Score = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{precision} + \text{recall}} \tag{19}$$

$$TPR = \frac{TP}{TP + FN} \tag{20}$$

$$FPR = \frac{FP}{FP + TN} \tag{21}$$

$$ROC = (TPR, FPR) \tag{22}$$

$$Novelty = \sum_{i \in L}\frac{\log_2 P_i}{n} \quad \text{where} \quad P_i = \frac{n - rank_i}{n - 1} \tag{23}$$

$$Serendipity = \frac{1}{n}\sum_{i \in n}\max(P_{user} - P_U, 0) \times rel_i \tag{24}$$

LoRa Frame

Preamble		Sync msg	PHY Header	PHDR-CRC						
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MAC Header					
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major			
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major	Dev Address		
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major	NwkID	NwkAddr	ADR
0	1	2	3	4	5	6	7	8	9	10

PHY Payload									CRC	
MAC Payload								MIC	CRC Type	Polynomial
Frame Header						FPort	**Frame Payload**	MIC	CRC Type	Polynomial
FCtrl				FCnt	FOpts	FPort	**Frame Payload**	MIC	CRC Type	Polynomial
ADRACKReq	ACK	FPending /RFU	FOptsLen	FCnt	FOpts	FPort	**Frame Payload**	MIC	CRC Type	Polynomial
11	12	13	14	15	16	17	18	19	20	21

LoRa Frame

- **Modulation :**
  - Lora: 8 Symbols, 0x34 (Sync Word)
  - FSK: 5 Bytes, 0xC194C1 (Sync Word)

- **Length :**
- **Sync msg :**
- **PHY Header :** It contains:
  - The Payload length (Bytes)
  - **The Code rate**
  - Optional 16bit CRC for payload

- **Phy Header :** CRC It contains CRC of Physical Layer Header
- **MType :** is the message type (uplink or a downlink)
  - whether or not it is a confirmed message (reqst ack)
  - 000 Join Request
  - 001 Join Accept
  - 010 Unconfirmed Data Up
  - 011 Unconfirmed Data Down
  - 100 Confirmed Data Up
  - 101 Confirmed Data Down
  - 110 RFU
  - 111 Proprietary

- **RFU :** Reserved for Future Use
- **Major :** is the LoRaWAN version; currently, only a value of zero is valid
  - 00 LoRaWAN R1
  - 01-11 RFU

- **NwkID :** the short address of the device (Network ID): 31th to 25th
- **NwkAddr :** the short address of the device (Network Address): 24th to 0th
- **ADR :** Network server will change the data rate through appropriate MAC commands
  - 1 To change the data rate
  - 0 No change

- **ADRACKReq :** (Adaptive Data Rate ACK Request): if network doesn't respont in 'ADR-ACK-DELAY' time, end-device switch to next lower data rate.
  - 1 if (ADR-ACK-CNT) >= (ADR-ACK-Limit)
  - 0 otherwise

- **ACK :** (Message Acknowledgement): If end-device is the sender then gateway will send the ACK in next receive window else if gateway is the sender then end-device will send the ACK in next transmission.
  - 1 if confirmed data message
  - 0 otherwise

- **FPending↓ /RFU ↑ :** (Only in downlink), if gateway has more data pending to be send then it asks end-device to open another receive window ASAP
  - 1 to ask for more receive windows
  - 0 otherwise

- **FOptsLen :** is the length of the FOpts field in bytes ă 0000 to 1111
- **FCnt :** 2 type of frame counters
  - FCntUp: counter for uplink data frame, MAX-FCNT-GAP
  - FCntDown: counter for downlink data frame, MAX-FCNY-GAP

- **FOpts :** is used to piggyback MAC commands on a data message
- **FPort :** a multiplexing port field
  - 0 the payload contains only MAC commands
  - 1 to 223 Application Specific
  - 224 & 225 RFU

- **FRMPayload :** (Frame Payload) Encrypted (AES, 128 key length) Data
- **MIC :** is a cryptographic message integrity code
  - computed over the fields MHDR, FHDR, FPort and the encrypted FRMPayload.

- **CRC :** (only in uplink),
  - CCITT $x^{16}+x^{12}+x^5+1$
  - IBM $x^{16}+x^{15}+x^5+1$

Outline

Outline

A Relay and Mobility Scheme for QoS Improvement in IoT

Related work[1]

- Only application requirements.
  - Environment conditions, operator rules, User preferences.
- Only one (simple) normalization function for all parameters.
  - Use **Fuzzy logic** with different rules for normalization.
- Only one objective function to fits all requirements.
  - Use **Genetic algorithms** with 3 objective functions.
- Only one application.
  - Use **3 applications** with different requirements

[1] A. A. Simiscuka and G. Muntean, " A Relay and Mobility Scheme for QoS Improvement in IoT Communications ", in *2018 IEEE International Conference on Communications Workshops (ICC Workshops)*, 00002, IEEE, May 2018, pp. 1–6.

Outline

Outline

Outline

- Configuration parameters:
  - *SF*
  - *CR*
  - P^{tx}
  - *BW*
  - *PS*
- Configuration metrics:
  - *DR*
  - *PDR*
  - *RTD*
  - *ToA*

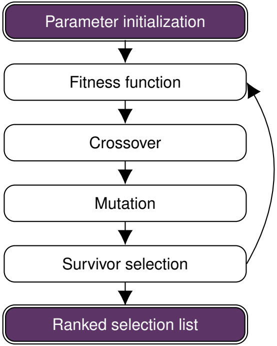
$$Qn,m = \begin{array}{r c} & \begin{array}{cccc} \textit{Metric } 1 & \textit{Metric } 2 & \dots & \textit{Metric } M \end{array} \\ \begin{array}{r} \textit{Configuration } 1 \\ \textit{Configuration } 2 \\ \vdots \\ \textit{Configuration } N \end{array} & \begin{pmatrix} q_{11} & q_{12} & \cdots & q_{1M} \\ q_{21} & q_{22} & \cdots & q_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ q_{N1} & q_{N2} & \cdots & q_{NM} \end{pmatrix} \end{array}$$

Outline

Genetic Algorithm

Background [11]

Definition: stopping criteria, population size P, and mutation probability p_m
Generate randomly the initial configurations
repeat:
. . . **for** each configuration do
. . . . . . Train a model & compute configuration's fitness
. . . **end**
. . . **for** each reproduction 1 ... P/2 do
. . . . . . **Select:** 2 configurations based on fitness
. . . . . . **Crossover:** Produce 2 child configurations
. . . . . . **Mutate:** child configurations with p_m
. . . **end**
until stopping criterion is met



Outline

Fuzzy Logic

Assign a degree of membership between 0 and 1

- We have a temperature value (16°) , and we want to represent this value with 3 weighted vales.
  - 0% hot
  - 0.4% warm
  - 0.6 % cold

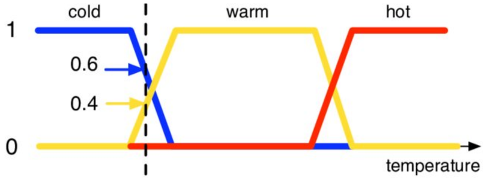


Figure 8. Temperature example.

Outline

Selection framework

Methods

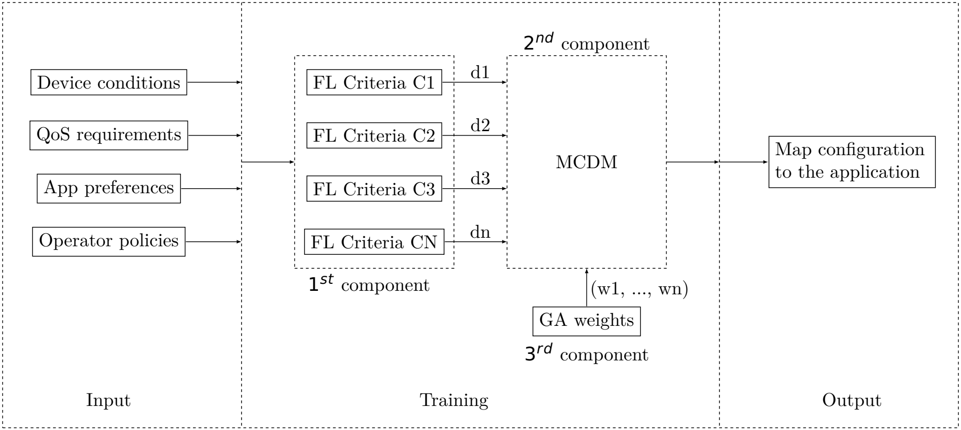


Figure 9. The proposed scheme for LoRa transmission parameters selection based on *GA*, *FL* and *MCDM*..

Outline

1. Introduction
2. Survey A
3. Genetic Algorithm For LoRa
    1. Background
    2. Method
    3. Experiments
    4. Results
    5. Discussion
4. EES
5. Q-Learning
6. Q-Learning
7. ...
8. Testbed
9. Conclusion
10. Survey plafforms

- **Inputs:**
  - Data structure
    - Voice, Images and Text transmission.
  - Environment conditions
    - Rural/Urban
    - Static/Mobile
    - Temperature
    - Interference/Noise
  - QoS metrics:
    - User layer: Cost
    - Network metrics: DR, Payload length.
    - Radio metrics: Receiver sensitivity, SNR, DR, Air time,
  - MAC configuration (SF, CR, BW, Tx)
- **Outputs:**
  - (SF_i, CR_j, BW_k, Tx_l) optimal

Outline

Results

Comparison

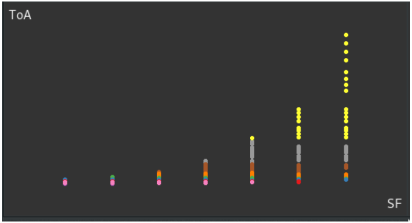


Figure 10. Impact of SF on ToA.

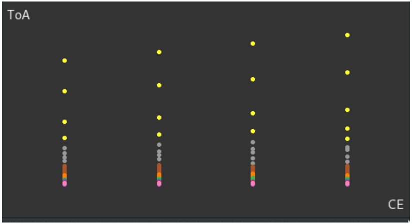


Figure 12. Impact of CR on ToA.

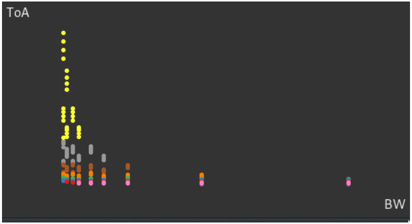


Figure 11. Impact of BW on ToA.

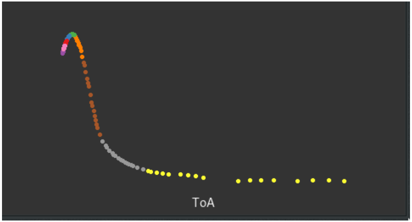


Figure 13. ToA distribution.

Outline

Multi criteria decision making

Layer	Maximize (Reward)	Minimize (Cost)
Application	Sec security	*SC*
Network	Range	*Jit*
	PDR	*TC*
	PS	*RTD*
	DR	*PER*
		O_{time}
		O_{space}
Radio	*Mob*	*BER*
	SR	P^{tx}
	BR	*CCI*
	Sen	*DC*
	RSSI	*ToA*
	SINR	*PL*
	SNR	
	SIR	

Table 5. Network selection inputs and classification of parameters [8] [9]

Multi criteria decision making

$$SNR_{\textbf{[dB]}} = 20.log(\frac{S}{N}) \tag{33}$$

$$RSSI = Tx_{power} \cdot \frac{Rayleigh_{power}}{PL} \tag{34}$$

$$SR_{\textbf{[sps]}} = \frac{BW}{2^{SF}} \tag{35}$$

$$BR_{\textbf{[bps]}} = SF * \frac{\frac{4}{4+CR}}{\frac{2SF}{BW}} \tag{36}$$

$$PL = |RSSI| + SNR + P_{TX} + G_{RX} \tag{37}$$

$$Sen_{\textbf{[dBm]}} = -174 + 10\log_{10} BW + NF + SNR \tag{38}$$

$$PER_{\textbf{[pps]}} = 1 - (1 - BER)^{n_{bits}} \tag{39}$$

$$BER_{\textbf{[bps]}} = \frac{8}{15} \cdot \frac{1}{16} \cdot \sum k = 216 - 1^k (\frac{16}{k}) e^{20.SINR(\frac{1}{k} - 1)} \tag{40}$$

$$ToA_{\textbf{s}} = \frac{2^{SF}}{BW_{[Hz]}} \tag{41}$$

$$PER_{\textbf{[pps]}} = 1 - (1 - BER)^{n_{bits}} \tag{42}$$

$$\tag{43}$$

Multi criteria decision making

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(p_i - r_i)^2 \tag{44}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(p_i - r_i)^2} \tag{45}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|p_i - r_i| \tag{46}$$

$$Recall = \frac{TP}{TP + FN} \tag{47}$$

$$Precision = \frac{TP}{TP + FP} \tag{48}$$

$$F1\_Score = \frac{2 \times \text{ Precision } \times \text{ Recall}}{\text{precision } + \text{recall}} \tag{49}$$

$$TPR = \frac{TP}{TP + FN} \tag{50}$$

$$FPR = \frac{FP}{FP + TN} \tag{51}$$

$$ROC = (TPR, FPR) \tag{52}$$

$$Novelty = \sum_{i \in L}\frac{\log_2 P_i}{n} \text{ where } \quad P_i = \frac{n - rank_i}{n - 1} \tag{53}$$

$$Serendipity = \frac{1}{n}\sum_{i \in n}\max(P_{\text{user}} - P_U, 0) \times rel_i \tag{54}$$

Outline

Outline

Problem statement

Introduction

- a
- b

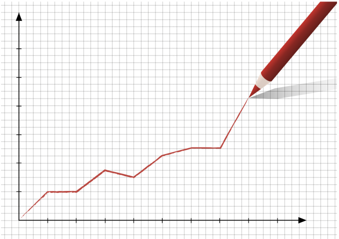


Figure 14. .

Outline

... (step 2)

Methods

... (step 3)

... (step 4)

Methods

Table 6

Outline

- a
- b

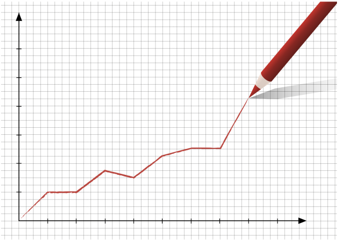


Figure 15. .

Outline

Results

Comparison

- a
- b

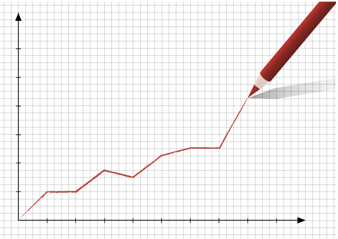


Figure 16. .

Outline

Discussion

- a
- b

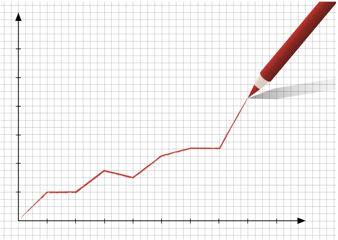


Figure 17. .

Outline

Outline

- a
- b

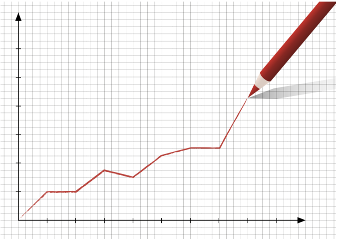


Figure 18. .

Outline

Outline

- **Players:** $K = \{1, ..., K\}$
- **Strategies:** $S = S_1 \times \ldots \times S_K$
  - S_k **is the strategy set of the** k^{th} **player.**
- **Rewards:** $u_k : S \longrightarrow R_+$ **and is denoted by** $r_k(s_k, s_{-k})$
  - $s_{-k} = (s_1, \ldots, s_{k-1}, s_{k+1}, \ldots, s_K) \in S_1 \times \ldots \times S_{k-1} \times S_{k+1} \times \ldots \times S_K$

Outline

For each step $t = 1, \ldots, T$

- **Arms: K = 1, ... , K**
- **Reward:** X_t^k **with** μ_t^k **= E** $[X_t^k]$
  - **Bernoulli rewards:** $x_{k_t} \sim B\left(\mu_{k_t,t}\right)$
  - **Best reward:** X_t^* **with** μ_t^* **= max** μ_t^k**, k∈K**
  - **The reward** k_t **is revealed** $x_{k_t} \in [0,1]$
- **Minimize the pseudo regret:**
  - $R(T) = \sum_{t=1}^{T} \mu_t^\star - \mathbb{E}\left[\sum_{t=1}^{T} x_{k_t}\right]$
  - **where**
    - $\mu_t^\star = \max_k \mu_{k,t}$

Growing number of Thompson Sampling f i,t :

- i denotes the starting time
- t the current time.

Let P(f i,t) be the probability at time t of the Thompson sampling starting at time i.

- Initialization: $\mathbb{P}(f_{1,1}) = 1, t = 1, \quad 2$
  - $\forall k \in K \alpha_{k,f_{1,1}} \leftarrow \alpha_0, \beta_{k,f_{1,1}} \leftarrow \beta_0$
- Decision process: at each time t:
  - $\forall i < t, \forall k : \theta_{k,f_{i,t}} \sim \mathrm{Beta}\left(\alpha_{k,f_{i,t}}, \beta_{k,f_{i,t}}\right)$
  - Play (Bayesian Aggregation):
    - $k_t = \arg\max_k \sum_{i<t} \mathbb{P}(f_{i,t}) \theta_{k,f_{i,t}}$
- Instantaneous gain update:

$$\forall i < t \mathbb{P}(x_t | f_{i,t}) = \begin{cases} \frac{\alpha_{k,f_{i,t}}}{\beta_{k,f_{i,t}} + \alpha_{k,f_{i,t}}} & \text{if } x_{k_t} = 1 \\ \frac{\beta_{k,f_{i,t}} + \alpha_{k,f_{i,t}}}{\beta_{k,f_{i,t}} + \alpha_{k,f_{i,t}}} & \text{if } x_{k_t} = 0 \end{cases} \tag{63}$$

- Arm hyperparameters update:

$$\forall i < t \begin{cases} \alpha_{k,f_{i,t}} = \alpha_{k,f_{i,t}} + 1 & \text{if } x_{k_t} = 1 \\ \beta_{k,f_{i,t}} = \beta_{k,f_{i,t}} + 1 & \text{if } x_{k_t} = 0 \end{cases} \tag{64}$$

- Distribution of experts update:
  - $\forall i < t, \mathbb{P}(f_{i,t}) \propto (1-\rho) \cdot \mathbb{P}(x_t | f_{i,t-1}) \cdot \mathbb{P}(f_{i,t-1})$
  - $f_{t,t} : \mathbb{P}(f_{t,t}) \propto \rho \sum_{i=1}^{t-1} \mathbb{P}(x_t | f_{i,t-1}) \cdot \mathbb{P}(f_{i,t-1})$
  - $\alpha_{k,f_{t,t}} = \alpha_0, \beta_{k,f_{t,t}} = \beta_0$

- **THOMPSON SAMPLING (TS)**
  - success counter: $\alpha_k = \#\left(x_{k_t} = 1\right) + \alpha_0$
  - failure counter: $\beta_k = \#\left(x_{k_t} = 0\right) + \beta_0$
  - At each t:
    - $\theta_k \sim \mathrm{Beta}\left(\alpha_k, \beta_k\right)$
    - $k_t = \arg\max_k \theta_k$
    - $\begin{cases} \alpha_k = \alpha_k + 1 & \text{if } x_{k_t} = 1 \\ \beta_k = \beta_k + 1 & \text{if } x_{k_t} = 0 \end{cases}$
- **SWITCHING ENVIRONMENT**

$$\mu_{k,t} = \begin{cases} \mu_{k,t-1} & \text{probability } 1 - \rho \\ \mu_{new} \sim U(0,1) & \text{probability } \rho \end{cases} \tag{65}$$

Outline

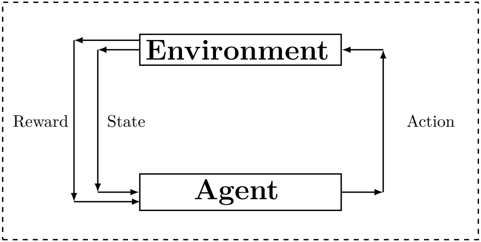


Figure 19. qlearning.

$Q(s_{t+1}, a_t) = Q(s_t, a_t) + \gamma(R(s_t, a_t) - Q(s_t, a_t))$

- $Q(s_{t+1}, a_t)$ = new Q-Value
- $Q(s_t, a_t)$ = old Q-Value
- γ = learning constant
- $R(s_t, a_t)$ = immediate reward received after executing action a in state s at time t

Outline

Marcov chain

Related work

$$V(s,\pi) = \mathbb{E}_s^{\pi}\left(\sum_{k=0}^{\inf} \gamma^k \cdot r(s_k, a_k)\right), s \in \mathbb{S} \tag{66}$$

$$r(s_k, a_k) = G_k \cdot PRR(a_k) \tag{67}$$

$$\pi^* = \arg\max_{\pi} V(s,\pi) \tag{68}$$

$$PRR = (1 - BER)^L \tag{69}$$

$$BER = 10^{\alpha e^{\beta SNR}} \tag{70}$$

Marcov chain

Related work

Learning iterative steps:

- **Choose** action $a_k(t) \sim \pi_k(t)$
- **Observe** game outcome
  - $a_{\_k}(t)$
  - $u_k(a_k(t), a_{\_k}(t))$
- **Improve** $\pi_k(t+1)$

Thus, we can expect that ∀k ∊K

$$\pi_{k(t)} \xrightarrow{t \longrightarrow \infty} \pi_k^* \qquad (71)$$

$$u_k(\pi_k(t), \pi_{\_k}(t)) \xrightarrow{t \longrightarrow \infty} u_k(\pi_k^*, \pi^*_{\_k}) \qquad (72)$$

Where:

- $\pi^* = (\pi_1^*, \ldots, \pi_k^*)$ is the NE strategy profile

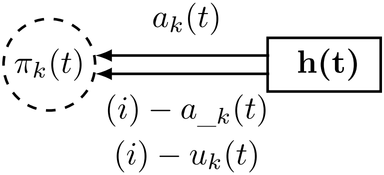


Figure 20. .

Outline

... (step 2)

Methods

... (step 4)

Methods

Table 7

Outline

Experimentation

Experimentation

- a
- b

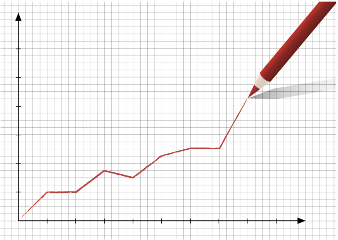


Figure 21. .

Outline

Results
Comparison

- a
- b

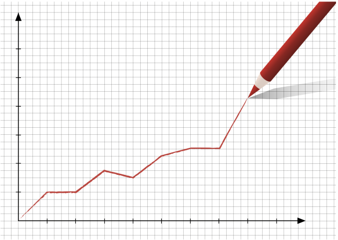


Figure 22. .

Outline

Discussion

- a
- b

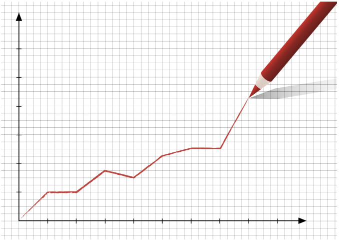


Figure 23. .

Outline

Outline

- a
- b

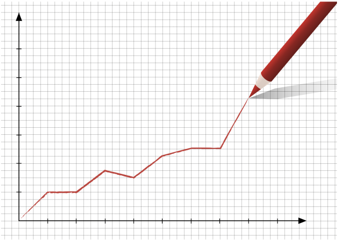


Figure 24. .

Outline

... (step 1)

Methods

... (step 4)

Methods

Table 8

Outline

Experimentation

Experimentation

- a
- b

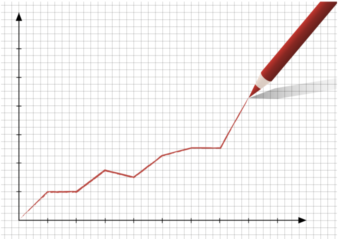


Figure 25. .

Outline

- a
- b

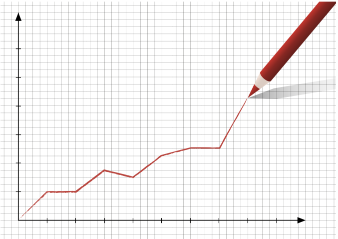


Figure 26. .

Outline

Discussion

- a
- b

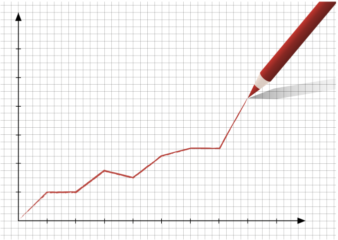


Figure 27. .

Outline

Outline

Problem statement

Introduction

- a
- b

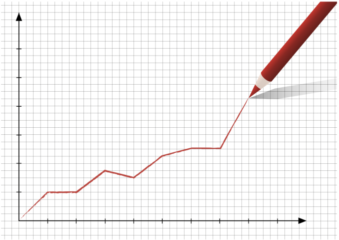


Figure 28. .

Outline

... (step 3)

Methods

Results

Comparison

Table 9

Outline

Experimentation

Experimentation

- a
- b

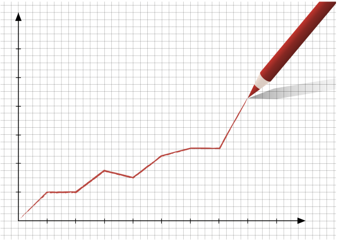


Figure 29. .

Outline

Results

Comparison

- a
- b

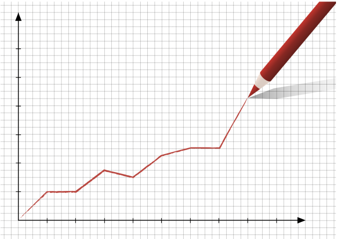


Figure 30. .

Outline

Discussion

- a
- b

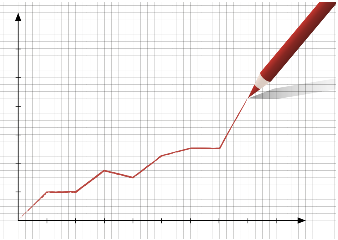


Figure 31. .

Outline

Outline

- a
- b

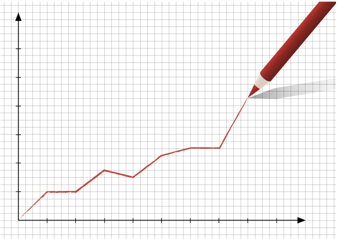


Figure 32. .

Outline

... (step 3)

Methods

... (step 4)

Methods

- E
-

Table 10

Outline

- a
- b

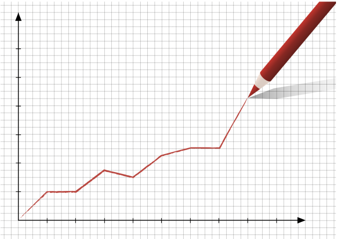


Figure 33. .

Outline

Results

Comparison

- a
- b

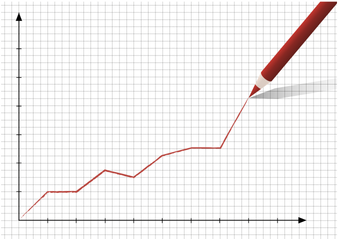


Figure 34. .

Outline

Discussion

- a
- b

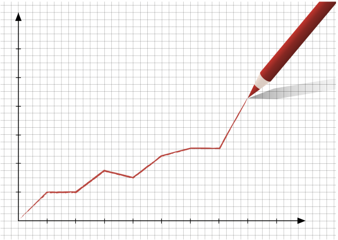


Figure 35. .

Outline

Conclusion

Our main goal was

- .
- .

Our main contribution was

- .
- .

Our main results was

- .
- .

Our future goal was

- .
- .

Outline

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