Outline

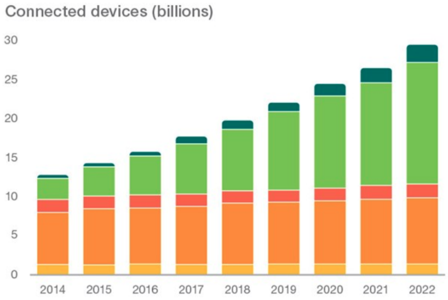
Why I started a PhD ?

3 main reasons

- Research methodology lecture.
- Bac+5 in networking ? not really !
- Being paid to study and to develop yourself !

IoT devices

IoT devices are useless without a good communication capability



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	16	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	10%

Figure 1. IoT devices [1].

IoT applications requirements

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

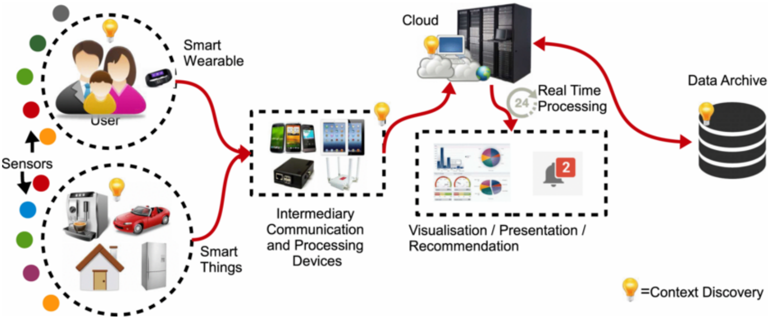


Figure 3. IoT platform.

Figure 4. IoT challenges.

IoT applications requirements

Context

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].

IoT wireless communication

Wireless communication performance need to be evaluated to match applications requirements

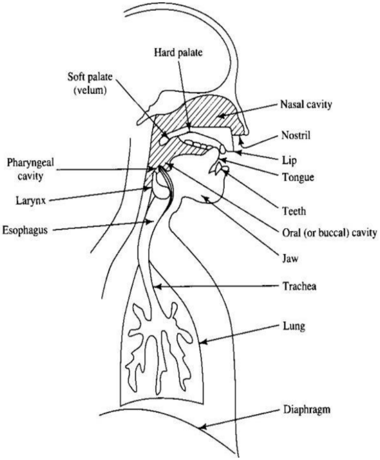


Figure 5. Human voice.

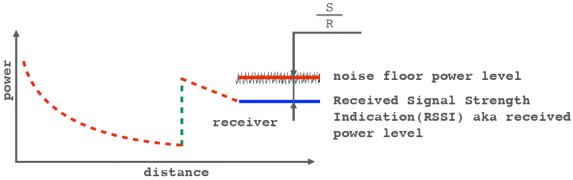


Figure 6. SNR & RSSI.

Figure 7. Time on air.

Problem statement

Introduction[2] ?

- Parameters
  - Bandwidth (*BW*)
  - Spreading Factor (*SF*)
  - Coding Rate (*CR*)
  - Transmission Power (*Tx*)
- Metrics
  - Receiver Sensitivity (*RS*)
  - Signal Noise Rate (*SNR*)
  - Data Rate (*DR*)
  - Air Time (*AT*)
  - Payload length (*PktL*)

Setting	Values	Rewards	Costs
BW	7.8 ➠ 500kHz	*DR*	*RS*, Range
SF	2^6 ➠ 2^{12}	*RS*, Range	*DR*, *SNR*, *PktL*, *Tx*
CR	4/5 ➠ 4/8	Resilience	*PktL*, *Tx*, *AT*
Tx	−4 ➠ 20dBm	*SNR*	*Tx*

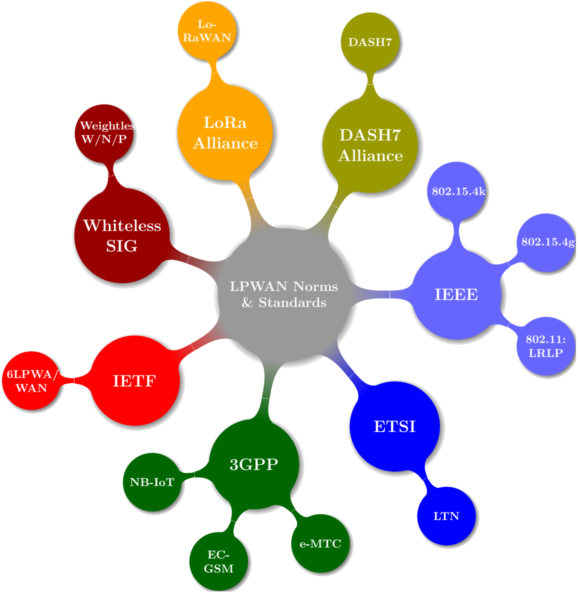
Table 3. [1]

[1] M. Cattani, C. Boano, and K. Römer, " An Experimental Evaluation of the Reliability of Lora Long-Range Low-Power Wireless Communication ", *Journal of Sensor and Actuator Networks*, vol. 6, no. 2, p. 7, 2017, 00042.

[2] **dimartino_internet_2018**.

IoT wireless communication

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



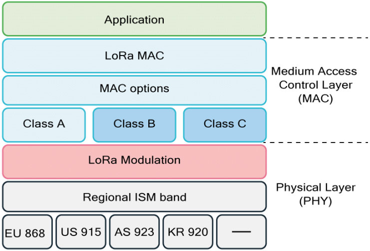


Figure 9. LoRa and LoraWan stack.

Problematic

One size fits all problem: 1) Many configurations, 2) Diversity of service requirements

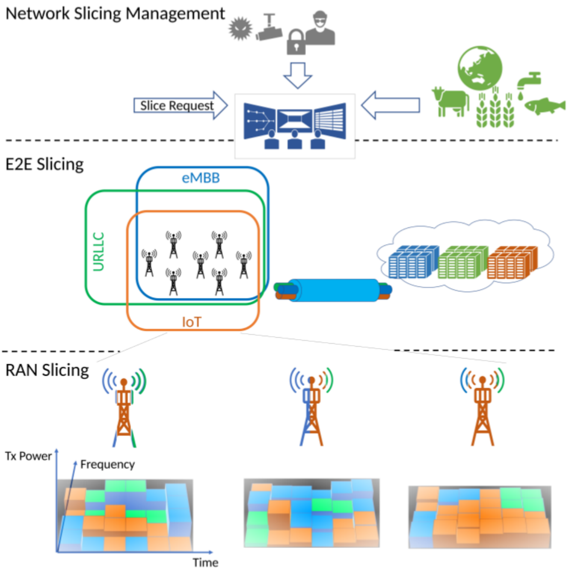


Figure 10. Key barriers in adopting IoT in the industry [6].

Problematic

One size fits all problem: 1) Many configurations, 2) Diversity of service requirements

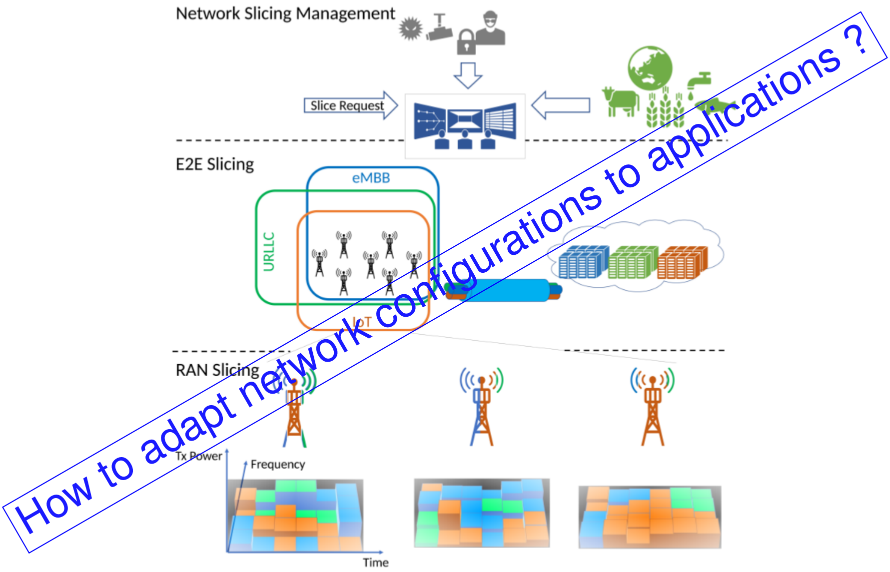


Figure 10. Key barriers in adopting IoT in the industry [6].

Problematic

Where is the problem ?

- Some network configuration are static and not adptive to the application
  - Decision and optimisation problem..
  - Various network acces
  - Various configuration of each network acces
  - Lake of selection tools
- Users have to select the network and the application
  - How to select the **best** network.
  - How to select the network required by the application.

End-to-end Network slicing

Exp: 4G/5G, Content provider (GAFA) want to be directly connected to users devices

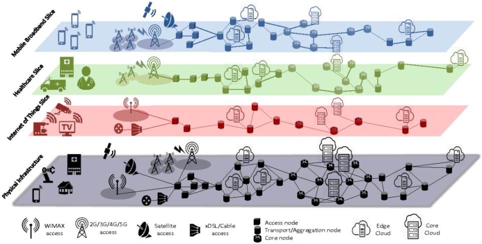
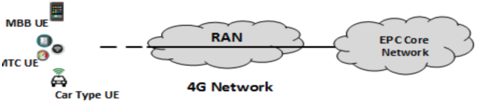
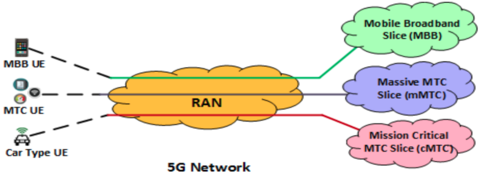


Figure 11. Network slicing [6].



(a) 4G without network slicing.



(b) 5G with network slicing.

Figure 12. Network slicing concept **sama_servicebased_2016**.

Conclusion

In the future, network administration function will disappear and will be replaced by a slice orchestrator

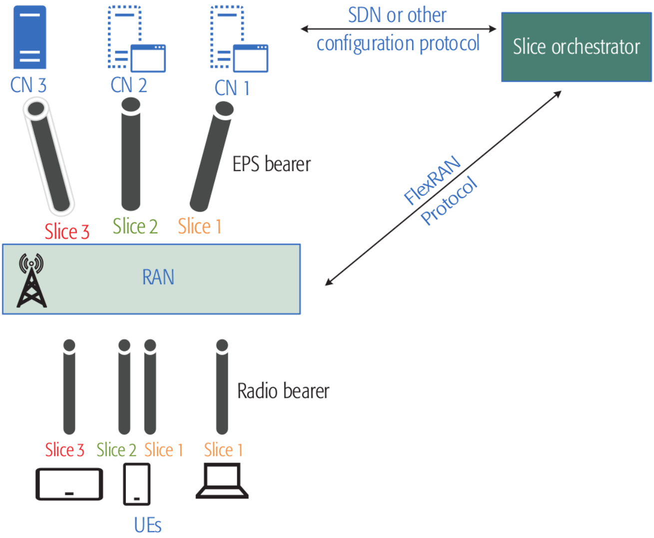
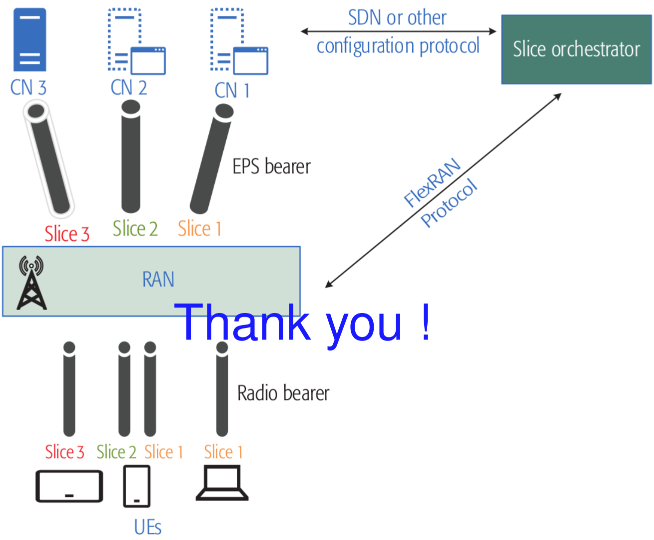


Figure 13. Slice orchestrator [7].

Conclusion

In the future, network administration function will disappear and will be replaced by a slice orchestrator



Thank you !

Figure 13. Slice orchestrator [7].

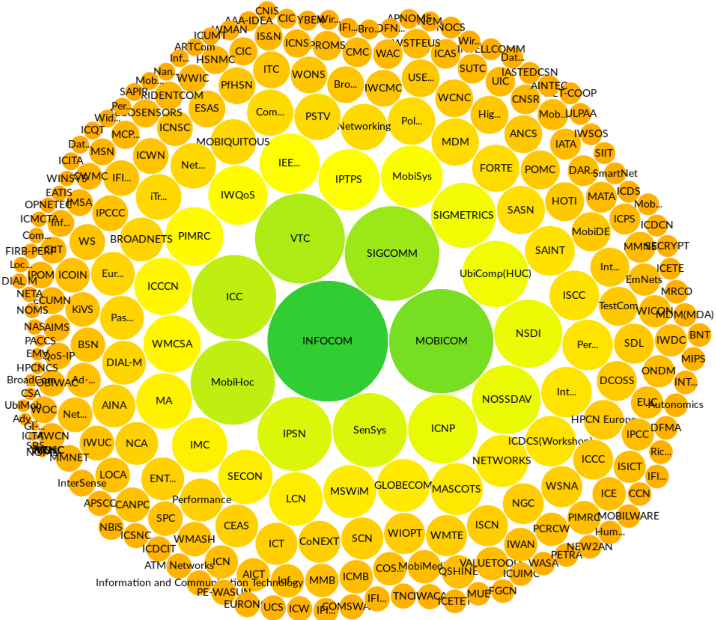
Contribution

Contributions

- **3 Applications**
  - Voice, Images and Text transmission.
- **3 Environment conditions**
  - Rural/Urban
  - Static/Mobile
  - Temperature
- **6 Scenarios**
  - Application protocol (MQTT, COAP, XMPP)
  - Network protocol (Start, Mesh)
  - MAC protocol (LoraWan, Sigfox, ...)
- **6 algorithms**
  - ..
  - ..
  - ..
- **Inputs:**
  - QoS metrics:
    - User metrics: Cost
    - Network metrics: Receiver sensitivity, SNR, DR, Air time, Payload length.
  - MAC configuration (SF, CR, BW, Tx)
- **Outputs:**
  - (SF_i, CR_j, BW_k, Tx_l)

Contribution

Contributions



Outline

Outline

MADM

Related work

$$
Qn,m = \begin{array}{c c}
 & \begin{array}{cccc} Metric_1 & Metric_2 & \dots & Metric_m \end{array} \\
\begin{array}{c} Configuration_1 \\ Configuration_2 \\ \vdots \\ Configuration_n \end{array} & \begin{pmatrix} q_{11} & q_{12} & \dots & q_{1m} \\ q_{21} & q_{22} & \dots & q_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ q_{n1} & q_{n2} & \dots & q_{nm} \end{pmatrix}
\end{array}
$$

$$
ETC_{ij} = \begin{array}{c c}
 & \begin{array}{cccc} Metric_1 & Metric_2 & \cdots & Metric_m \end{array} \\
\begin{array}{c} Metric_1 \\ Metric_2 \\ \vdots \\ Metric_n \end{array} & \left\{ \begin{array}{cccc} ETC_{11} & ETC_{12} & \cdots & ETC_{1m} \\ ETC_{21} & ETC_{22} & \cdots & ETC_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ ETC_{n1} & ETC_{n2} & \cdots & ETC_{nm} \end{array} \right.
\end{array}
$$

Outline

Outline

Multi-Armed-Bandit Algorithm

Related work

- **Arms: K = 1, ... , K**
- **Decision: T = 1, ... , T**
- **Reward: X_t^k with μ_t^k = E $[X_t^k]$**
  - **Best reward: X_t^* with μ_t^* = max μ_t^k, k∈K**

Outline

Genetic Algorithm

Related work **alkhawlani_access_2008a**

- **N** transceiver configurations: $(x_1, ..., x_n)$
- **I** QoS metrics $(m_1, ..., m_i)$. ex: the operators, the applications, and the network conditions.
- **I** weights $(w_1, ..., w_i)$ are sent to the MCDM in the second component.
- GA component assigns a suitable weight (w 1 ,w 2 ,...,w i)

Genetic Algorithm

Related work

Evaluation function

Define the number of parameters	{SF, Tx, CR, BW}
Define the target QoS	{RSSI, SNR, delay, PDR, RTD}
Define evaluation function	Score(SF, Tx, CR, BW) -> {RSSI, SNR, delay, PDR, RTD}

Parameters

Define a population of individuals (solutions)	6720
Define probabilities of crossing and mutating	0.5, 0.2
Define the number of generations	60

Generations

Select individuals randomly	$\{SF_i, Tx_i, CR_i, BW_i\}^{random}$
Clone, crossover and mutate this individuals	$\{SF_{i+1}, Tx_{i+1}, CR_{i+1}, BW_{i+1}\}^{random}$
Evaluate the offspring with an invalid Fitness	Score$(SF_{i+1}, Tx_{i+1}, CR_{i+1}, BW_{i+1})$

(Crossover, Mutation)

Remove some bad solutions
Duplicate some good solutions
Make small changes to some of them

Outline

Q Learning
Related work

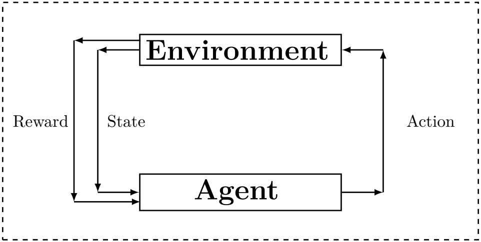


Figure 15. qlearning.

Outline

Marcov chain
Related work

$$V(s,\pi) = \mathbb{E}_s^{\pi}\left(\sum_{k=0}^{\inf} \gamma^k \cdot r(s_k, a_k)\right), s \in \mathbb{S} \tag{1}$$

$$r(s_k, a_k) = G_k \cdot PRR(a_k) \tag{2}$$

$$\pi^* = \arg\max_{\pi} V(s,\pi) \tag{3}$$

$$PRR = (1 - BER)^L \tag{4}$$

$$BER = 10^{\alpha e^{\beta SNR}} \tag{5}$$

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

$$\pi_{k(t)} \xrightarrow{t \longrightarrow \infty} \pi_k^* \quad (6)$$

$$u_k(\pi_k(t), \pi\_k(t)) \xrightarrow{t \longrightarrow \infty} u_k(\pi_k^*, \pi^*\_k) \quad (7)$$

Where:

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

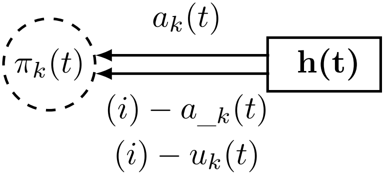


Figure 16. .

Outline

Fuzzy Logic

Related work

Outline

Utility Function

Related work

Set of devices, slices, gateways and flows

G	set of LoRa Gateways
S	set of Slices
D_s	set of devices associated to slice s
$F_{d,s,g}$	subset of packets from device d in slice s to GW g

Parameters

F_c	packets with SF = c
$BW_{s,g}$	bandwidth assigned for slice s over GW g
Tx_g	transmission power of GW g

Constants

$i_{d,s}$	association index of device d to slice s
$i_{d,g}$	association index of device d to GW g
w_d	urgency factor for device d
w_s	priority of slice s

Metrics

$DR_{d,s,g}$	data rate achieved by a device d
$SINR_{i,j}$	SINR with SF=i and SF=j
$Tx_{d,g}^{gain}$	power gain between a GW g and a device d
$Rx_{d,s,g}$	Receiver sensitivity
RTD_d	instant packet delay for device d
PDB_d	packet delay budget for device d
$U_{d,s,g}$	utility for device d in slice s on GW g

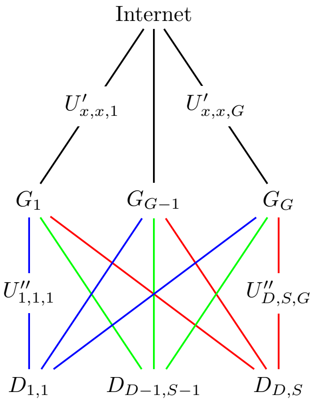


Figure 17. Slicing.

Utility Function

Related work

$$max \sum_{d \in D} \sum_{s \in S} i_{d,s} \cdot U_{d,g,s} \qquad , g \in G \tag{8}$$

$$\begin{aligned}
C1 &: \textstyle\sum_{s \in S} i_{d,s} && = 1, \forall d \in D \\
C2 &: \textstyle\sum_{d \in D} i_{d,g} \cdot tx_{d,s,g} && \leqslant Tx_g^{max}, \forall g \in G, \forall s \in S \\
C3 &: \textstyle\sum_{d=1}^{N} i_{d,s} \cdot i_{d,g} \cdot DR_{d,s,g}. && \leq BW_{s,g}, \forall s \in S, \forall g \in G
\end{aligned} \tag{9}$$

$$\begin{aligned}
U_{HCC} &= \delta_r (\sigma_r w_r, \tau_{ld} w_{td}) \quad with \quad \delta_r \in \{0,1\} \\
U_{MCC} &= \sigma_r w_r + \sigma_{ld} w_{ld} \\
U_{LCC} &= \sigma_{ld} w_{ld} \\
U_{d,s,g} &= U'_{d,s,g} + U''_{d,s,g} \\
E_{d,s,g} &= \frac{p_i^{tx} + p_i^{rx}}{V + epa} \cdot d_{tx/rx}
\end{aligned} \tag{10}$$

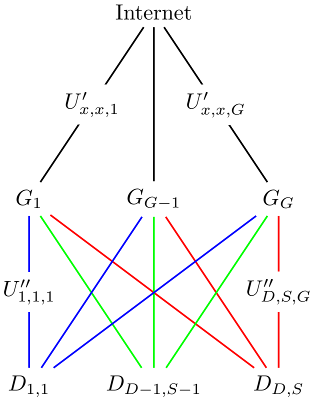


Figure 18. Slicing.

BIRCH: Clustering

balanced iterative reducing and clustering using hierarchies

T: max number of device per cluster,
B: maw number of childes per cluster.

t_0 : number of clusters = number of devices;
t_i : get D2 the set of closest devices to cluster D1

- if D1+D2 < T -> merge
- eif D2< B -> create sub-cluster D2 of D1

$$CF : (D_s, LS, SS) = \left(D_s, \sum_{d=1}^{D_s} w_d, \sum_{d=1}^{D_s} w_d^2 \right) \tag{11}$$

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

Game theory

Related work

Outline

Discussion

- a
- b

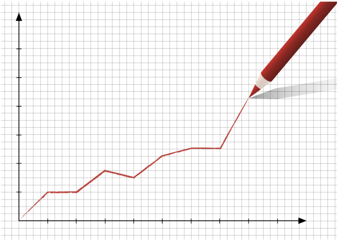


Figure 19. .

Outline

Conclusion

Our main goal was

- .
- .

Our main contribution was

- .
- .

Our main results was

- .
- .

Future Challenges

Conclusion

Our future goal was

- .
- .

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