# WELCOME

# What learning can do for 5G ?

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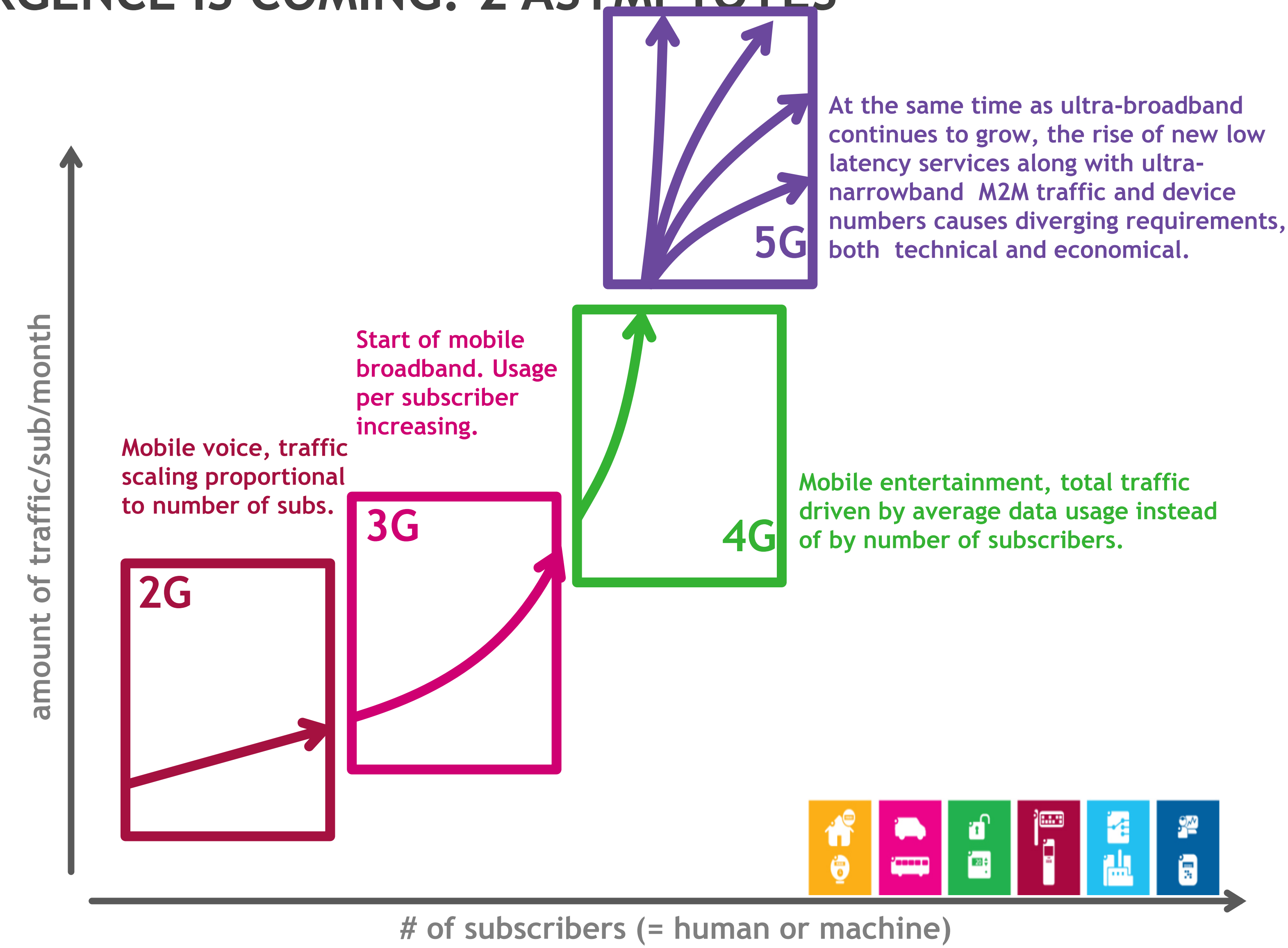
# What is 5G ?

Nobody knows ! (yet)

# So…

# What could be 5G ?

# A DIVERGENCE IS COMING: 2 ASYMPTOTES



# 5G VISION

5G = unified ecosystem …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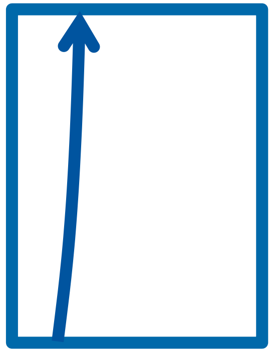
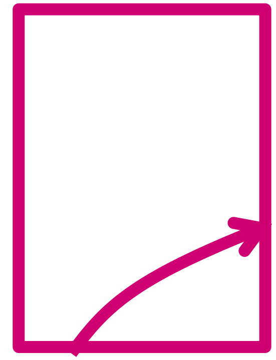
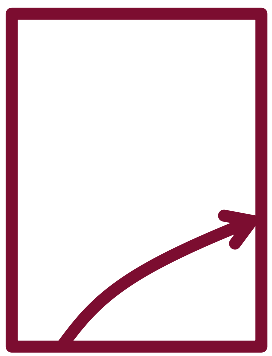


**Ultra-broadband**
Offering higher bitrates and supporting extreme traffic densities for the evolution of comms and entertainment

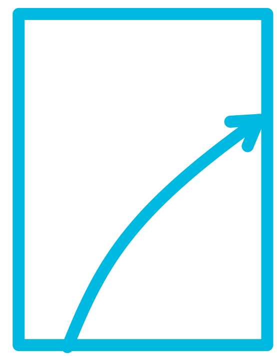


**Ultra low latency**
Mission critical specialized services and immersive virtual reality

Serving both traditional as well as potential new applications like drones, real time video surveillance, mobile augmented and virtual reality, IoT…



**Ultra-narrowband**
Efficient sensing and control added to LTE broadband; massive densities of low traffic devices and bearers

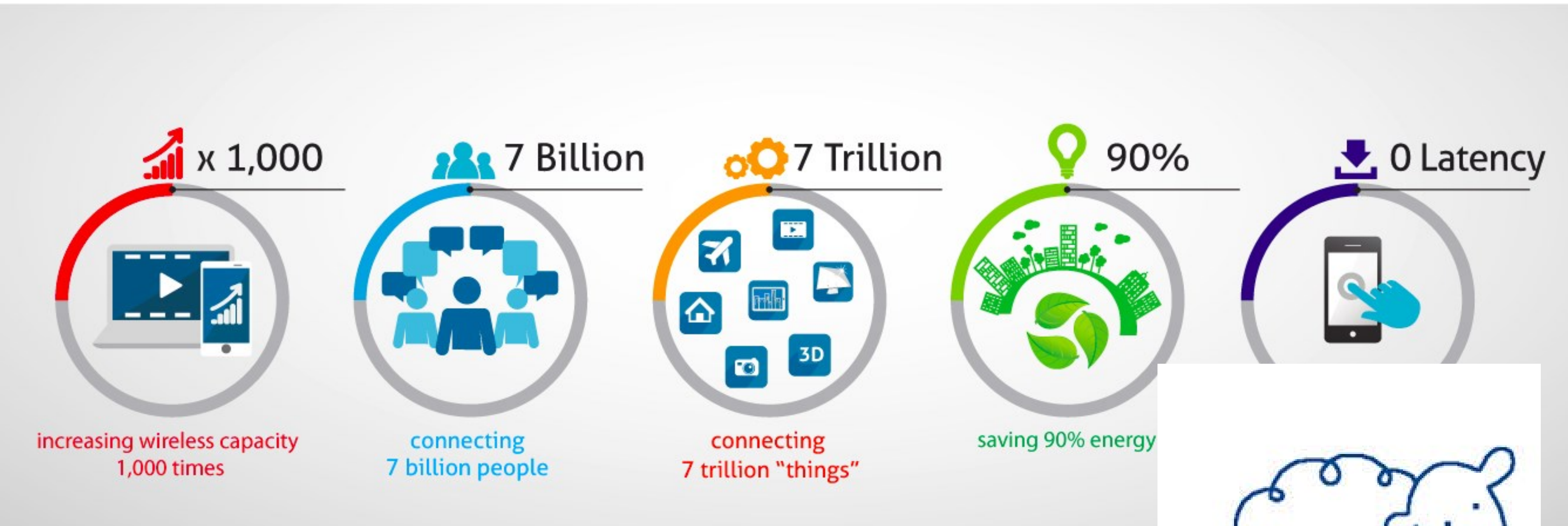


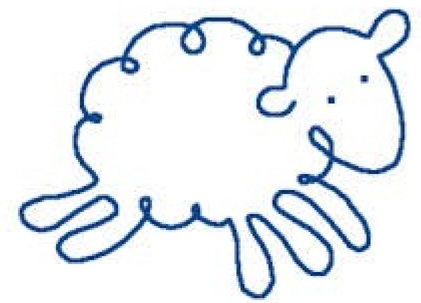
**Consistent user experience**
Better bits rather than simply more cheap bits to offer a more wireline like experience

Plus ..
Multi-carrier LTE remains in place to carry bulk of wide area broadband traffic
WLAN continue to play a key role to carry local broadband traffic

# 5G BY … 5GPPP

**Key Performance Indicato**



- **10 times lower energy consumption**
- **End-to-End latency of < 1ms**
- **Ubiquitous 5G access including in low density areas**

# DIRECTIONS FOR IMPROVEMENT

Increase bits/Hz

- Beyond OFDM
- Massive MIMO
- Network MIMO

Spectrum efficiency

Network densification

Reduce distance, increase SINR

- Smart Multi-RAT
- Cells shrinking
- D2D/Relay

Spectrum extension

More Hz, more bits

- Cognitive radio
- mmWaves
- *Smart Multi-RAT*

Network efficiency

Transport faster, manage better

- Anticipation
- Cloud RAN, SDN, NFV
- Low latency

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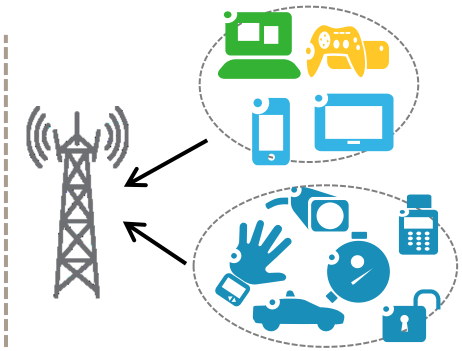
# LTE-A EVOLUTION WILL TAKE US SOME OF THE WAY WITH KEY 5G FOUNDATION TECHNOLOGIES

## IMPROVING PERFORMANCE CONSISTENCY AND COVERAGE

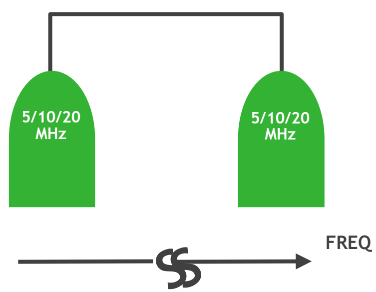
MIMO ENHANCEMENTS FOR CELL EDGE AND CAPACITY

CoMP FOR CELL EDGE AND CAPACITY

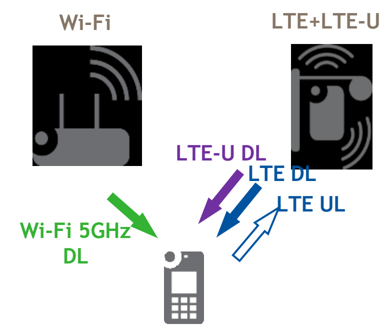


IoT/MTC ENHANCEMENTS FOR CAPACITY, COVERAGE AND COST

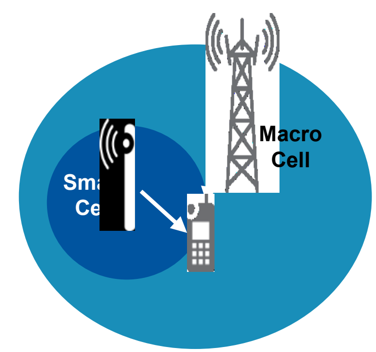
## INCREASING CAPACITY AND USER BITRATES




CARRIER AGGREGATION COMBINING CARRIERS FOR BITRATES




MULTI-RAT (LTE, LTE-U AND WIFI BOOST) FOR CAPACITY




DUAL CONNECTIVITY COMBINING SITES FOR CAPACITY

# 5G IN 5 MORE…

- More and more (and more)* data traffic
- More spectrum to handle
- More complex radio techniques (Massive MIMO, CoMP, ICIC,low latency, …)
- More density of network (smaller cells) and IoT
- More resources to manage in a better way

Then…

# (A PART OF) THE ANSWER IS NETLEARN

ANR NETLEARN

Projet ANR "Orchestration d'algorithmes d'apprentissage distribués pour la gestion

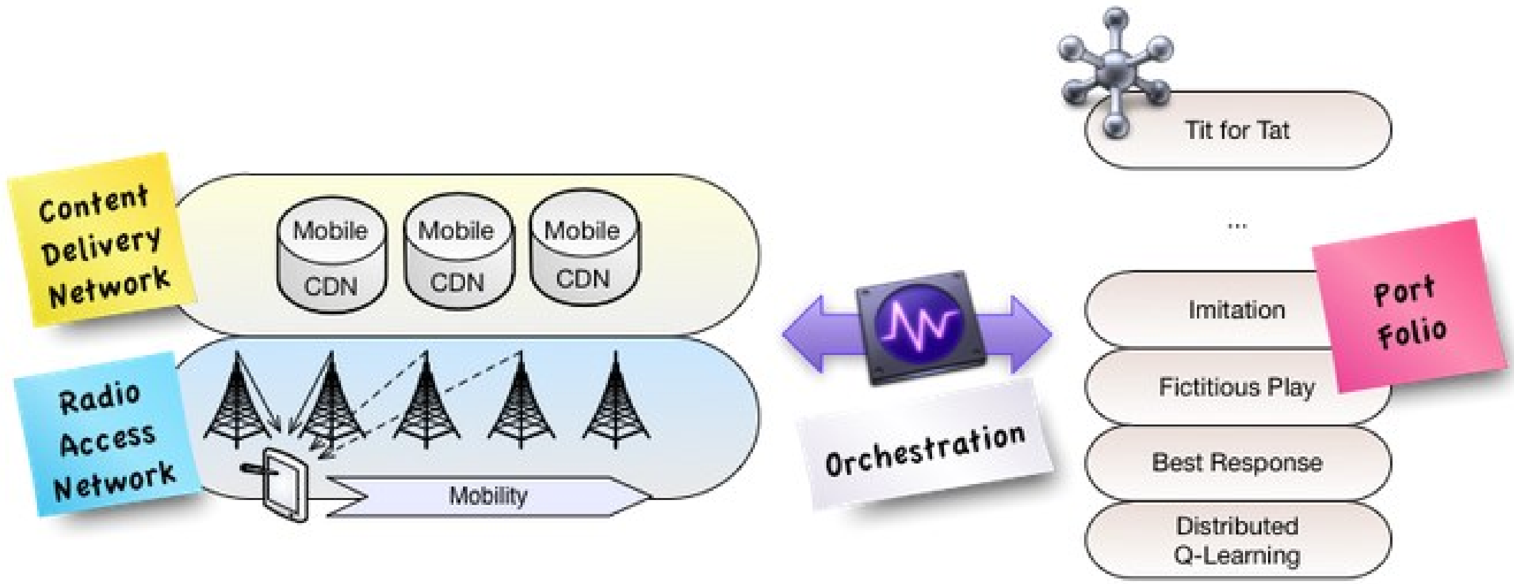
## Project Presentation

NETLEARN is a collaborative research project financed by the french national agency for research (ANR) and which aims at developing new tools based on recent advances in learning theory for the management of various resources in mobile networks. It started the 21 Oct. 2013 and will end the 20 Apr. 2017. Partners of the projects are: INRIA (LIG), UVSQ (PRISM), University Paris Dauphine (LAMSADE), Institut Mines-Telecom (Telecom ParisTech), Alcatel-Lucent Bell Labs and Orange Labs. It is organized in four work packages.

The main objective of the project is to propose a novel approach of **distributed, scalable, dynamic and energy efficient algorithms** for managing **resources in a mobile network**. This new approach relies on the design of an **orchestration mechanism of a portfolio of algorithms**. The ultimate goal of the proposed mechanism is to **enhance the user experience**, while at the same time to **better utilize the operator resources**.

# AT A GLANCE

## Objectives



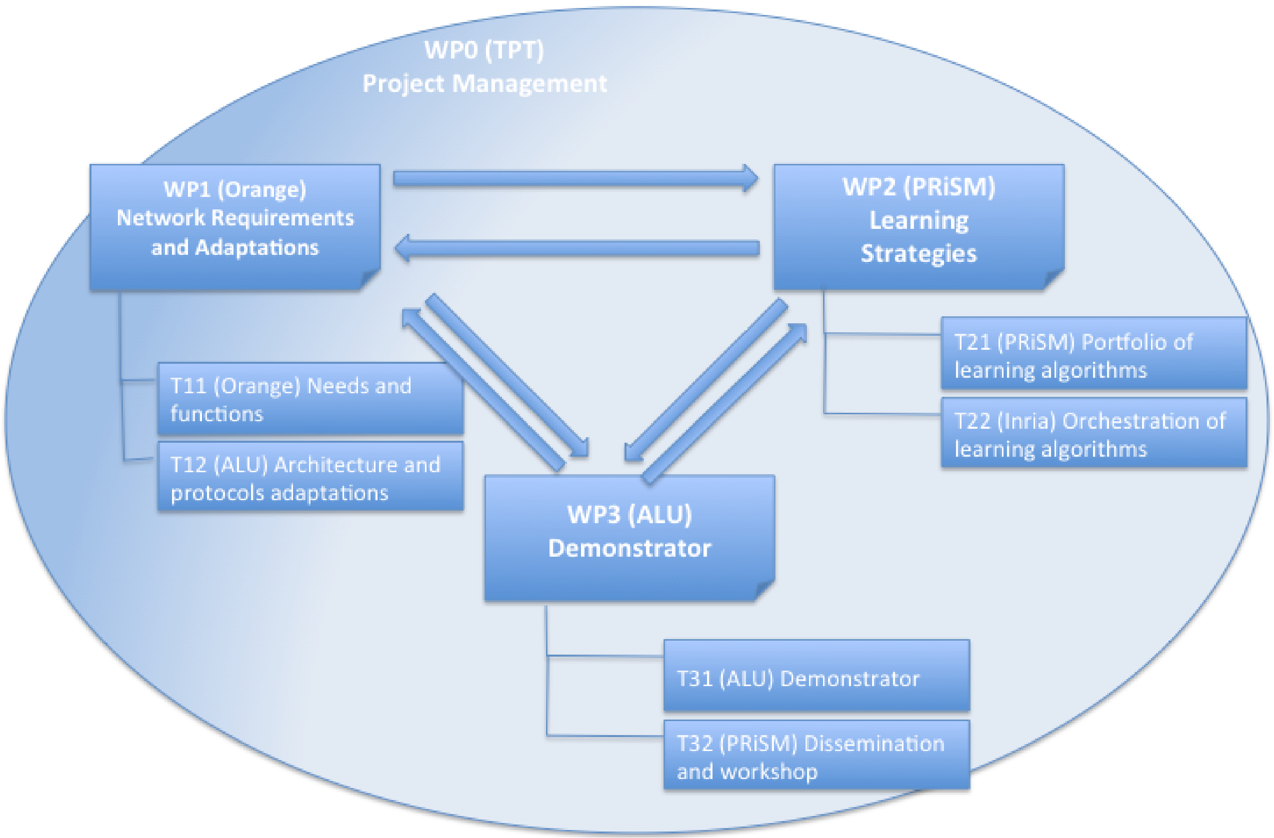

Challenges:

- Which algo is the best for which case?
- Detect case and apply corresponding algorithm
- Smooth shift from one algorithm to another
- …

# AT A GLANCE

Partners:
- Alcatel-Lucent Bell Labs
- Dauphine/LAMSADE
- INRIA Grenoble
- Orange Labs
- Telecom ParisTech (
- UVSQ/PRISM

Duration:
- 42 months (ends in April 2017)

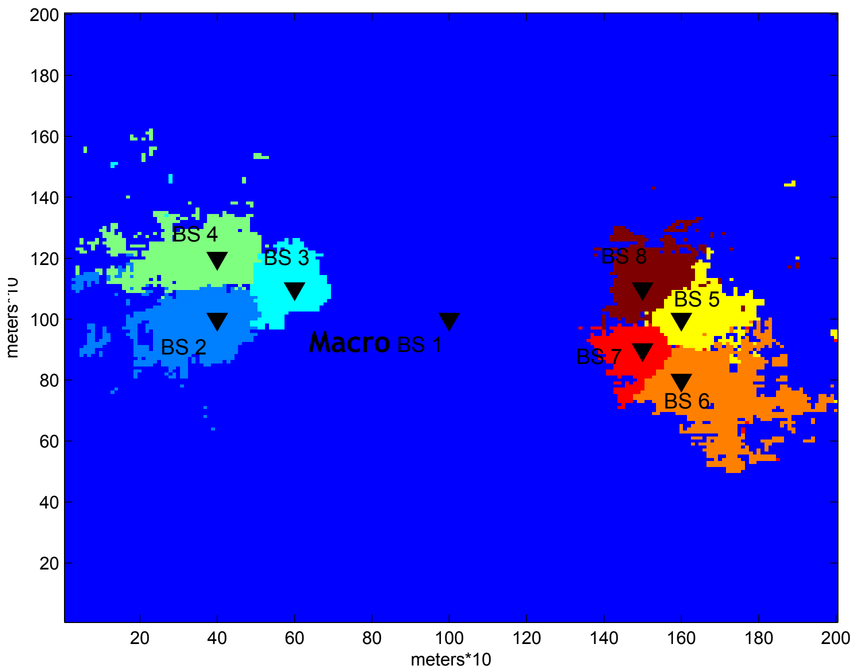


# RESULTS SO FAR PRESENTED TODAY

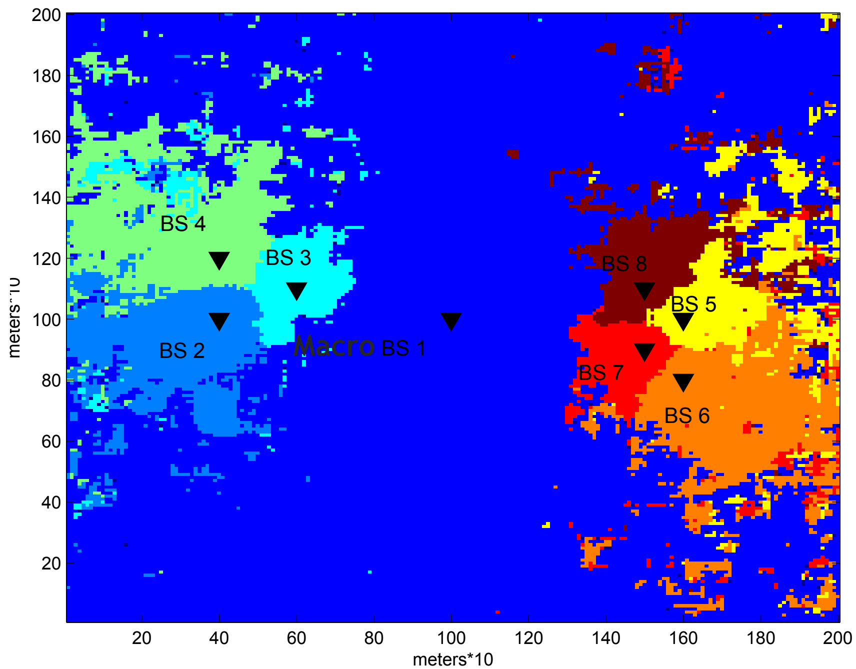
1. Distributed load balancing using Cell Range Expansion (CRE)
   - Partial information is sufficient for practical implementation
2. Massive MIMO optimization
   - tracks the system's optimum transmit policy as the environment evolves over time
3. Self-learning and prediction method to optimize resources allocation in CDN
   - Phase identification in content utilisation to select the best algorithm per phase
4. Category in learning
   - Use one learning vector per distinct case leads to better result than one vector

# LEARNING IN HETNETS

Objective: Distributed load balancing using Cell Range Expansion (CRE) association and Almost Blank Subframes (ABS)
Methodology: Use log-linear learning algorithms in near-potential game framework with complete or partial information in order to minimize an alpha fairness objective function.



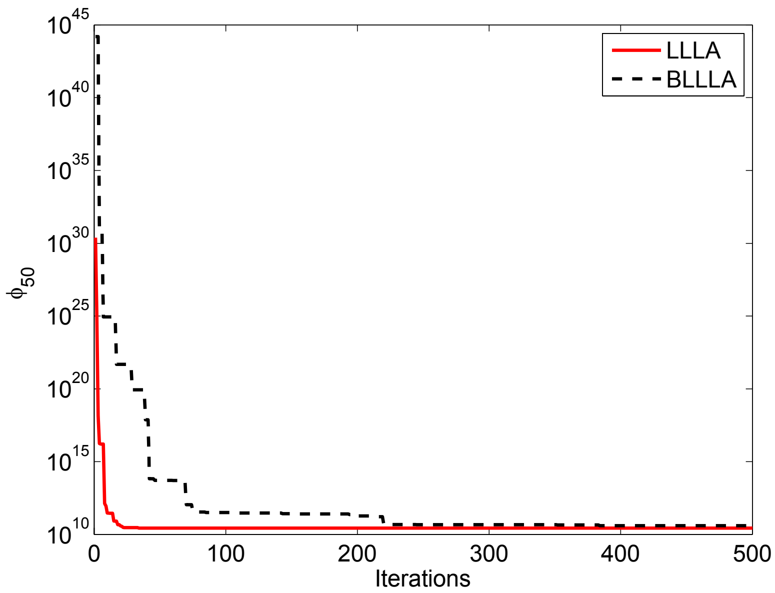

Without CRE bias




With optimal CRE bias

# CONVERGENCE RESULTS

- LLLA for complete information: BS knows the cost of every feasible action
- BLLLA for partial information: BS knows only the cost of his current action
- (B)LLA are guaranteed to converge to the best Nash Equilibrium even in presence of shadowing

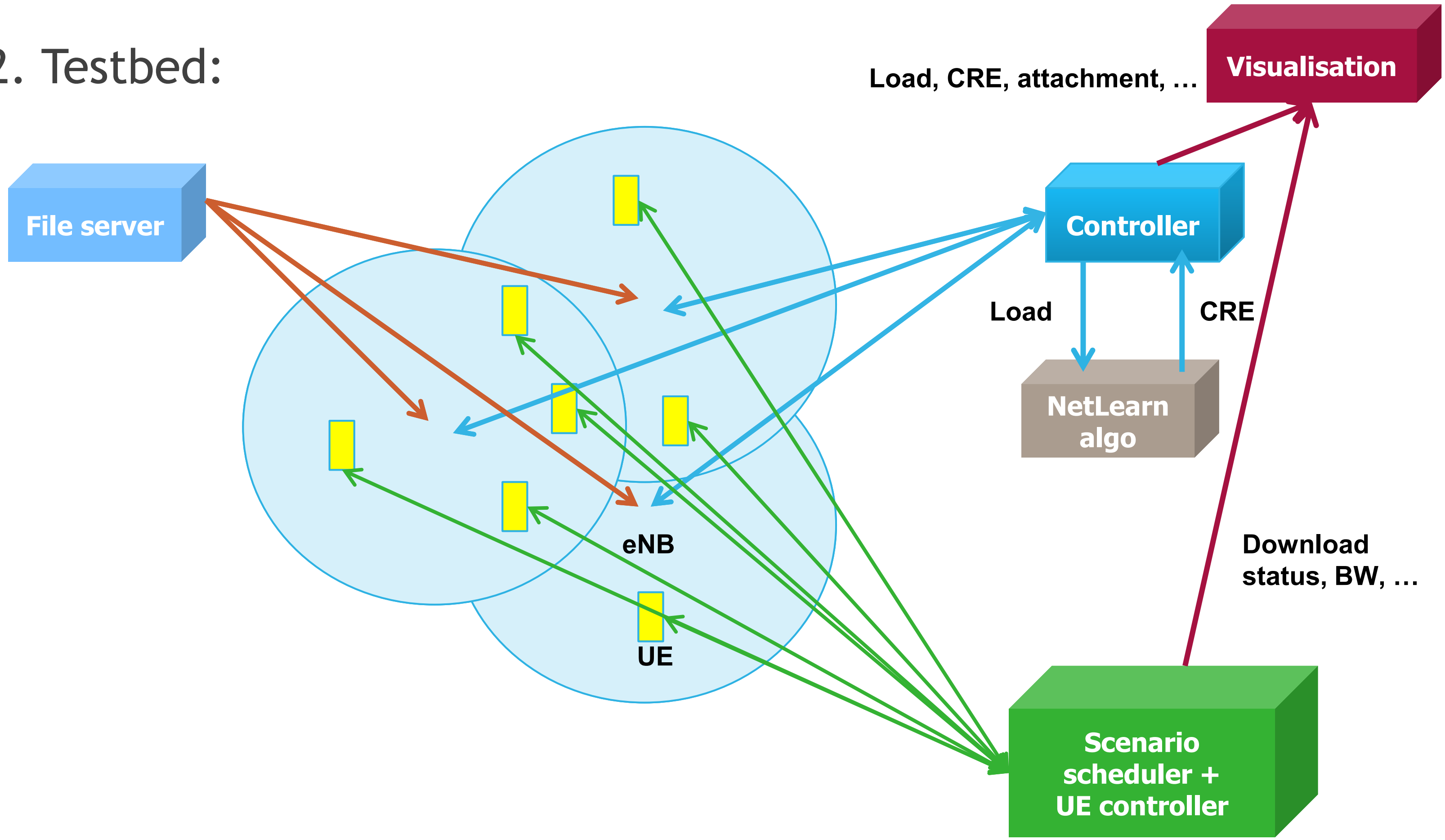



➢ **Communication is needed only in the BS close neighborhood**
➢ **Partial information is sufficient for practical implementation**

# NEXT STEPS

1. Orchestration:
- Several LLLA with different parameters

2. Testbed:



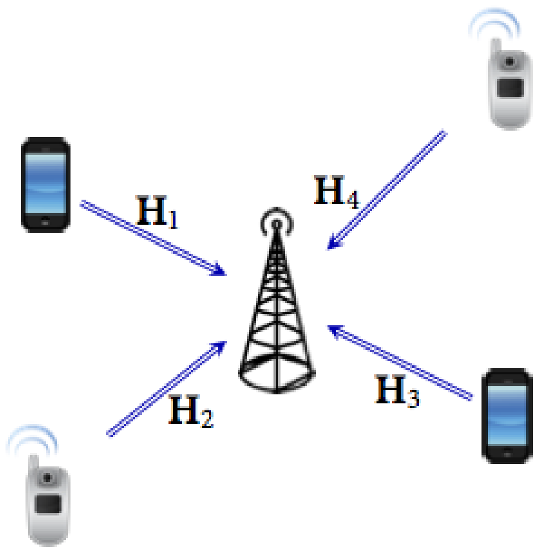
# ONLINE OPTIMIZATION IN (MASSIVE) MIMO SYSTEMS

Objective: Optimize the achieved throughput (or energy efficiency) in dynamically varying MIMO (or MIMO-OFDM) systems

Methodology: Employ advanced exponential learning and online mirror descent methodologies to design an adaptive learning scheme that tracks the system's optimum transmit policy as the environment evolves over time

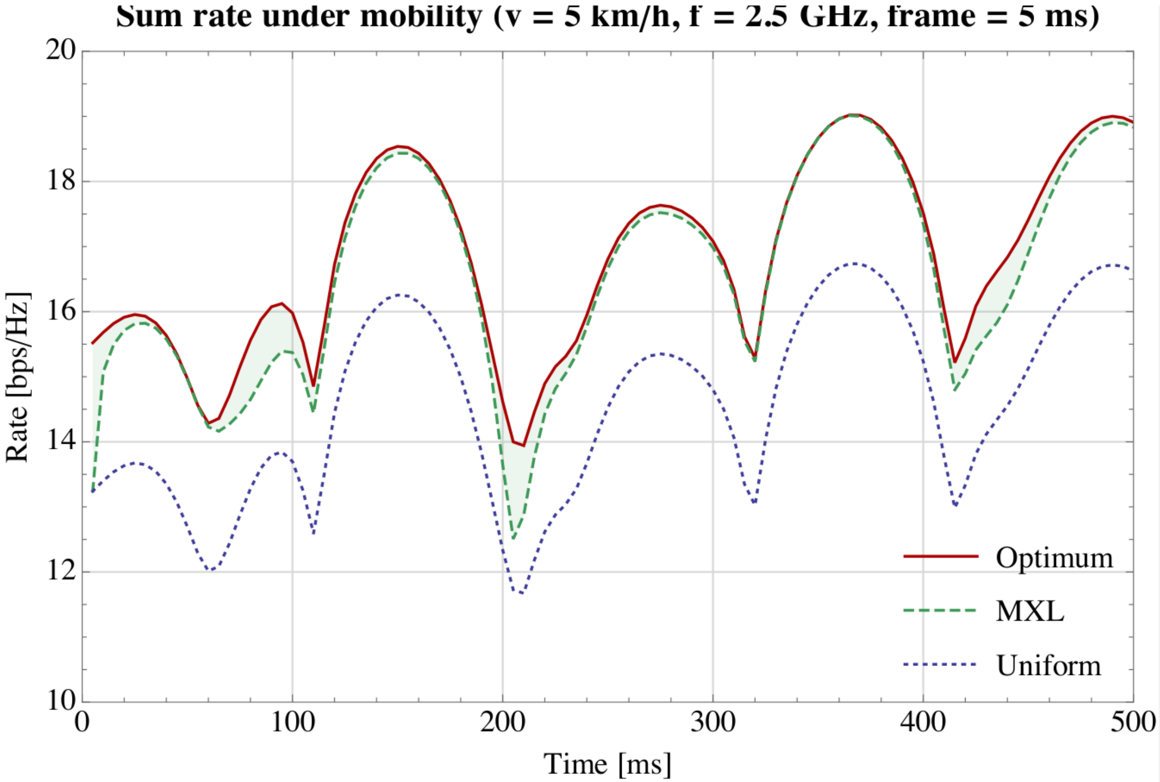
- MIMO/OFDM multiple access channel
- Dynamic channels (fading, mobility)
- Reactive system (users modulate transmit characteristics constantly)

Transmit controls: signal covariance matrix
Objective: sum rate (bits/sec/Hz) or energy efficiency (bits per transmit Watt)



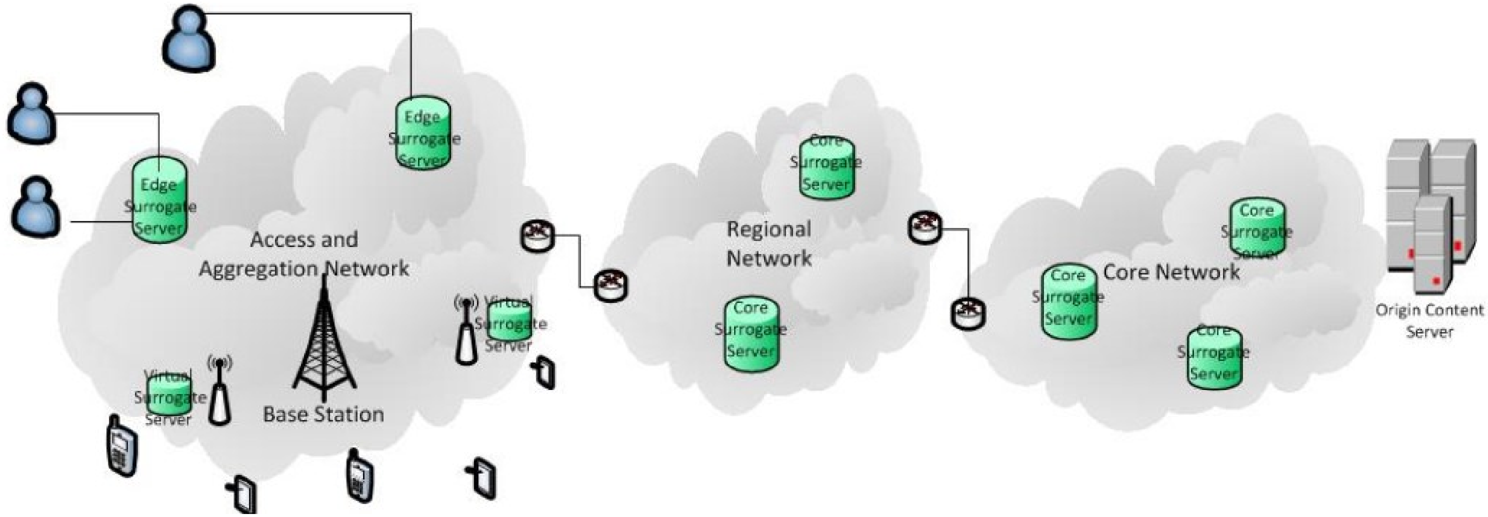
# LEARNING RESULTS

NETLEARN contribution: Matrix Exponential Learning (MXL)




- ➢ **Requires same information as distributed water-filling**
- ➢ **Variant implementation: just one bit of feedback per iteration**

# CONTENT CACHING IN CDN

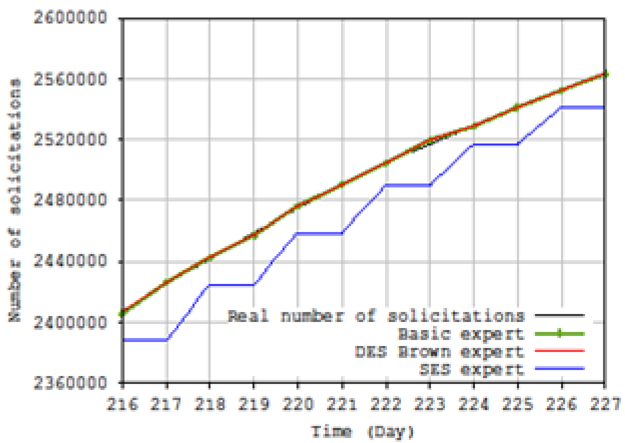



- Objective:
  - maximizing hits number while satisfying constraints
    - Cache size
    - Network load
- Solution:
  - Put most popular contents close to the users
- Challenge:
  - Predict popularity of content

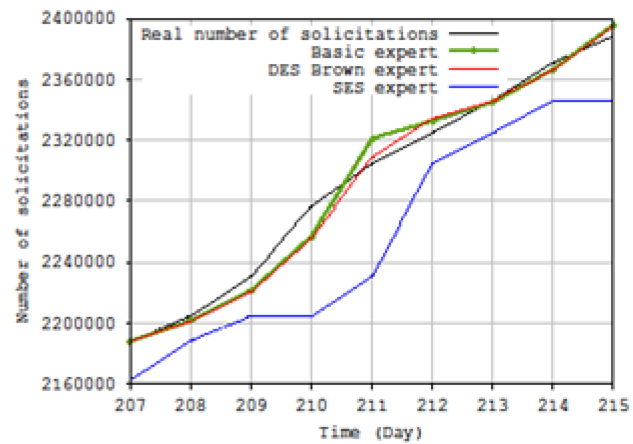
# VARIOUS ALGORITHMS WITH VARIOUS PERFORMANCES

Experts learning strategies:

1. Basic: difference between the two last known demands
2. Single Exponential Smoothing SES: weighted average of the previous observed values in an observation window and the last prediction
3. Double Exponential Smoothing DES Brown: takes into account and predicts some form of trend in the environment values evolution




SES experts underestimates the number of solicitations in most cases.




Basic expert is reactive and accurate when there is a phase change, defined by a change in the slope of the solicitation curve.

➢ **Selecting at each time the more efficient expert for the dynamic situation**

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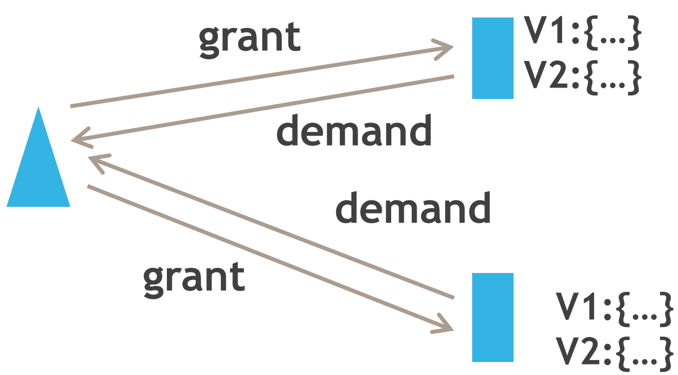
# CATEGORY IN LEARNING

Case: Distributed cell resource allocation
- Mobiles send ressource demand
- Cell allocates resource depending on demand and own capacity
- Category depends of cell load
  - Mobile uses learning vector corresponding to the category



# CURRENT RESULTS


Best learning when using same number of vectors than number of category

Next steps:

- Analysis of behavior depending on demand strategy
- Categorization strategy

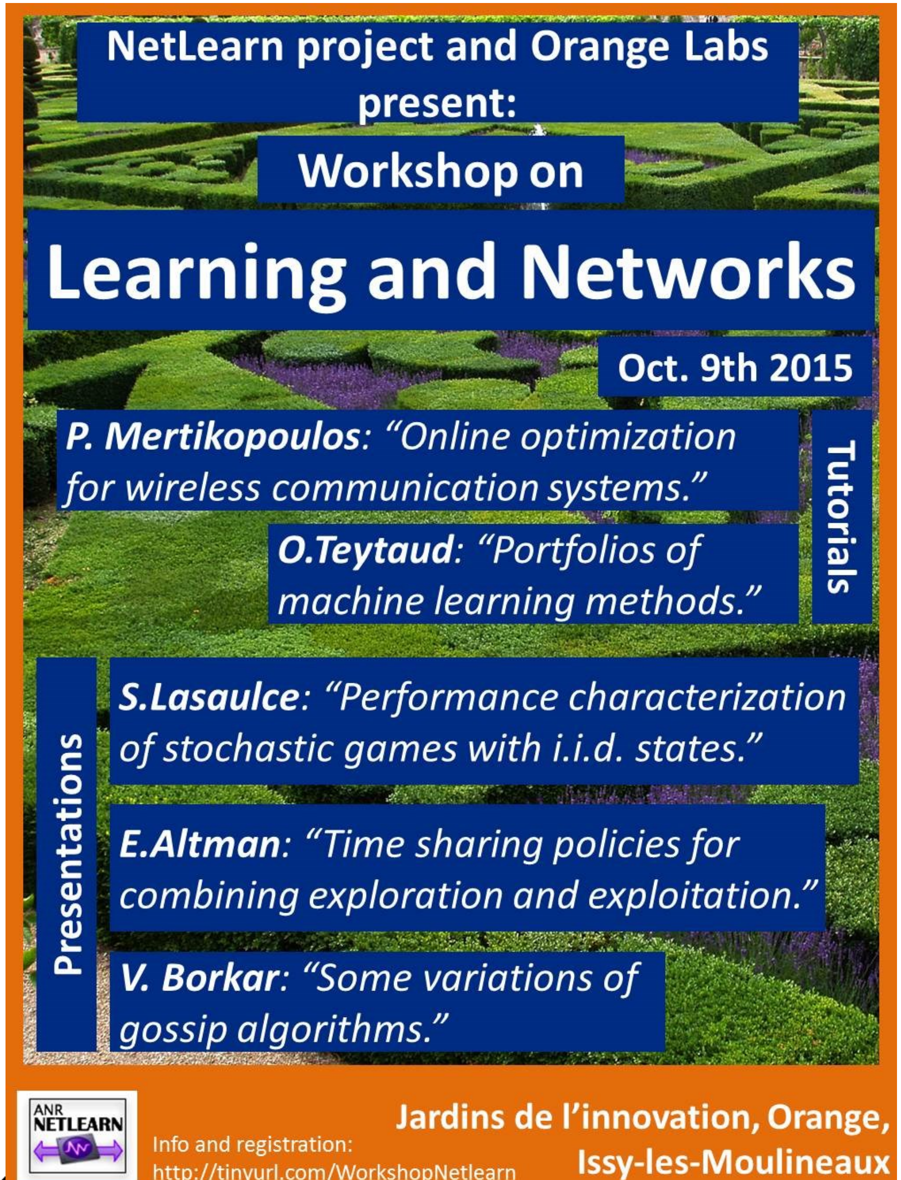
# PERSPECTIVE

- Whatever the technologies used in 5G, complex resources management will be needed
  - Large amount of resources to manage in different ways
  - Huge amount of users
- Not one unique algorithm
  - Depends on case, time, etc.
- Need for orchestration of learning algorithms
  - How and when to select which  algortihms ?

# NETLEARN CONTRIBUTIONS

- Demonstrating value of orchestration
  - Analysis, simulation, tesbted and demo
  - Two use cases for demo: wireless network (CRE), CDN
- Proposing architecture and solution for orchestration of learning algorithms
  - OpenFlow framework considered
  - Will benefit to future 5G architecture

# NETLEARN PARTNERS INVITE YOU TO



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