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# Evolutionary Actor-Multi-Critic Model for VNF-FG Embedding

Presenter

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Collaborative work

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# Outline

- Introduction
- VNF-FG Placement problem
- State of the Art
- Motivations
- DRL Agent + Evolutionary Actor-Multi-Critic Model
- Results
- Conclusions

# Idea behind networking slicing ...

- Network slicing allows to simultaneously accommodate a wide range of services
  - over a **common network infrastructure**
- May support new services on-demand and in near real-time

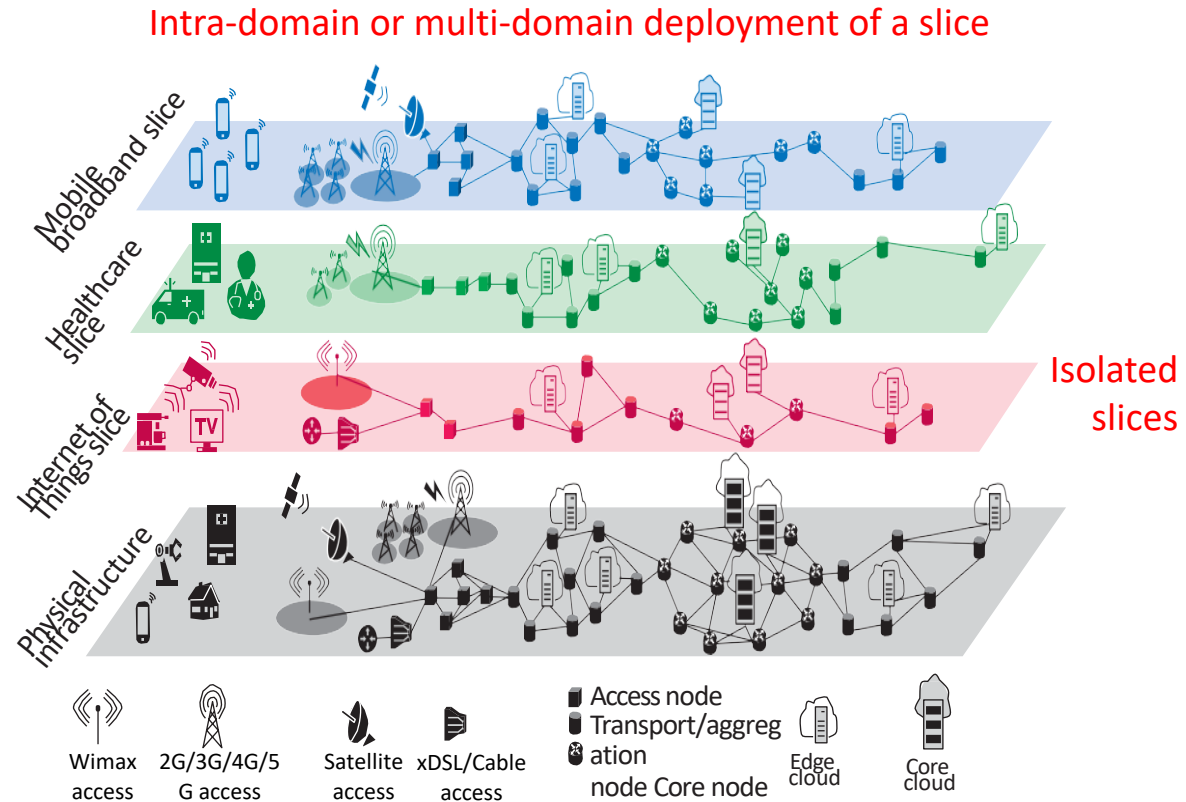


Figure taken from an IEEE ComMag paper

# What are the challenges facing network operators today?

Complex  
networks

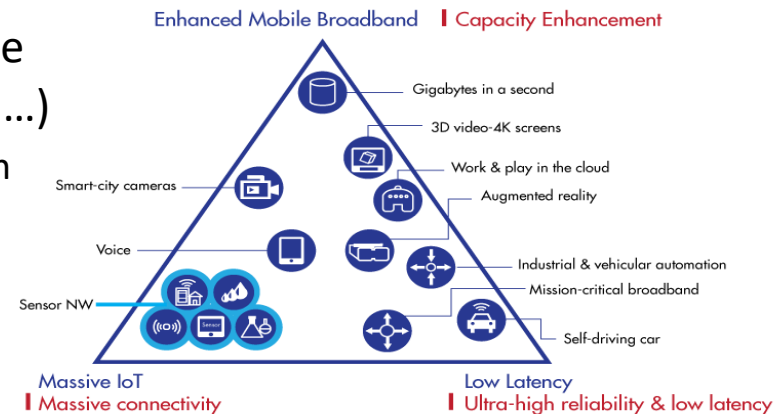
High  
costs

Lack of  
agility

No  
growth

# What are the challenges facing network operators today?

- Ever-increasing infrastructure **complexity**
  - **Diversification** of services (IoT, Smart cars, ...)
    - Very diverse needs in terms of QoS (SLA)
    - Within the same network infrastructure
  - **Limits of the human being** to manage a large number of equipments (10K, 100K devices, ...)
    - Very **high risk of mistakes**, the cost of which can be prohibitive
    - Very slow service provisioning (not automated)



Source: ETRI graphic, from ITU-R IMT 2020 requirements

# What are the challenges facing network operators today?

- **Very high** investment (CAPEX) **cost**
  - Equipment excessively expensive to purchase
- **Very high** operational (OPEX) **cost**
  - Significant operational costs with the **human factor** at the different levels of control and supervision



High  
costs

# What are the challenges facing network operators today?

- **Lack of agility**

- Equipment that can **hardly be adapted** to the needs and of which any **update** is complex and **not always possible**
- **Scaling is not always possible** and oversizing is costly (unlike the Cloud)



Lack of  
agility

# What are the challenges facing network operators today?

- It is very **difficult to grow**
  - **Renting** infrastructure is **no** longer as **profitable**
    - Difficult to be profitable when you don't decide on the rates
    - It's difficult to get a return on investment when having a continuous evolution of the infrastructure ...
  - Operators are not part of the delivery chain of the service, which is very profitable (e.g. CDN)



# Operators' needs

- **Automated network** infrastructure
  - Self configuration, self healing, self scaling, self \*, ...
- **Supporting current and future services** within the same infrastructure
  - With **very diverse constraints** (latency, bandwidth, loss, CPU, FPGA, ...)
- **Softwarization** of the network and the services
  - Ability to lease infrastructure to third parties without compromising the network and its efficiency
  - Higher programmability (e.g. Yang, P4 ...)
- **Being part of the service delivery value chain**

Complex networks

High costs

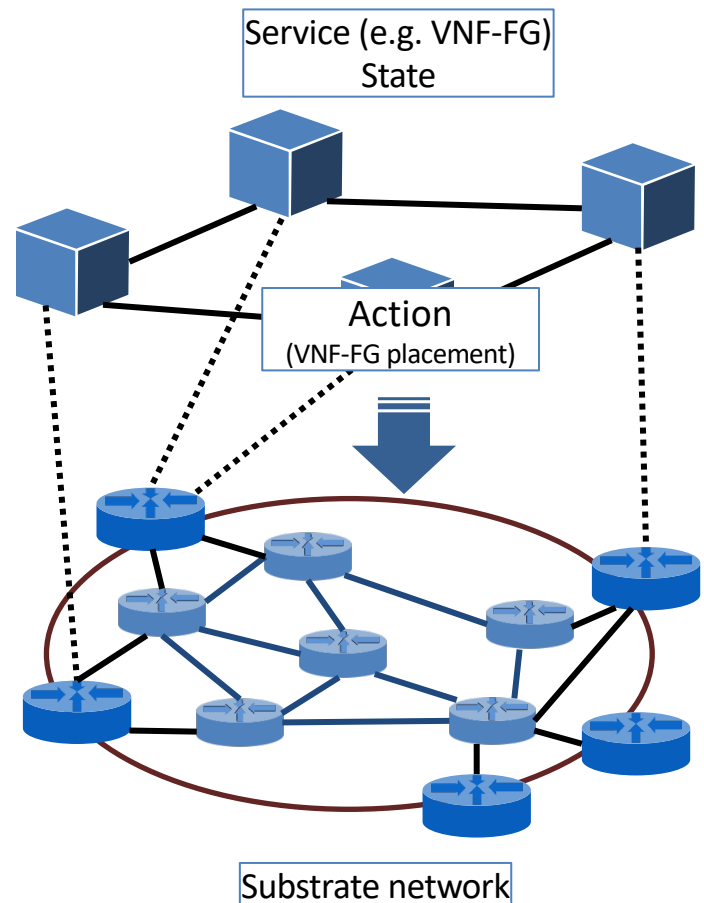
Lack of agility

No growth

Network slicing (in particular) is seen as an opportunity to meet these different objectives

# In practice, what does slicing a network consist of?

- Most simple form
  - Placement of services consisting in one VNF
    - **Offline vs online problem** (bin packing problem)
      - May consider 1 or several metrics for the placement (e.g. latency, load, reliability, ...)
    - **NP-complete problem**
- More advanced form (more complex)
  - Placement of services in a **VNF-FG** form
    - Involves not only the **placement of VNFs** but also addressing a **routing** problem
    - Need to consider several metrics (QoS requirements)
- Most advanced forms
  - Placement and scalability of services
  - Run-time placement
  - ...



# What metrics are considered for placement?

- This naturally depends on the problem being addressed (SLA) ...
  - Reliability
    - Loss
    - K-connectivity, average connectivity, ...
  - Service requirements
    - Bandwidth
    - **System requirements (CPU, RAM, Disk, FPGA, ...)**
    - **QoS/QoE**
    - Load balancing
  - Scalability
  - Energy/power saving

Some problems require addressing **one metric** and others **several metrics at a same time** ... with the risk of a combinatorial explosion.

# Services placement: A well studied problem!

- The problem of placement is an old and well-studied problem<sup>1</sup>
  - Many papers in the Cloud context
  - Conventional service placement comes down to a problem of bin-packing or knap-sack
    - NP-hard problem
  - Realistic placement of services, like the VNF-FG placement is much more complex
    - Services are composite, since they include several sub-services, and multi-constrained
      - Must be added the multiple constraints on the links
- Less attention has been paid to the placement of VNF-FG, which is actually a fairly recent issue
  - Most of the paper address the problem of VNE, which is less complex

<sup>1</sup> DANTZIG, G. B., "Discrete-Variable Extremum Problems", *Opns. Res. Soc. Am.* 5, 266-277 (1957)

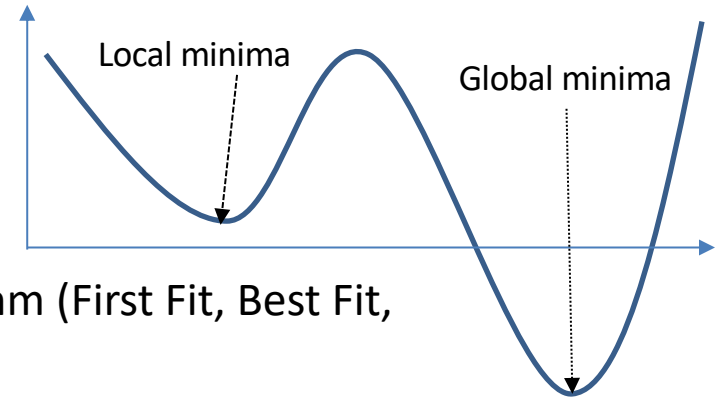
# Classification of existing Approaches for the Placement

1. Mathematical optimisation-based approaches
  - Most of the paper fall in this category
  - Use of: Integer Linear Program (ILP) or Mixed ILP (MILP) ...
    - Integer Programming is an NP-complete problem. So:
      - There is no known polynomial-time algorithm
      - **Even small problems may be hard to solve**
        - » Propose more efficient heuristics for solving the problem, so they fall into another category.
  - Main limitation:
    - **Some parameters are only obtained during run-time (latency and loss) which makes these approaches sometimes ineffective in a real context.**

# Classification of existing Approaches for the Placement

## 2. Heuristics-based approaches

- Most of the paper fall in this category
- Use generally : a two step approach
  - Placing VNFs using traditional algorithm (First Fit, Best Fit, nearest search procedure, ...)
  - Then placing VLs (using Shortest path "SP", K-SP, ...)
  - **Very fast, effective and deal with very large problems**
    - » **For some industrials, this is the best solution**



### • Main limitation:

- In systems where **constraints and objectives are changing**, these types of approaches are **not very suitable** since they generally **require a total redesign**. Moreover, with heuristics we have a rapid convergence at the price of the risk of **sticking at a local minima**.

# Classification of existing Approaches for the Placement

## 3. Metaheuristics-based approaches

- Use generally : a two step approach
  - Placing VNFs using an evolutionary, greedy, ... algorithm
  - Then placing VLs using Shortest path "SP", ... or using a metaheuristic
  - **Slow, very effective and deal with very large problems**
    - » Explore all solutions, or only feasible solutions (faster with risk of stacking at a local optimum)
  - With enough time this may converges to **global optimum**
- Comment ...
  - As the fitness (cost) function is function of VNFs + VLs placement ... **it comes to placing both at the same time ...**

# Classification of existing Approaches for the Placement

## 3. Metaheuristics-based approaches

- Features and main limitation:
  - Metaheuristics make it possible to respond effectively to the problem VNF-FG placement. They can very easily integrate new objectives or constraints without reconsidering the solution, unlike heuristics.
- However, to address a new placement you almost always need to start from the beginning ... as there is **no real learning**

# Classification of existing Approaches for the Placement

## 4. Learning-based approaches

- Only very few approaches (not so few now)
- Use generally : a two step approach but ... the reward function concerns VNFs + VLs placement, which means that we are addressing both at the same time.

– **Very slow**

» Unclear whether these approaches can adequately address the problem.

### • Main limitation:

- Efficient approaches still **need to be developed**.

# Deep Learning Approach

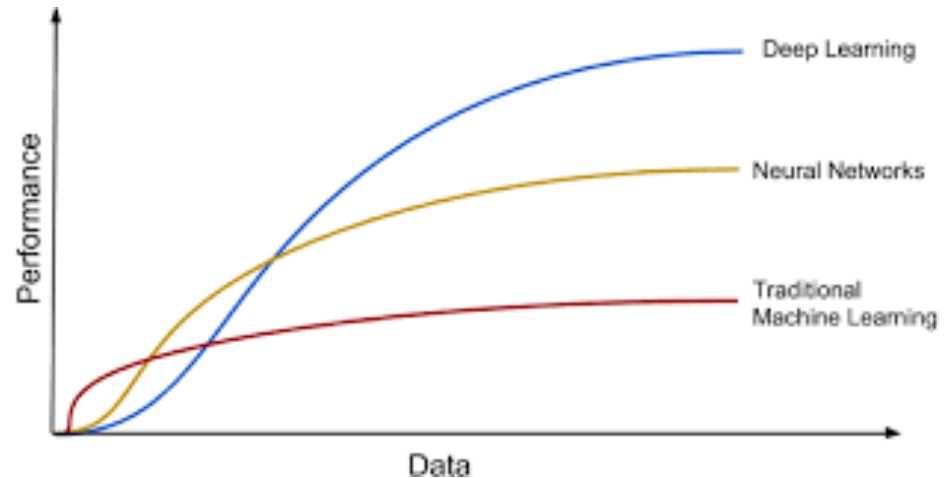
- Machine Learning or Optimization-based?
  - Optimization-based approaches need accurate models
  - Difficulties in determining accurate models for complex networks (multi-hop)(\*)
  - Machine learning addresses this by learning hidden characteristics of any network
- Why go deep?
- Why reinforcement learning?

(\*) Z. Xu *et al.*, "Experience-driven Networking: A Deep Reinforcement Learning based Approach," *IEEE INFOCOM 2018 - IEEE Conference on Computer Communications*, Honolulu, HI, 2018, pp. 1871-1879.

# Deep Learning Approach

- Machine Learning or Optimization-based?
- **Why go deep?**

Data dependency

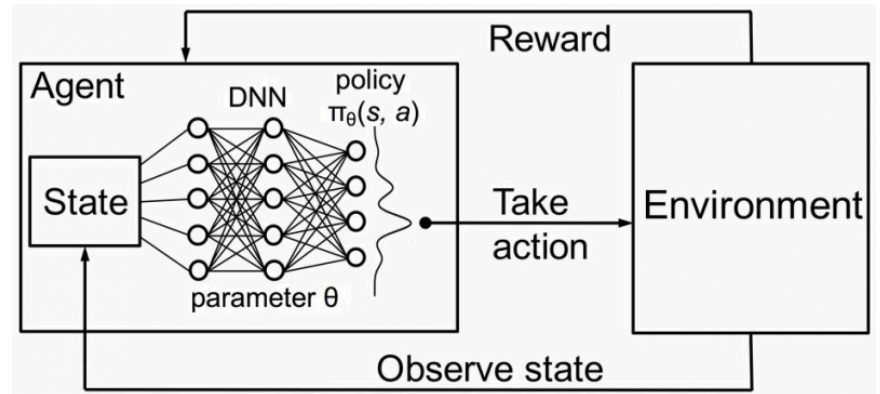


<https://www.sumologic.com/blog/machine-learning-deep-learning/>

- Why reinforcement learning?

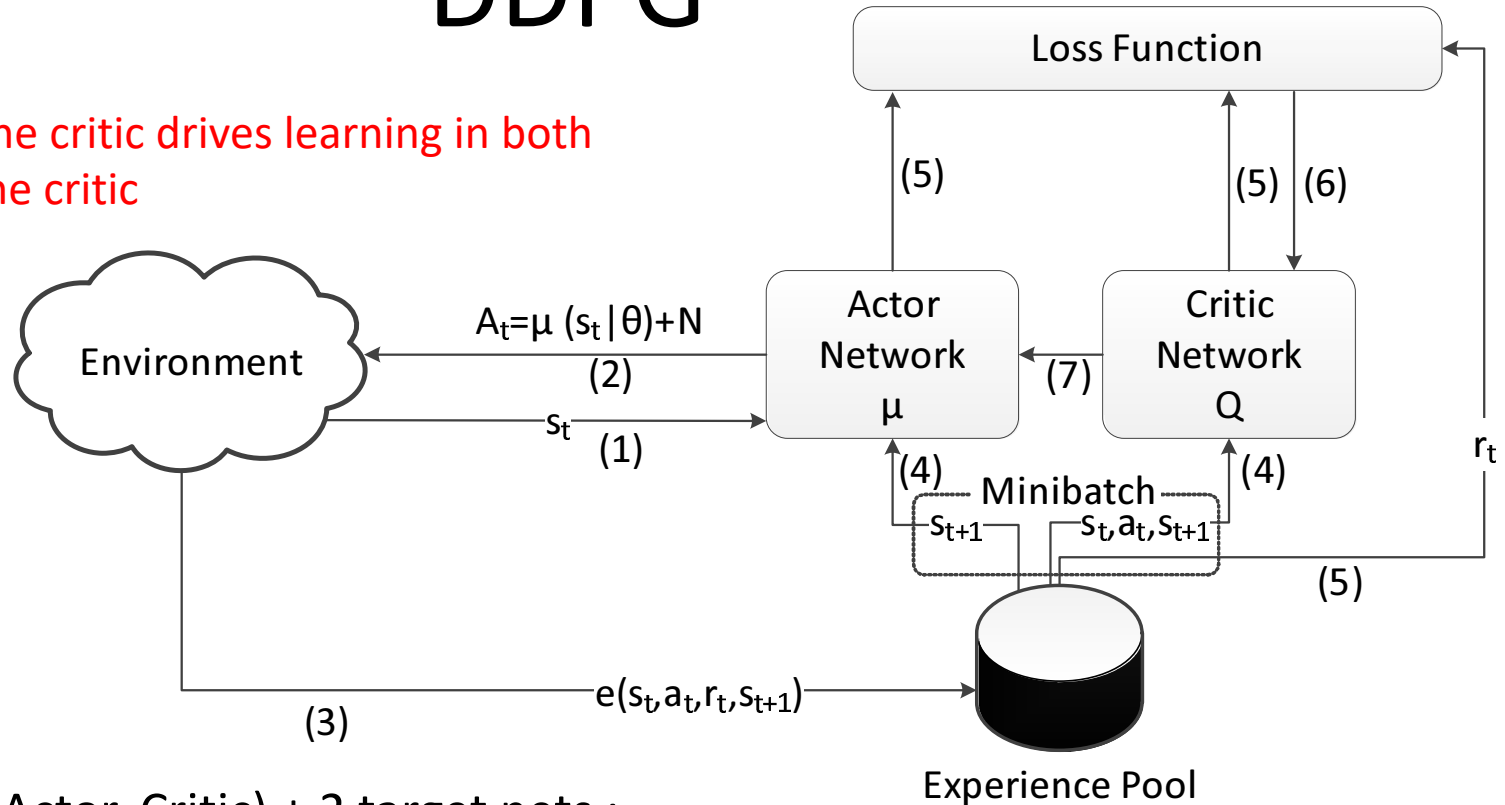
# Deep Learning Approach

- Machine Learning or Optimization-based?
- Why go deep?
- **Why reinforcement learning?**
  - Its good performance and capability have been confirmed (\*)



# DDPG<sup>1</sup>

The output of the critic drives learning in both the actor and the critic

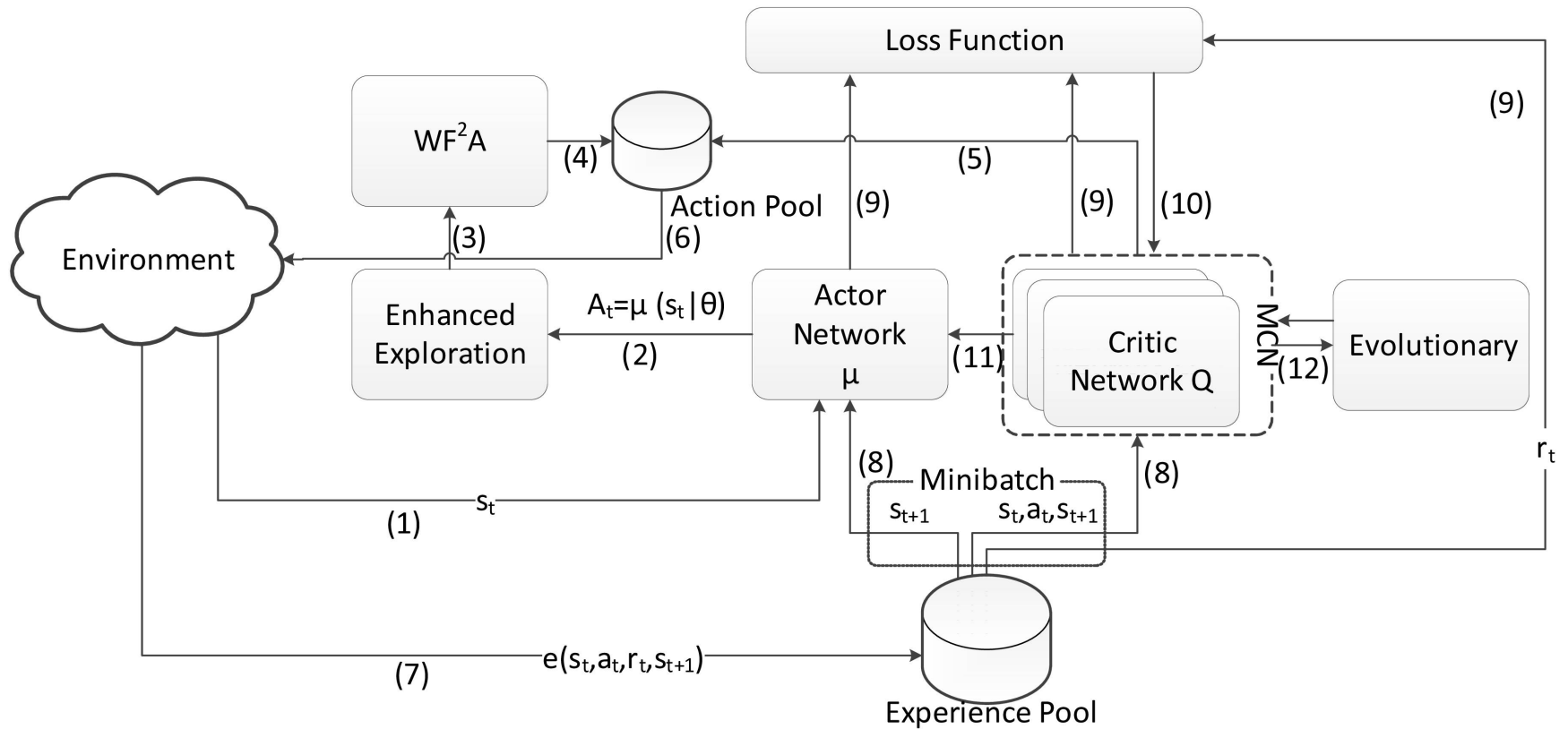


2 neural nets (Actor, Critic) + 2 target nets :

- Critic network learns Value function
  - Based on state + action
- Actor network learns the Policy

# DRL Agent

Based on DDPG



# DRL Agent

- **Weighted First Fit Algorithm (WF<sup>2</sup>A)(\*)**

**For VNF embedding:**

- Step 1: Sort substrate nodes in terms of their weights
- Step 2: Attempt deploying VNF at the lowest weight substrate node
- If the substrate node can host the VNF
  - Step 3a: Update remaining resources of the substrate node
- If the substrate node cannot host the VNF:
  - Step 3b: Remove that node from the selection process and back to step 2

**For VL embedding:**

Use Dijkstra algorithm to identify the lowest cost path to connect VNFs

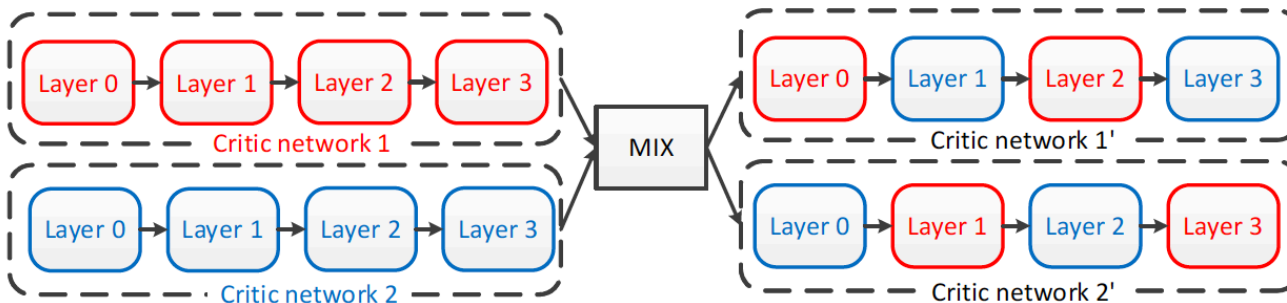
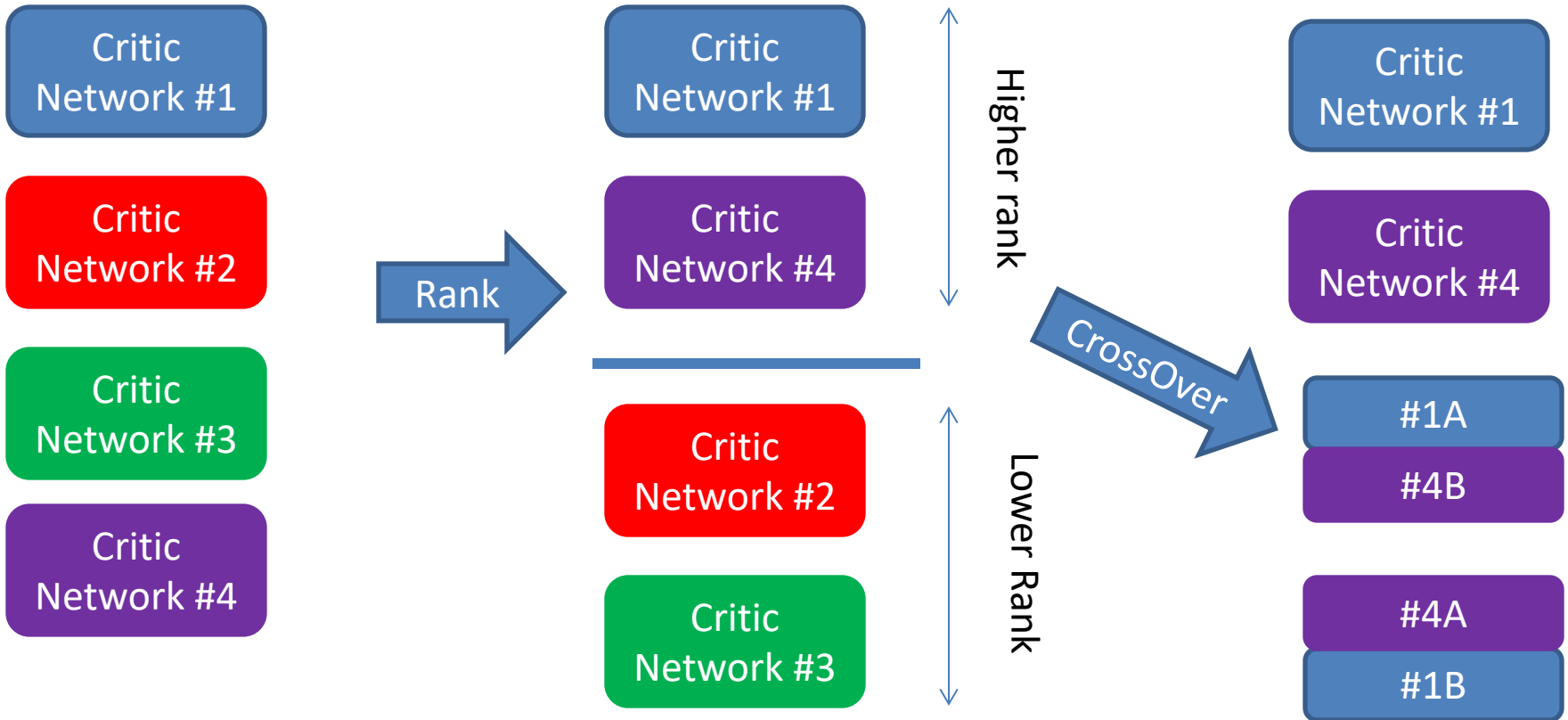
→ Final allocation decision

(\*) This algorithm has been introduced in

P. T. A. Quang, Y. Hadjadj-Aoul and A. Outtagarts, "A Deep Reinforcement Learning Approach for VNF Forwarding Graph Embedding," in *IEEE Transactions on Network and Service Management*, vol. 16, no. 4, pp. 1318-1331, Dec. 2019.

doi: 10.1109/TNSM.2019.2947905

# Evolutionary Actor-Multi-Critic Model



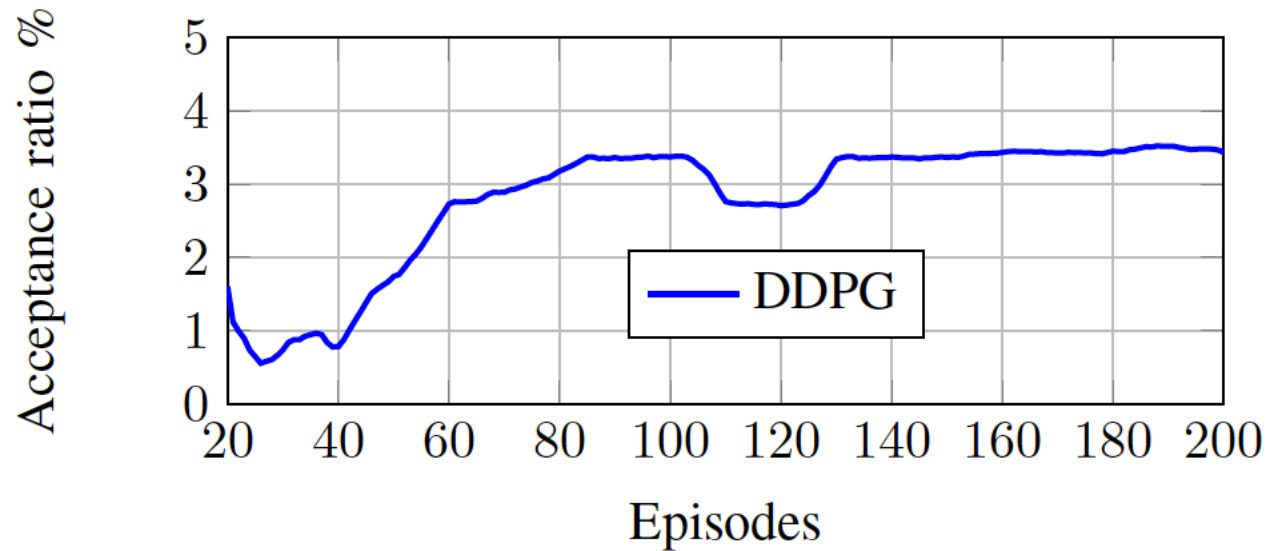
# Environment

## Two versions

- Simulated environment
  - Python, Tensorflow, Keras
  - OMNET++
  - REST interfaces
- Emulated environment
  - Python, Tensorflow, Keras
  - MININET (ContainedNet - Docker)
  - Orchestrator + SDN
  - REST interfaces

# Results

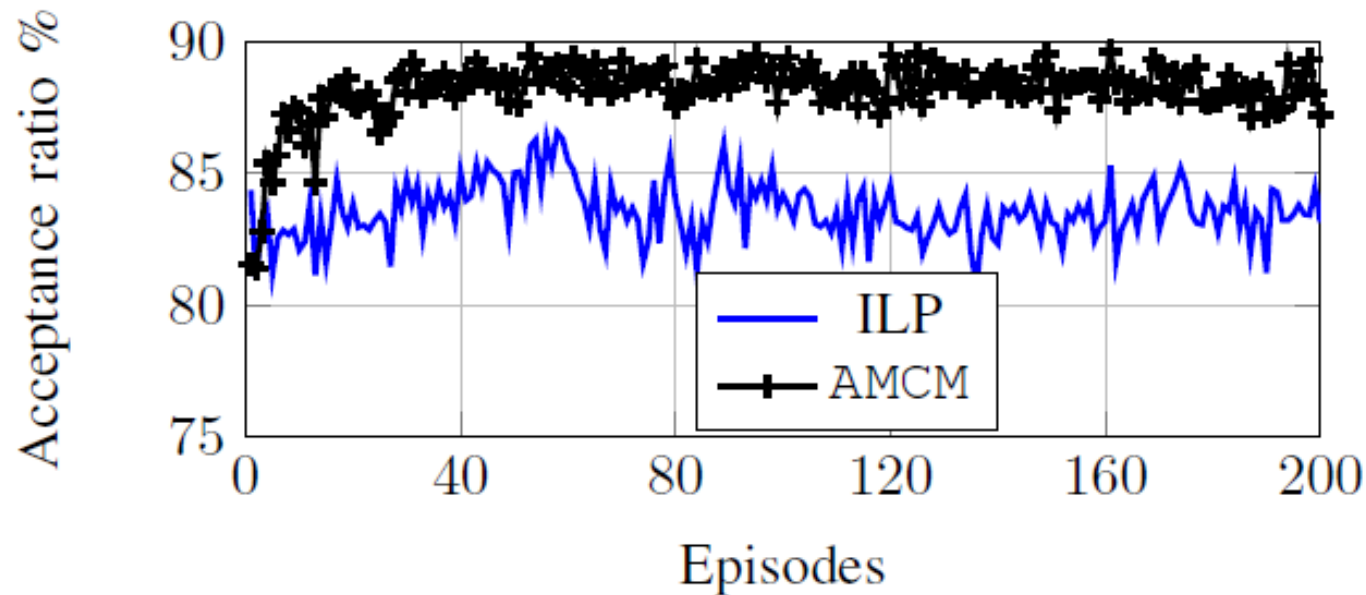
- Placement with DDPG



# ILP vs AMCM

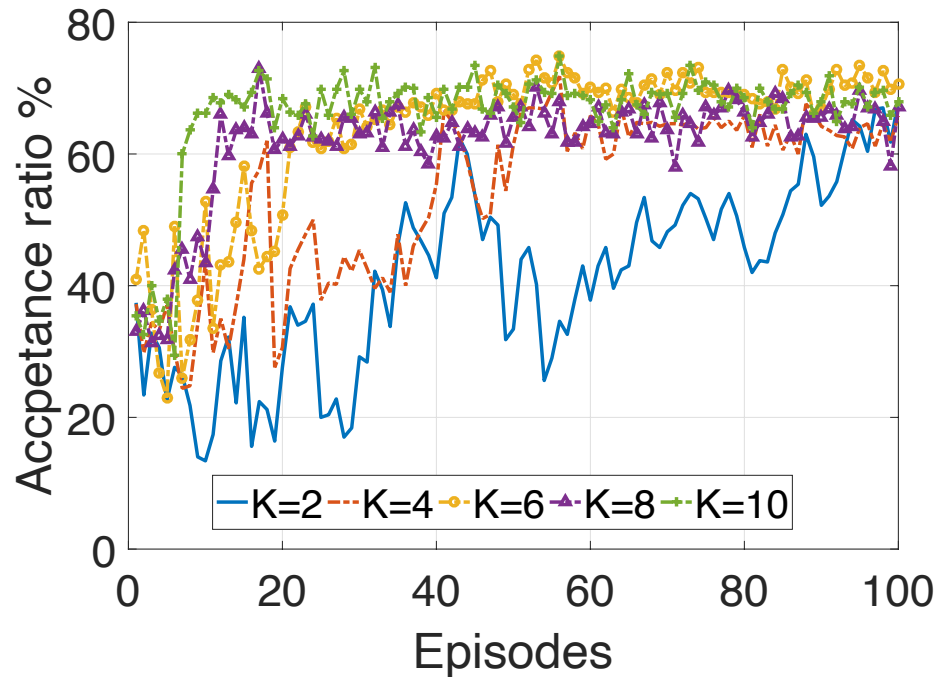
ILP: Integer Linear Programming based solution

AMCM: Actor-Multi-Critic Model (\*)

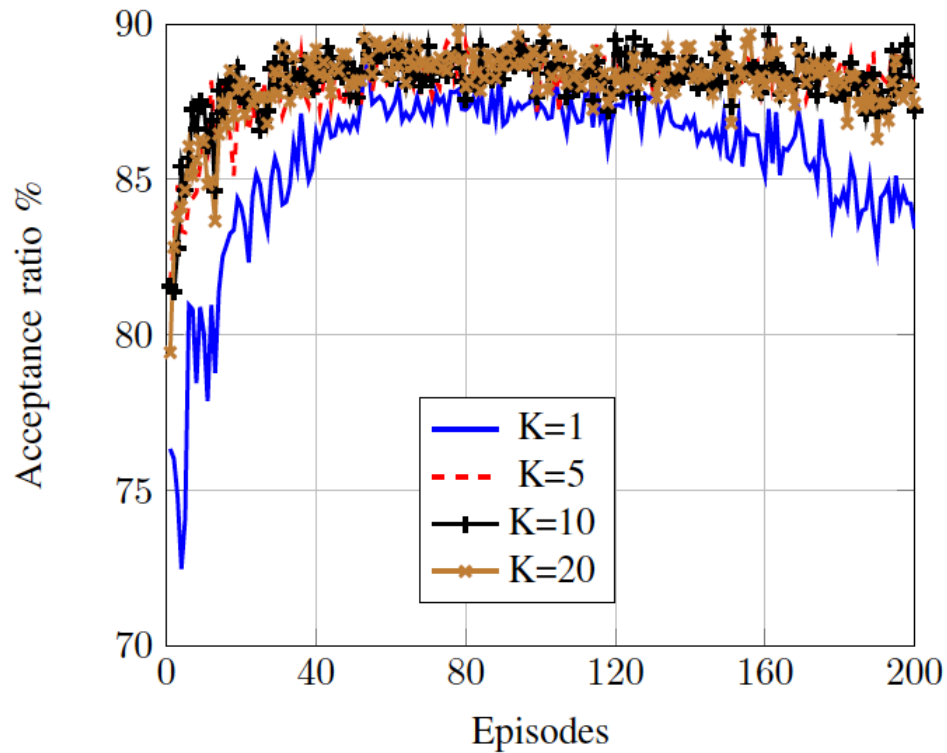


(\*)P. T. A. Quang, Y. Hadjadj-Aoul and A. Outtagarts, "A Deep Reinforcement Learning Approach for VNF Forwarding Graph Embedding," in *IEEE Transactions on Network and Service Management*, vol. 16, no. 4, pp. 1318-1331, Dec. 2019.  
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# Impact of the number of fully connected Layers

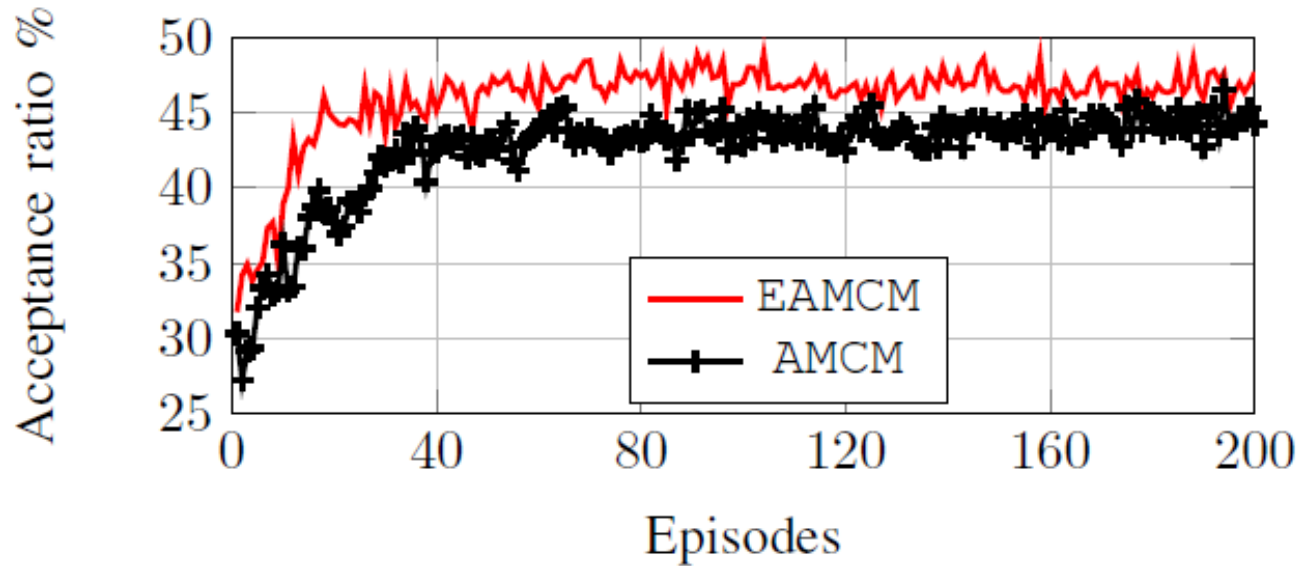


# Impact of the number of critic nets



# AMCM vs EAMCM

More congested system ...



# Conclusions

- Adopt Enhanced Exploration framework to boost the performance of DDPG
- Proposed an evolutionary algorithm to improve the learning process of critic networks
- The simulation confirms that the evolutionary algorithm can improve the performance remarkably

Thanks for your attention