AI無線通訊實驗
Reinforcement Learning, RL for Network Resource Allocation

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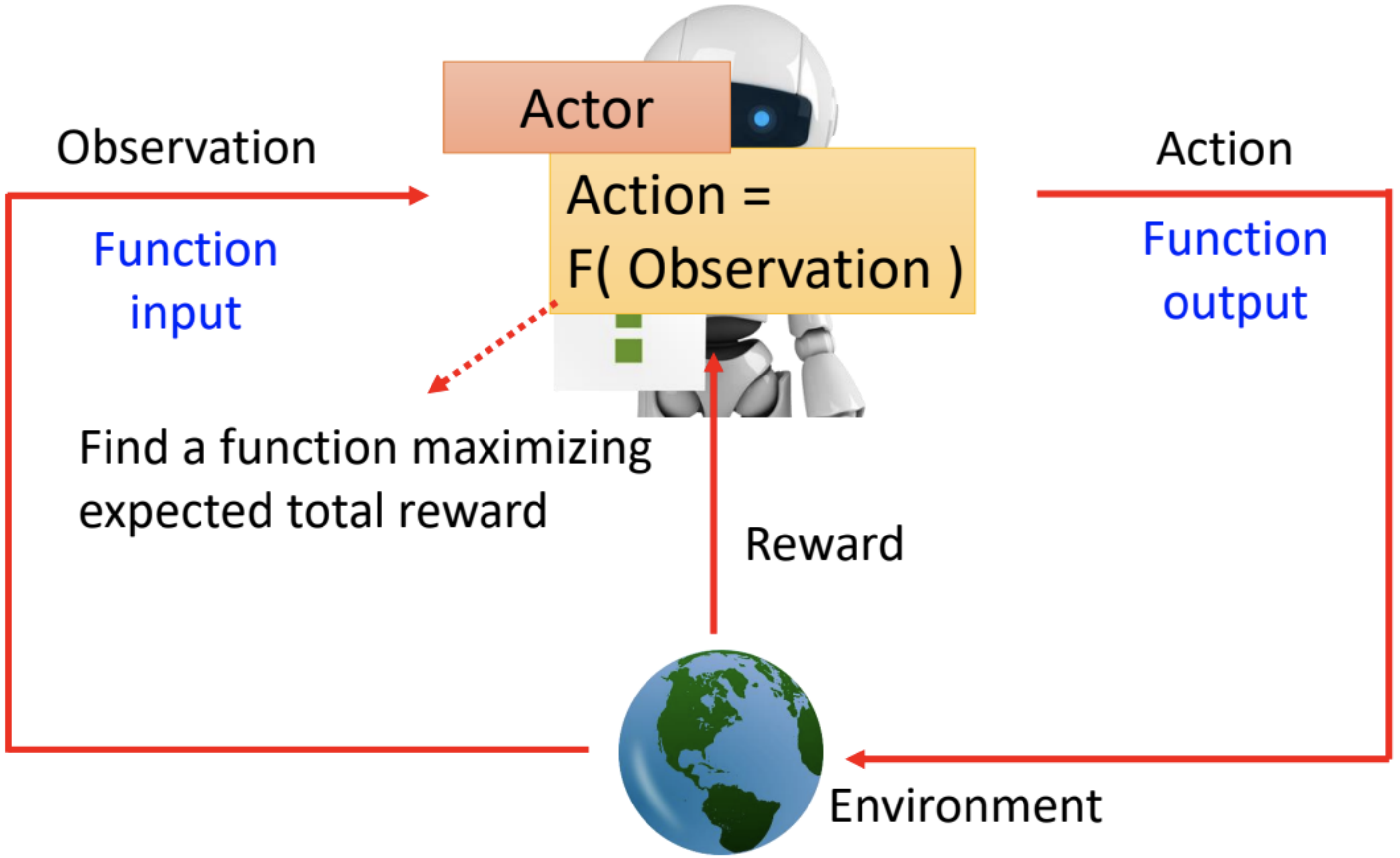
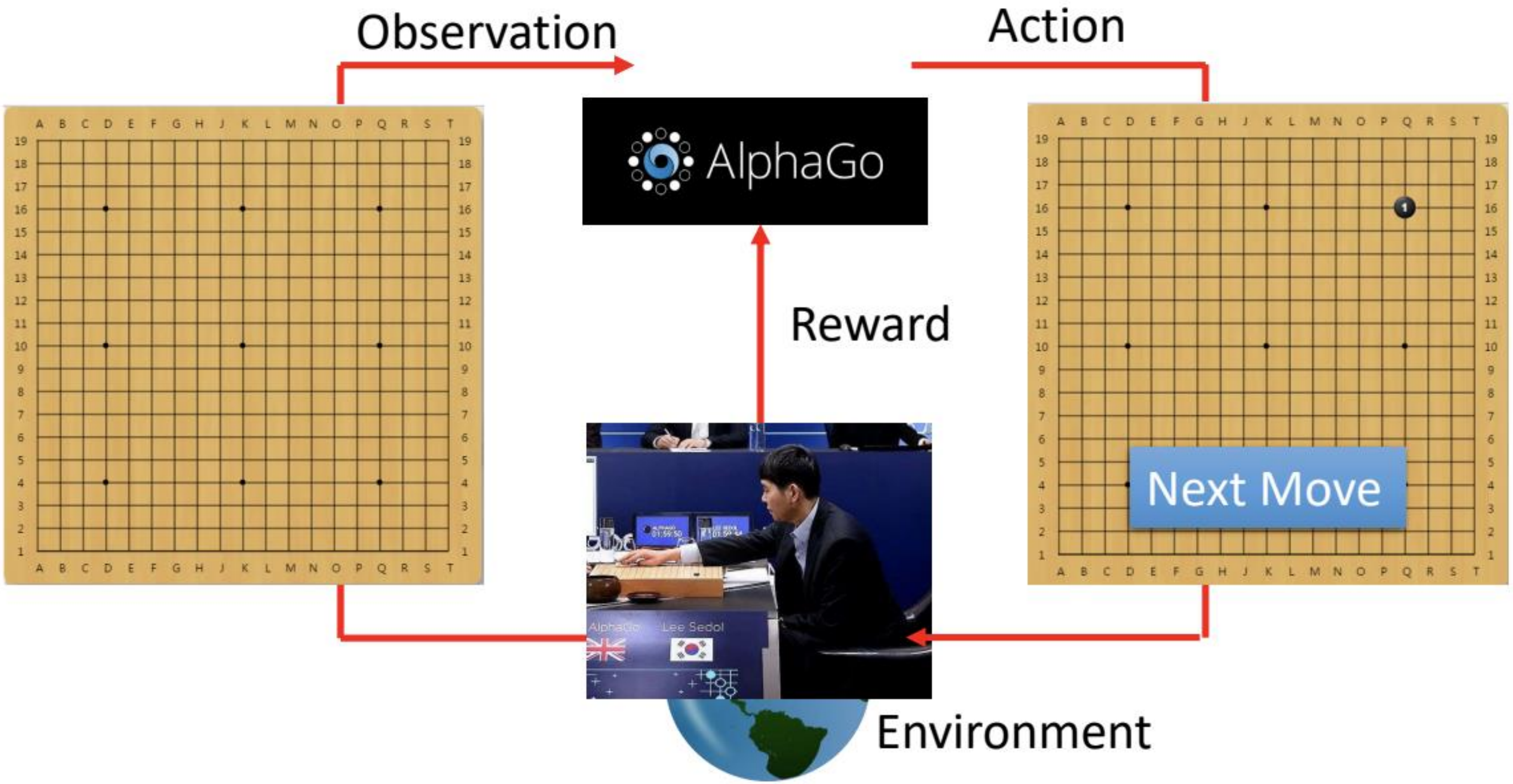
Reinforcement Learning, RL

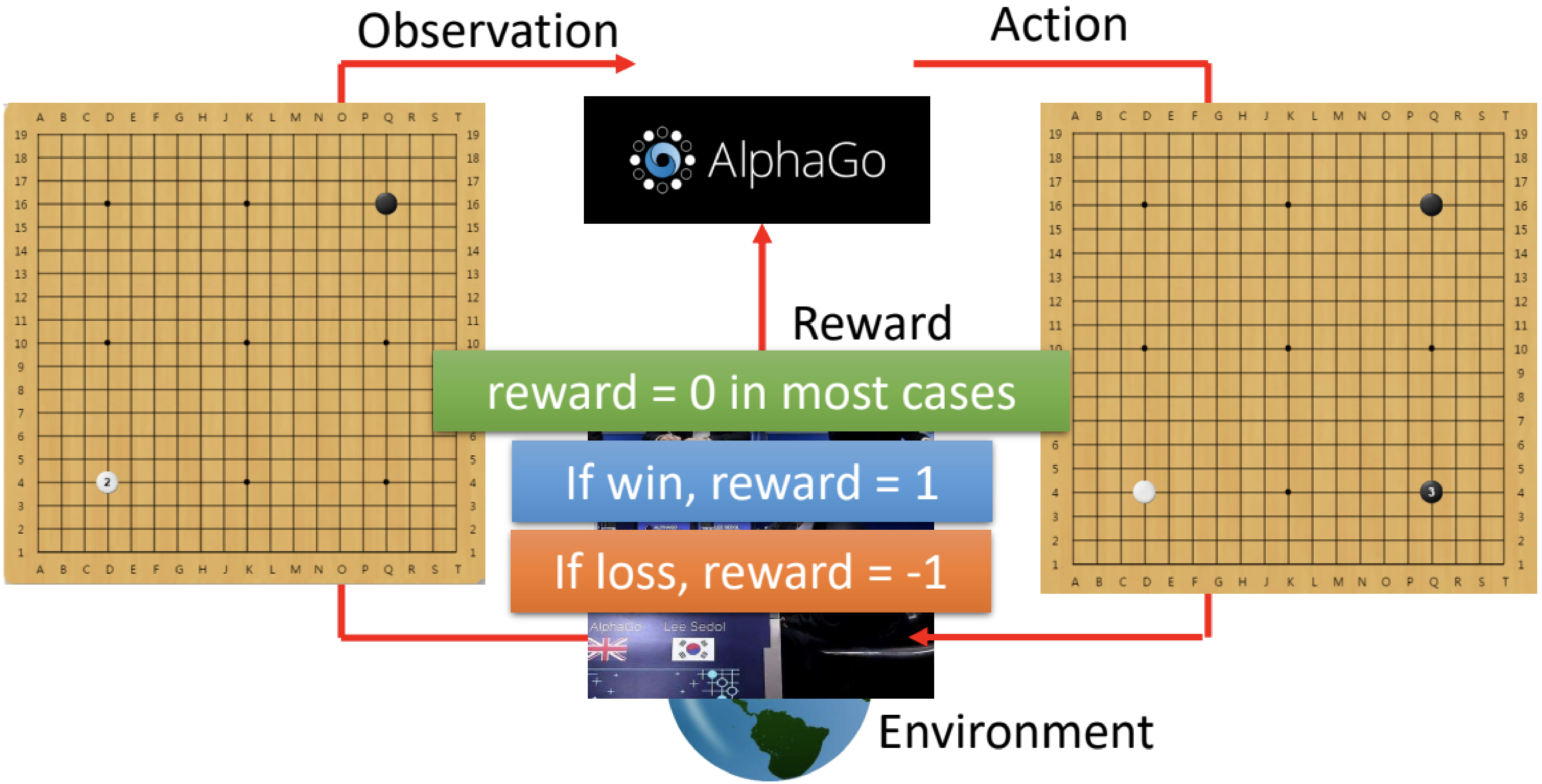


AlphaGo

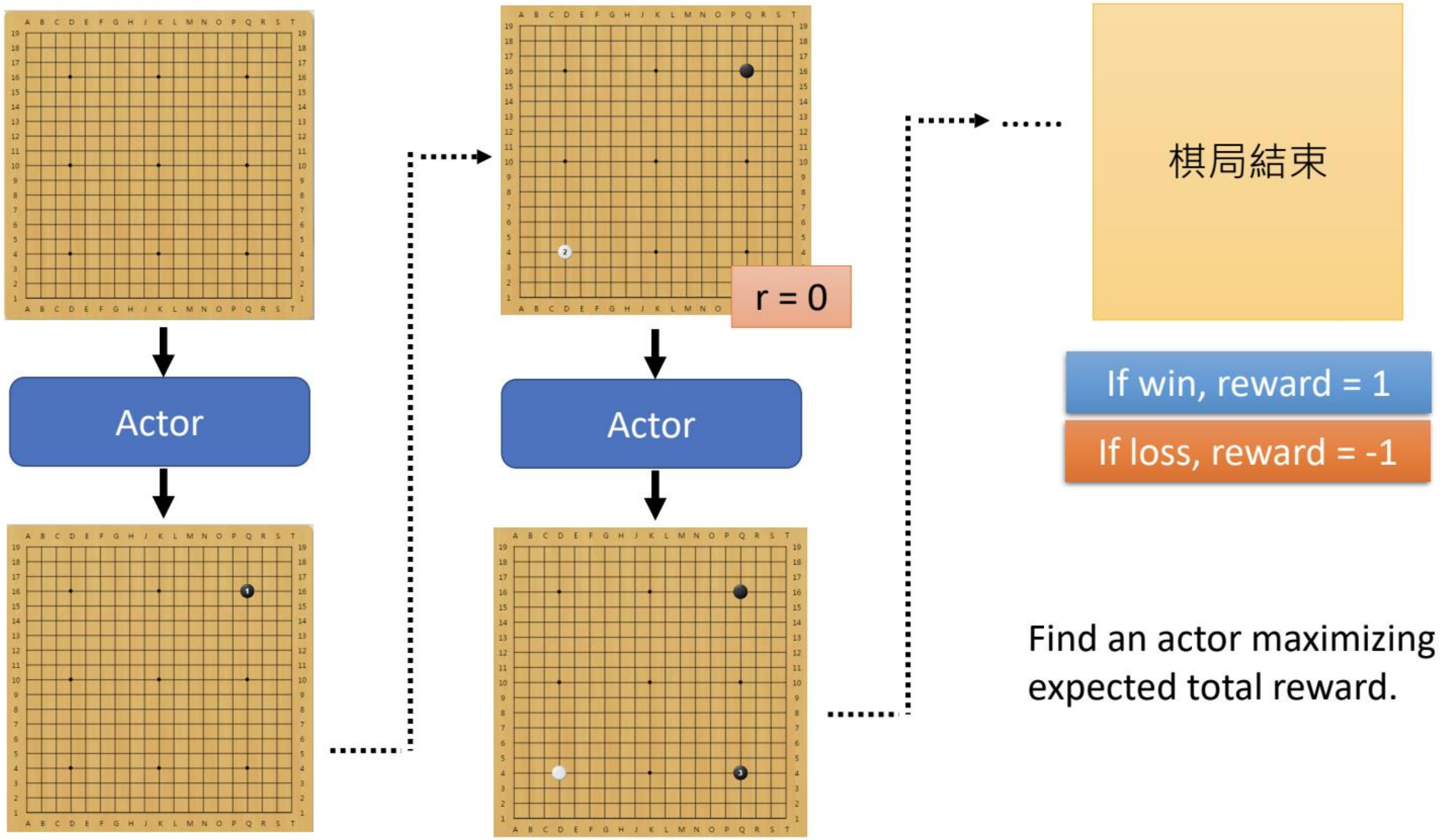

Observation
Action
AlphaGo
Reward
Next Move
Environment
AlphaGo
Lee Sedol

AlphaGo

Find an actor maximizing expected total reward.



AlphaGo



Find an actor maximizing
expected total reward.

Resource Allocation

- In a real mobile communication, the system always simultaneously performs several tasks under different demanding services from devices
  - However, each device has different channel conditions that we have to take into account for providing optimum resource allocation
- There exist a great number of resources provided from the central system
  - Spatial resources
  - Temporal resource
  - Frequency bandwidth
  - Transmit power

Resource Allocation

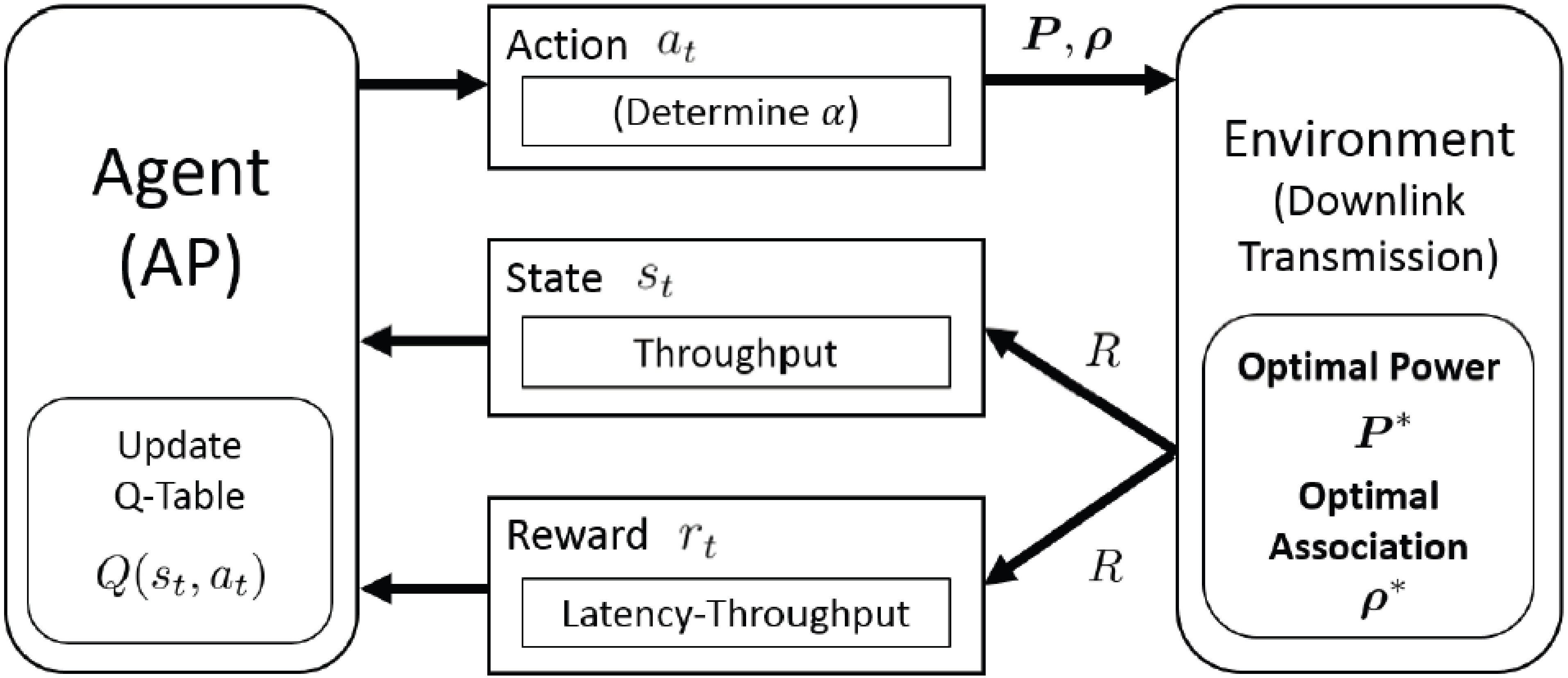
- Channel Gain as the channel gain set from N APs to K UEs
$$\boldsymbol{H} = \left\{h_{n,k} \middle| \forall 1 \leq n \leq N, 1 \leq k \leq K\right\}$$
  - $h_{n,k}$: the channel gain from the n-th AP to the k-th UE
- The downlink transmit power of AP is denoted as
$$\boldsymbol{P} = \{P_n | \forall n\}$$
- The association indicator set for AP-UE connection
$$\boldsymbol{\rho} = \left\{\rho_{n,k} \in \{0,1\} \middle| \forall n, k\right\}$$
- we can obtain the SINR for the n-th AP to the k-th UE as
$$\gamma_{n,k} = \frac{P_n G_{n,k} h_{n,k}}{\sum_{j \neq n}^{N} P_j G_{j,k} h_{j,k} + \sigma^2}$$
  - $G_{n,k}$: the beamforming gain obtained in the beam training process
  - σ^2: background noise

Resource Allocation

- We can then formulate the problem that determines the allocation of power and user association, which is given by

$$
\begin{aligned}
&\max_{\boldsymbol{P},\boldsymbol{\rho}} \quad R \\
&\text{s.t.} \quad 0 < P_n \leq P_{max}, \qquad \forall n \\
&\qquad \rho_{n,k} \in \{0,1\}, \qquad \forall n,k, \\
&\qquad \sum_{n=1}^{N} \rho_{n,k} \leq 1, \qquad \forall k.
\end{aligned}
$$

Q-learning based Resource Allocation



Q-learning based Resource Allocation

- The action is referred as power allocation and association assignment, which is expressed as selection of the maximum value in the Q-table as

$$a_t = \underset{a'_t}{\operatorname{argmax}} Q(s_t, a'_t)$$

  - t: the current training or testing time step

- Since the state is a discrete variable, we quantize the sum rate objective as discrete states as

$$s_t = \left\lceil \frac{R \cdot s_n}{R_{max}} \right\rceil$$

  - R_{max}: the maximum throughput among off-line collected training dataset
  - s_n: pre-defined constant indicating the total number of given states

- Rewards

$$r_t = R = \sum_{n=1}^{N} \sum_{k=1}^{K} \rho_{n,k} \log\left(1 + \gamma_{n,k}\right)$$

- According to the Bellman equation, the Q-table is updated by

$$Q_t(s_t, a_t) \leftarrow Q_t(s_t, a_t) + \eta \cdot \left[r_t + \delta \cdot \max_{a_{t+1}} Q(s_{t+1}, a_{t+1}) - Q_t(s_t, a_t)\right]$$

Q-learning based Resource Allocation

Algorithm 8: Q-Learning for Resource Allocation

Initialization: Time step $t = 0$, learning rate η, discount factor δ, exploitation probability ϵ

Offline: Collect training dataset of power and association, find R_{max}, and update the Q-table based on **Q-learning**

Online: Based on trained Q-table, perform online testing based on **Q-learning**

Q-learning:

while Not converged as $t < T$ **do**

    $t = t + 1$

    Randomly generate a number $\kappa \in [0, 1]$

    if $t = 1$ or $\kappa > \epsilon$ **then**

        Select random action a_t

    else

        Select optimal action based on $a_t = \underset{a'_t}{\operatorname{argmax}}\, Q(s_t, a'_t)$

    end if

    Obtain power $\boldsymbol{P}$ and association $\boldsymbol{\rho}$ decision based on a_t

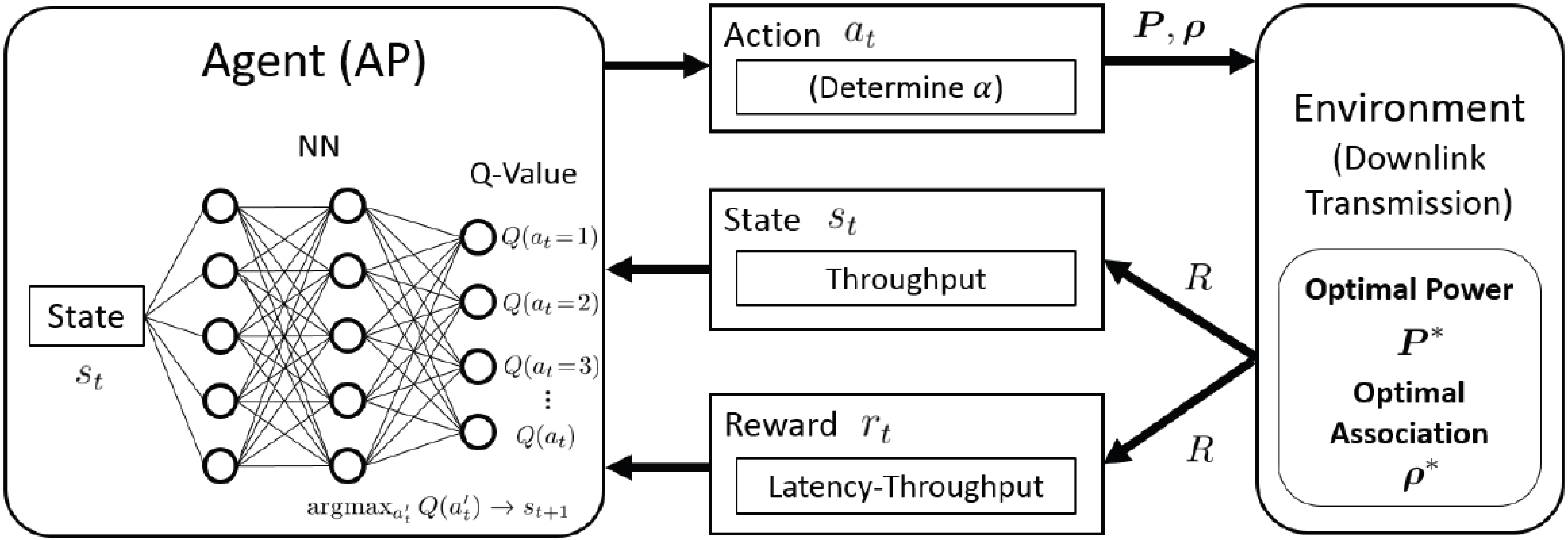
    Obtain reward: $r_t = R$

    Update Q-table: $Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \eta \cdot \left[r_t + \delta \cdot \max_{a_{t+1}} Q(s_{t+1}, a_{t+1}) - Q(s_t, a_t)\right]$

    Update next state: $s_{t+1} = \left\lceil \frac{r_t \cdot s_n}{R_{max}} \right\rceil$

end while

Deep Q-learning



Deep Q-learning