# Reinforcement Learning Based Routing in Networks: Review and Classification of Approaches

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# Q-routing

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Most of the existing RL-based routing protocols today are extensions of their work.

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1: **function** QROUTING( )
2: Initialize $Q_i$ matrix randomly
3: **while** termination condition holds **do**
4: **if** packet $P$ is ready to be sent to $d$ **then**
5: Determine node $j^* \leftarrow \arg\min_{j \in \mathcal{N}(i)} Q_i(d, j)$
6: Send packet to node $j^*$
7: Collect estimate $\theta_{j^*}(d)$ from node $j^*$
8: Update $Q_i(d, j^*) \leftarrow (1 - \alpha) \cdot Q_i(d, j^*) + \alpha \cdot \left[ W_i^q(P) + T_{ij^*} + \theta_{j^*}(d) \right]$
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- $i$ is the node that is currently running the algorithm
- $P$ is a packet that node $i$ needs to forward to destination $d$
- $Q_i(d, j)$ is the *delivery delay* that $i$ estimates it takes, for node $j$, to deliver the packet $P$ at destination $i$
- $\mathcal{N}(j)$ is the set of $j$'s neighbors
- $\theta_j(d)$ is $j$'s estimate for the time remaining in the trip to destination $d$ of packet $P$
- $W_i^q(P)$ is the time spent by packet $P$ in node $i$'s queue
- $T_{ij}$ is the transmission time between nodes $i$ and $j$

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Upon sending packet $P$ to node $j^*$, node $i$ receives back from node $j^*$ the estimate

$$\theta_{j^*}(d) = \min_{k \in \mathcal{N}(j^*)} Q_{j^*}(d, k)$$

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Then, node $i$ updates $Q_i(d, j^*)$ based on the *update formula* for Q-learning:

$$Q(s_t, a_t) = (1 - \alpha) \cdot Q(s_t, a_t) + \alpha \cdot \left[ R_{t+1} + \gamma \cdot \max_{a \in \mathcal{A}} (s_{t+1}, a) \right]$$

# Q-learning

Despite the wide adoption, Q-routing has some flaws. Some problems are direct consequences of Q-learning such as

- *slow convergence*
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Despite the wide adoption, Q-routing has some flaws. Some problems are direct consequences of Q-learning such as

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However, there are also problems arising from the algorithm itself.

For instance the **Q-value freshness**: $\theta_j(d)$ is evaluated only upon packet transmission on a route, therefore if a route is not used for a long time its estimate becomes *outdated*.

# Classification criteria

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These criteria are divided into 3 groups:

1. **Context of use**: criteria based on the *target applications*
2. **Design characteristics**: criteria based on the *design* of the protocols
3. **Performance**: criteria based on qualitative evaluation on *overhead* and *metrics*

# Context of use — Network class and assumptions

TODO

# Context of use — Routing optimization context

A *good* protocol should be able to determine and select the optimal paths to convey data from sources to destinations. This can be TODO

# Context of use – Unicast or Multicast

Categorizing between **unicast or multicast** approaches is a natural choice, given the inherent *overhead* that multicast routing protocols require.

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Indeed, RL should be applied in multicasting scenarios only when links are sufficiently stable and/or partial delivery is allowed, otherwise convergence may be outright *impossible*.

# Context of use — QoS metrics for optimization

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**Quality of Service (QoS)** metrics that have been addressed as objectives for RL-based routing include:

- **delivery rate**: average time to deliver a packet
- **delivery ratio**: proportion of packets successfully delivered
- **hop count**: average number of hops from source to destination
- **loss ratio**: proportion of packets not delivered

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**Quality of Service (QoS)** metrics that have been addressed as objectives for RL-based routing include:

- **bandwidth**: average bandwidth provided to sources
- **throughput**: average amount of bytes delivered in the entire network per time unit
- **path stability**: it indicates how a path between source and destination changes over time
- **energy consumption**: average energy consumption of the network

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**Quality of Service (QoS)** metrics that have been addressed as objectives for RL-based routing include:

- **network lifetime**: average time over which the network is still alive
- **transmission power**: power for performing a transmission
- **hit delay**: average delay to return requrested data in peer-to-peer networks
- **hit ratio**: proportion of satisfied requrests in peer-to-peer networks

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**Quality of Service (QoS)** metrics that have been addressed as objectives for RL-based routing include:

- **gain**: average revenue (in \$) received by the agent — in business contexts
- **overhead**: average *cost* to deliver data packets at destination — the *cost* definition depends on the application

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Lastly, a few routing protocols are aimed at providing QoS guarantees, regarding delivery delay to meet some requirements of **delay-sensitive applications**.

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For instance, this is essential in *multimedia applications*.