Research Progress Report

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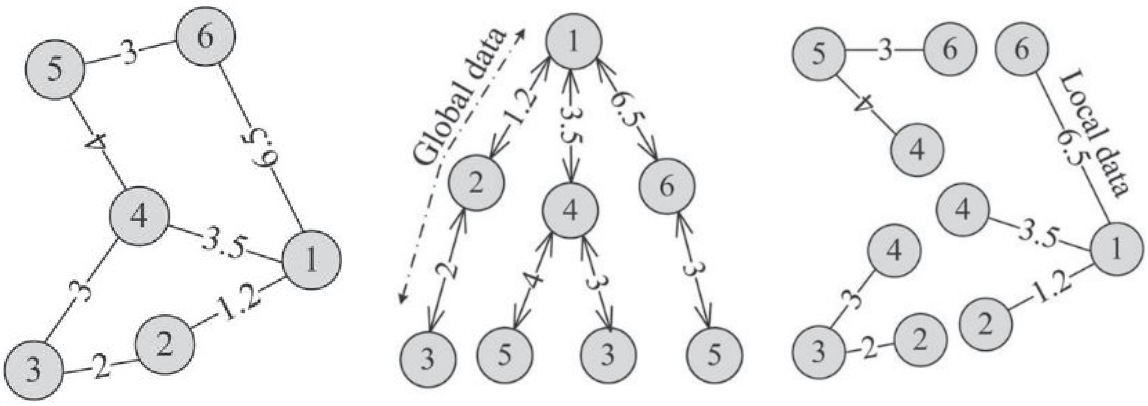
1 Reading and Research Activities

1.1 Reading Summary

With the growth of network nodes and the expansion of application environment of WSNs, it needs to have the ability to handle huge network traffic and more flexibility. So, here are some main problems that need to be solved by Machine Learning.
1) Because of the changing rapidly of WSNs environments over time, it need to be adapted to these environments.
2) For complicated network environments, a good mathematical model is needed to describe network behavior, which can reduce the complexity of WSNs problems.
3) Relationship among network features, such as packet size, delay, error and path, are difficult to extract and describe.
4) How to prolong the lifetime of WSNs by choosing the optimal path?

Why machine learning is a good choice to solve these problems? Here is an example for routing search. Figure 1(a) shows the original graph and Figure 1(b) is the traditional spanning tree routing. However, the routing problem can be divided into sub-problems by employing machine learning, shown in Figure 1(c). Each node only needs to consider neighboring nodes' information for deciding the optimal next node.



(a) (b) (c)

Figure 1: Example of routing problem

For the machine learning-based network topology, there are two main ideas: centralized model and distributed model. With regard to the centralized model, the advantage is that it uses the base stations with huge computation power to train machine learning model while the disadvantage is that the common network nodes are difficult to find the base stations in some cases, like the limitation of geography. However, in the distributed model, each node or edge router needs to train several machine learning models according to previous history network traffic for deciding next node. So, the main problems is each node needs to have the abilities of huge computation and storage. Specially, reinforcement learning and neural networks are the most commonly machine learning-based algorithms used in the distributed WSNs. Here is a brief summary and Table 1 gives a detailed investigation.

1) Key steps of applying Neural Network in wireless networks
There are several steps that we need to consider for applying Neural network in wireless network.

Table 1: Investigation of machine learning-based routing search

Ref.	Network Simulation Tool	ML Tool	Dataset Input	Dataset Output	Evaluation Index
[1]	Mininet [2]	TensorFlow [3]	Network states + traffic matrix	optimal path	accuracy
[4]	NS2	NS2	location and energy of node and its neighbor	next node	packets sent, delivery ratio, average delay, network lifetime
[5]	Aqua-sim(NS2)	Aqua-sim(NS2)	states set actions set	next node	average latency residual energy transmission errors lifetime
[6] [7]	C++	WILL [8]	traffic pattern	next node	total throughput average per -hop delay
[9]	Qualnet 5.0	word2vec	node vector message	node degree	packet delivery rate route discovery time
[10]	OMNeT++	not mentioned	traffic matrix link weight	mean of delay	transmission delay
[11]	Not mentioned	CPLEX	traffic pattern	next node	average congestion ratio
[12]	NS2	Not mentioned	distance between each node and heads	position of cluster head	energy dissipation
[13]	NS2	NS2	energy consumption transmit cost receive cost data packet size sensing radius	network lifetime packet delivery packet delay network balance	

Table 2: The comparation of literatures

ML Techniques	Ref.
Neural Network	[6] [7] [14] [15] [16]
Reinforcement Learning	[4] [5] [10] [13] [17] [18]

- The extraction of traffic features matrix or vector
  The input vectors is very important in training neural network. Because of the self-similarity of network traffic, we can use the previous network traffic characteristics to represent the later network traffic. How to choose the appropriate parameters to represent the relationship of network traffics is a very important issue. [9] creates a collection of 20-dimension vectors that can express a single feature in the node vector.

Device type	Signal strength	Hop number	Distance	Coverage area	Neighbor number	Energy degree	Delay	Communication mode	Move speed	Additional BS

Figure 2:

- The design of neural network architecture
  There are different neural network models and it is important to choose which one. Normally, any neural networks comprise an input layer, multiple hidden layers and an output layer, shown in Figure 3. The input layer has N units which can be defined as the total number of nodes in the network. In the hidden layers, each layer can compute a non-linear transformation of the previous layer. The output of neural network is the routing path indicating the next router along the path from the source router to the destination. A N-dimensional vector can represent the output and each of its elements has a binary value. Only the position with value of 1 indicates the next node.

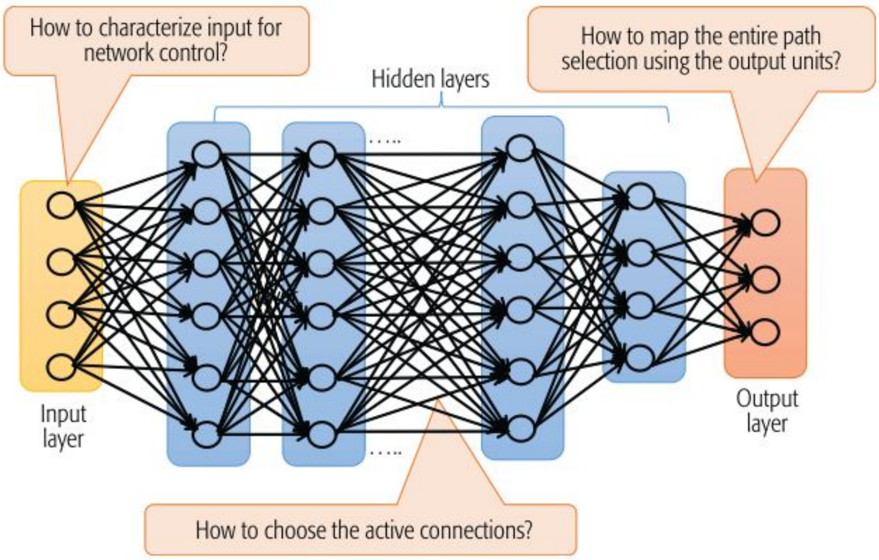


Figure 3: Neural network architecture

- Routing search
  Assume there are 10 routers in the network, the source node is n_1, and the destination node is n_10. The first step of the running phase is to find the optimal router to the source. The NN model $NN_{1,10}$ is run by n_1. The input of $NN_{1,10}$ is vector $A = [\alpha_1, \alpha_2, \cdots, \alpha_10]$, where α_i is the traffic pattern of router i. At the output side, one out of 10 routers is chosen which is n_3

in the figure 4. Following that, node n_1 runs model $NN_{3,10}$ to find the second hop node. This operation is repeated until the destination node is reached.

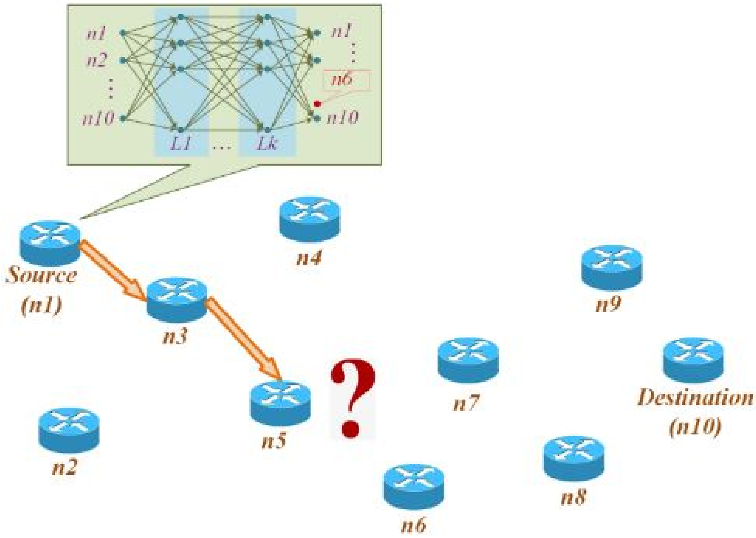


Figure 4: Routing search

In addition to the summary of the important parts above, there are other steps in the process of using neural network, such as initial phase, data collection and NN weight matrix update, etc. Here is a simple flow chart. For the detailed introduction of applying neural network into the field of routing search, please see ref. [6].

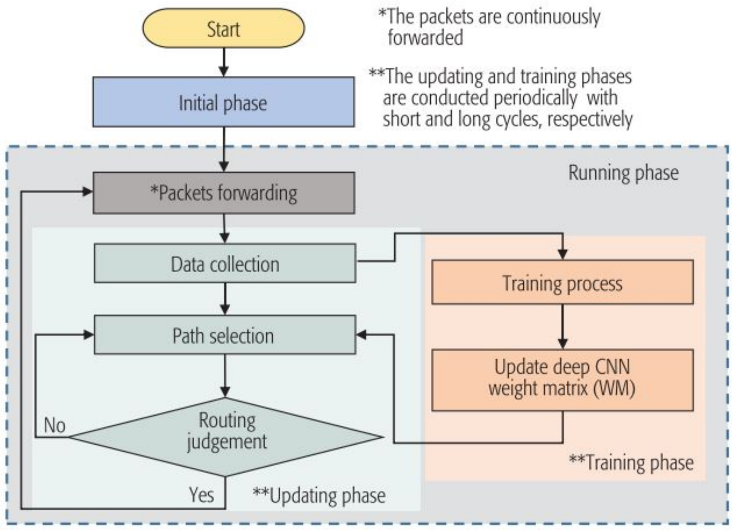


Figure 5: The flow chart of neural network based routing search method

2) Reinforcement learning in wireless networks

Reinforcement learning is a branch of machine learning, which is good at controlling an individual who can act independently in a certain environment, and constantly improve its behavior through interaction with the environment. Reinforcement learning problems include how to do it, how to map the environment into action and how to get the greatest reward. In reinforcement learning, learners are decision-making agents. They try to run repeatedly to find the behavior that can get the greatest reward. Generally speaking, actions will not only affect the current incentives, but also the environment at the next time point and all subsequent incentives.

Reinforcement learning mainly solves continuous decision making problem, which is very similar to routing search. In reinforcement learning, the routing problem can be consider as a Markov decision process, the agent decides at each state which action to take based on its experiences. After taking an action, the agent gets a reward or cost from the environment. The agent uses the reward to update its policy. The advantage of reinforcement learning based routing is that each node does not need global network information, but can still approximate global optimality. Some research has been done in this area, shown in the table 2. Please see ref. [17] for detailed introduction.

By reading some literatures, only Professor N. Kato has done a lot of work in using neural network in the field of routing search. But his work assumes each node in the networks has the ability to train the neural network, which requires that each node has enough energy, storage capacity and computing capacity. At the same time, the neural network is supervised learning, how to obtain labeled data is also a big problem.

Reinforcement learning seems to be a good way to solve routing problems, because it has decision making ability, but has no way to solve perceptual problems. Neural network has strong perception ability, but lacks certain decision making ability. Therefore, deep reinforcement learning, combing deep learning with reinforcement learning, provides a solution for the routing search. The next stage will focus on this point.

1.2 Course Summary

Studied chapter 4 of Neural Networks and Deep Learning and chapter 1 of Improving Deep Neural Networks, **Coursera**, `https://www.deeplearning.ai/deep-learning-specialization/`

2 Objectives for the Next 2 Weeks

2.1 Reading

Reading papers foused on Deep Reinforcement Learning-based routing.

2.2 Course

Study chapter 2, 3, 4 of Improving Deep Neural Networks, **Coursera**, `https://www.deeplearning.ai/deep-learning-specialization/`

3 Advisor's Comments

Bibliography

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