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Utilizing Machine Learning to estimate Link Quality and adjust Wireless Connection Parameters accordingly

Abstract

The connectivity of a wireless network strongly depends upon the link quality between individual nodes which influences the optimal parameter choices of the respective communication devices. However, in the Network Coding Module (NCM) these parameters are often set to static values that are not optimal for the current link quality between the nodes, resulting in a suboptimal network performance. Building upon the gained knowledge of the networking commmunity in the last years [1], this project aims to utilize machine learning to estimate the link quality and adjust the parameters of the communication devices using the NCM accordingly. As a result, we expect to be able to improve the overall network performance of the NCM, especially in heterougenous wireless network environments with quickly changing wireless standards.

1 Topics

Our project will focus on the following topics:

- **Link Quality Estimation (LQE):** As the conditions of a wireless communication channel can vary widley, it is important for certain wirless protocols/mechanisms to have an accurat metric estimating the link quality. Therefore, we investigate different approaches estimating the link quality between two nodes using the NCM in a wireless network, first and formost by utilizing machine learning techniques.
  The main task is: Implement a machine learning based wireless link quality estimation scheme.
  - Evaluate available link quality estimation schemes
  - Add a fitting scheme into the NCM
  - Compare the machine learning based link estimator to rate adaptive link quality estimator (RALQE)
- **Wireless Parameter Optimization:** Wireless connection devices utilizing the NCM use serveral static parameters (e.g. generation sizes, redundancy factor, default MTU, ...) that are well selected for the most common wireless technologies. However, as underlying wireless standards change rapidly in heterougenous systems, these parameters often lead to a suboptimal network performance. As a result, we will investigate the current choices for these parameters and introduce dynamically adjusted parameters based on certain metrics of the network connection (e.g. link quality, round trip times, throughput, WiFi standard, ...), preferrably by using machine learning techniques.
  The main task is: Implement a dynamic parameter approach for the NCM
  - Determine static parameters
  - Evaluate a dynamic adoption of these parameters
  - Create meaningful dynamic adoption schemes
  - Compare the dynamic approach to the static one

2 Goal

In this project, we aim to combine both of the above-stated topics. The goal is to estimate the link quality in a wireless system and subsequentially optimize the parameters of the wireless connection devices dynamically,

Title	Technology	Goal	Input	Output	Data
PRR is not enough 2008	IEEE 802.11 IEEE 802.15.4	Link State Estimation	PRR	Link quality transition probability	Rutgers and Mirage trace-sets
Temporal adaptive link quality prediction with online learning 2012, 2014	IEEE 802.15.4	Link Quality Estimation Improve Routing	PRR RSSI SNR LQI	Binary, estimates if link quality above threshold	480 000, Rutgers and Colorado trace-sets

Table 1: Publicly available work on link quality estimation using real network data traces.

in order to improve the overall network performance. This behaviour can be seen in lots of industry standard wireless devices [1].
We will showcase this functionality in the Network Coding Module (NCM) introduced in the lecture by utilizing machine learning techniques. As a result, we expect to be able to improve the overall network performance of the NCM, especially in heterougenous wireless network environments with quickly changing wireless standards.

3 Approach

For the Link Quality Estimation (LQE), we train a machine learning model with a large amount of traces captured from a real system's environment. Either the data will be collected manually using the NCM or publicly available datasets will be leveraged. For the latter option, we have to take into account that these public datasets might not be fitting very well for optimizations in the NCM. There are several datasets available as mentioned in Gregor Cerar et. al. [1], each having certain advantages and drawbacks. Metrics like Packet-Reception-Ratio (PRR), Received Signal Strength Indicator (RSSI) or Link Quality Indicator (LQI) are most widely used when it comes to input metrics for LQE models [1]. For this, we will investigate more research wether we could use one of the promising datasets of table 1.
Machine learning LQEs are becomming incresingly popular in the past few years [1]. For the model itself, there are a lot of different approaches in literature using all kinds of ML techniques. We will focus on supervised learning using Artificial Neural Networks (ANN), Support Vector Machines (SVM) or Deep Neural Networks (DNN) as they usually outperform simpler linear methods like regression [1]. Nevertheless, we need to evaluate if resource hungry methods like DNNs perform well on the NCM. If not, we will fall back to simpler, linear ML methods.

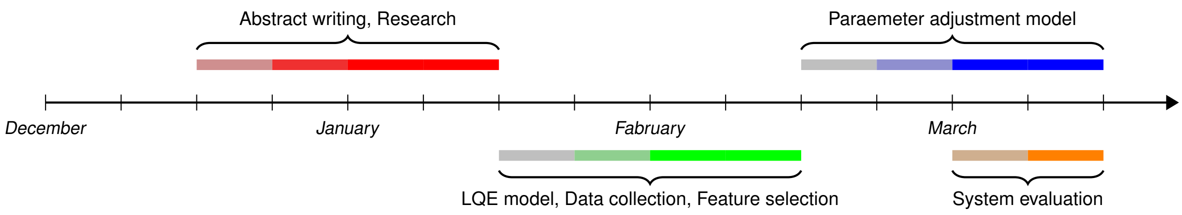
Regarding dynamic parameter adjustments, we propose using reinforcement learning. Reinforcement learning is an area of machine learning concerned with how intelligent agents take actions in an environment in order to maximize the cumulative reward. Our developed model should be able to quickly obtain feedback whether input features like round trip time and throughput improved by the parameter adjustments made by the model.
For the model feature selection, we will utilize the link quality provided by the LQE model of the previous step but also metrics like round trip times, throughput or the used WiFi standard. The model should then optimize for different parameters, e.g. troughput or latency of the network connection. The optimized values are then committed (so actually changedin in the wireless connection) after each generation, depending (or whenever else this is possible).

We aim to mainly use the following programming languages and frameworks: Python (PyTorch, PyTorch Lightning, NumPy) for Machine Learning related tasks and C for the integration into the NCM (and therefore networking related tasks). Exchanging data between the NCM and the machine learning models will be done via raw UNIX sockets that can be opened in C and Python.

4 Project Timeline

We organize the project into four major phases:

- **Writing Abstract / Research (from Mid December until Mid January):** In order to get a feel for the LQE and dynamic parameter adjustment topic, we first start writing a research proposal for our project. In parallel, we do research on the current state-of-the-art methods in this field by studying Gregor Cerar et. al. [1] and take a glance at some of the there-referenced papers.
- **Estimation of link qualities (from Mid January until Mid February):** As the first step, we estimate the link qualities between nodes in wireless networks. As there has already been quite a lot of research in this field, we rely on the findings of Gregor Cerar et. al. [1] (and the respective papers cited there) in order to select the best suited features / datasets as well as Machine Learning architectures. However, we need to take the special nature of the NCM into account for these tasks, therefore posing a challenge.
  - Data collection / Feature selection
  - Model implementation / Optimization
  - Evaluation
- **Dynamically adjusting parameters (from Mid February until Mid March):** Based on the outcome of the previous step (estimation of link qualities) as well as further key metrics (round trip time, link throughput, WiFi standard, ...), we try to dynamically adapt the currently statically set wireless parameters of the NCM. Examples for these parameters might be default MTU, MTU offset, memory alignment, different network coding generation sizes, as well as the network coding redundancy factor. A key research aspect here is when which parameters can be adjusted, for example some parameters like generation size can only be ajusted between different network coding generations.
  - Data collection / Feature selection (also using the output of the previous step)
  - Model implementation / Optimization
  - Evaluation
- **Evaluation of the overall system (from Mid March until End of March):** Evaluate the wireless connection which is influenced by the dynamically adjusted wireless parameters based on the link quality (and other metrics). Compare throughput and latency of the connection to the regular NCM without these dynamically adjusted parameters.



References

[1] Gregor Cerar, Halil Yetgin, Mihael Mohorcic, and Carolina Fortuna. Machine learning for wireless link quality estimation: A survey. *IEEE Commun. Surv. Tutorials*, 23(2):696–728, 2021.