早稲田大学大学院 基幹理工学研究科

博 士 論 文 概 要

論 文 題 目

Researches on TCP Throughput Prediction and Adaptive Bitrate Control in Mobile Network
モバイルネットワークにおけるTCPスループット予測と適応レート制御に関する研究

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With the rapid development of mobile applications, it becomes more and more important to provide fluent media streaming to satisfy the requirement of users. In order to ensure good service for video streaming, prediction of network performance and adaptive bitrate (ABR) control are essential issues. Throughput prediction can assist in adaptive bitrate control and help decide the target playout buffer size, thus avoiding playback interruption. Moreover, it enables reduction in playout buffer size when sufficient bandwidth is available, thereby decreasing unnecessary video traffic and saving energy. Adaptive bitrate control plays an important role in media transmission to select proper video bitrate, which can ensure high quality of service (QoS) and quality of experience (QoE) for users.

Throughput prediction is one of the promising techniques to improve QoS and QoE for mobile applications. It is a non-trivial task especially in mobile network, due to the frequent change of communication scenario. Throughput prediction accuracy is important as it is the basis for adaptive bitrate control and traffic management techniques for media transmission. In this thesis, TCP throughput prediction methods are proposed. Besides historical throughput data, other measurements of network characteristics and sensor data are adopted to construct the prediction model. In addition, the influence of user scenario is also taken into consideration. The datasets are classified into different scenarios by the features such as interface, user movement pattern, time and location. Statistics and machine learning techniques are adopted to model the throughput characteristics based on the collected data. The prediction error between the predicted value and actual data, such as relative prediction error, the root mean square relative error (RMSRE) and normalized root mean squared error (NRMSE) are utilized to evaluate the methods. Results show the prediction methods are effective in various scenarios.

Adaptive bitrate control is essential for video streaming to choose the proper video bitrate dynamically via the optimization and trade-off between video quality and rebuffering. In this thesis, we propose an ABR method where the predicted throughput and buffer occupancy are both taken into consideration. MPEG-Dynamic Adaptive Streaming over HTTP (DASH) is accepted as a unifying standard protocol which is studied worldwide these years. We developed and tested ABR algorithms based on DASH. Since large scale deployment is not possible for academic research, we establish a trace-based emulation for DASH to evaluate different ABR methods with limited experiments. QoE metrics include bitrate, rebuffering time, initial delay and bitrate switch are considered when evaluate the ABR methods. Results indicate that better prediction accuracy can help improve the performance of ABR method. Furthermore, a novel adaptive bitrate method named Decision Map Method (DMM) is proposed in this thesis. This method takes both throughput prediction and buffer occupancy into consideration when choosing the bitrate for video streaming. Meanwhile, the aggressive and conservative mechanisms are adopted to choose proper bitrate in different situations. Evaluation results show DMM can control bitrate effectively to ensure high QoE.

The thesis consists of six chapters.

Chapter 1 introduces the background and motivation of this research. As throughput prediction plays a significant role for adaptive bitrate control in mobile network, we first focused on prediction research and construct several prediction models. Next, in order to ensure high QoE for user, research on adaptive bitrate control methodology is conducted in this thesis.

In Chapter 2, we introduce several related works including wireless communication methodology, user movement pattern recognition, TCP throughput prediction, adaptive bitrate control, and QoS/QoE optimization. These are the related materials for this thesis that have been referred to.

In Chapter 3, Throughput prediction methods using statistics and machine learning are proposed. The first method uses Gaussian mixture model (GMM) to cluster the data. It adopts forward-backward algorithm to find the most likely hidden states and obtains the corresponding observations. Then it utilizes Viterbi algorithm to find the state transition path which has the largest probability. After this, total variance is used to evaluate the fluctuation of the former sequence. Then linear prediction and locally weighted linear prediction is applied to predict the future throughput for different fluctuation situation. Based on this method, another method named the Hybrid Prediction with the Autoregressive Model and Hidden Markov Model (HOAH) is developed to predict TCP throughput. The method adopts Support Vector Machine (SVM) as classifier for the sequence, and switches between autoregressive model (AR model) and Gaussian Mixture Model Hidden Markov Model (GMM-HMM) to predict future data. The characteristics of data such as autocorrelation and variance are utilized to construct the SVM classifier. Evaluation in different scenarios is conducted to evaluate the method. Results show the HOAH method can choose the proper prediction model correctly and predict future throughput effectively.

In Chapter 4, a two-stage TCP throughput prediction method uses long short-term memory (LSTM) model is proposed. The method is named throughput prediction based on LSTM (TRUST). In this method, not only throughput measurements, but also other parameters such as the communication factors, sensor data and scenario information are applied as features to construct the neural network model. This method can realize long and short-term prediction for TCP throughput. A set of data processing methods is proposed to enhance the performance of the prediction model. In order to classify data into the different scenarios, user movement pattern recognition via machine learning is utilized to identify the user movement mode. Data of the same scenario is used to train the prediction model. Field experiments are conducted to evaluate the method. Relative error and NRMSE is used to examine the performance of different methods. Results show the TRUST method can decrease the prediction error by a maximum of 44% in the moving bus scenario compared with conventional methods. For other scenarios, the prediction errors are decreased by maximum 38%, 40%, and 34% under static, walk, and train scenarios, respectively. We also compared the models trained with mixed dataset. It is found that the

training data from the same scenario is better than data from mixed scenarios for prediction. This is because the data from the same scenario share very similar characteristics, thus can obtain the precisely trained model to predict future throughput.

In Chapter 5, a trace-based emulation for MPEG-DASH is established to evaluate the performance of different methods on adaptive bitrate control. The emulation method can provide the reproducible network condition artificially, thus the throughput between server and client can be constrained identically. This allows the comparison of algorithms quantitatively with limited experiments. The throughput prediction methods are implemented into DASH to evaluate the effect of prediction methods on QoE for video streaming. Results indicate a good prediction can contribute to good QoE performance. The proposed prediction method can contribute to higher QoE compared with conventional prediction methods. As there is still space to improve the QoE performance of the bitrate selection methodology, the decision map method with aggressive mechanism (DMM-A) is proposed for adaptive bitrate control. The method incorporates both prediction and buffer occupancy information and choose the bitrate aggressively. When the situation falls in the aggressive area, the bitrate will be chosen as one rank higher than the rate-based decision. By using this decision map, the choice of bitrate can be more aggressive than rate-based method. Although the average bitrates increase, the rebuffering events also increase. To solve this problem, a new adaptive bitrate control method DMM using decision map is proposed, which is developed based on the DMM-A. In DMM, an additional conservative mechanism is also constructed for the situation in which the buffer occupancy is small. Both aggressive and conservative mechanisms are considered properly in different situations. When the buffer occupancy is within the conservative area, no matter what the throughput prediction is, the conservative action should be taken immediately to avoid rebuffering events. Experiments are conducted to evaluate the method. The results show that DMM can increase the average bitrate and avoid extra rebuffering event at the same time. The total QoE is improved by 32.1% in the ferry trace, which shows the effectiveness of DMM.

In Chapter 6, the conclusion and future work are given. Chapter 3 and 4 demonstrate the TCP throughput prediction methods using various measurements for mobile network. The evaluations show that the proposed methods can predict throughput accurately. Chapter 5 establishes a trace-based emulation for DASH and proposes the adaptive bitrate method DMM which uses aggressive and conservative mechanism. Emulation results show that the proposed throughput prediction is effective on bitrate control methodology for media transmission. In the future, parameters of lower layers of mobile network will be collected and adopted to improve the throughput prediction models. In addition, more experiments will be conducted to evaluate the ABR method. We will continue to improve the ABR algorithm for better handling different circumstances such as sudden network cutoff. We will also deploy the DMM algorithm into real network environment and test the performance.

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