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Traffic engineering cooperating with traffic monitoring for the case with incomplete information

Kodai Satake Tatsuya Otoshi
Yuichi Ohsita Masayuki Murata

Graduate school of Information Science and Technology, Osaka University

2017 / 11 / 24

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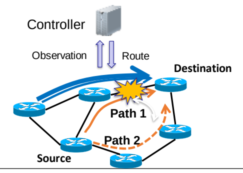
Background

- **The time variation of Internet traffic becomes large.**
  - Growth of the Internet services such as streaming, cloud service, etc
  - When traffic fluctuates greatly, it is necessary to accommodate traffic avoiding congestions.
- **Traffic Engineering (TE)**
  - A controller collects the traffic information and optimize routes.
  - By dynamically changing the routes, the controller avoids congestion even when traffic change occurs.



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Problems of existing TE

- **It is necessary to shorten the control interval.**
  - In conventional TE, congestion lasts for long time because the control period is long such as one hour or more.
  - The control interval should be set to a shorter value when traffic fluctuates drastically.
    - Example: Control in several seconds is required in data center networks [1]
- **It is difficult to obtain measuring traffic information accurately of the whole network in a short interval.**
  - It is because of the overhead to monitor and collect the traffic information.

Require TE which avoid congestion even if the traffic information is incomplete / inaccurate

[1] T. Benson, A. Anand, A. Akella, and M. Zhang, "MicroTE: Fine-grained traffic engineering for data centers," in Proceedings of the Seventh Conference on emerging Networking EXperiments and Technologies, p. 8, ACM, 2011.

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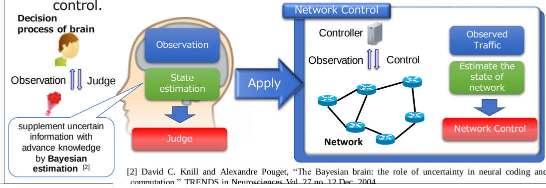
Approach

- **The brain can judge even when only incomplete and uncertain information can be obtained.**
  - Brain understands uncertain information abstractly, and supplement uncertain information with prior knowledge, and judge.
- **Apply the process of brain to TE**
  - Controller understands the traffic information abstractly, supplements uncertain information by using the prior knowledge of the traffic, and control.



[2] David C. Knill and Alexandre Pouget, "The Bayesian brain: the role of uncertainty in neural coding and computation," TRENDS in Neurosciences Vol. 27 no. 12 Dec. 2004

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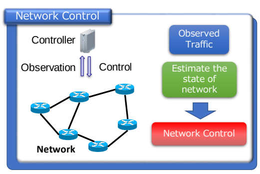
Keys of our method

- **TE which can control even though only incomplete information can be obtained**
  - Estimating current state by Bayesian estimation
  - Predictive control considering uncertainty
  - Selectively obtaining necessary information



Handle traffic amounts as a stochastic variable
- The stochastic variable can express how incomplete and uncertain the information is.

Supplement uncertain information by using the prior distribution and the prediction based on prior knowledge

Network Control considering uncertainly
- Route control to reduce congestion risk
- Obtaining information whose uncertainty should be lowered

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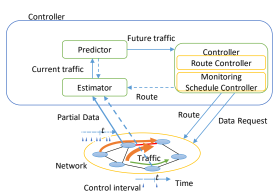
Overview

- **Our method consists of estimator, predictor, and controller.**



Estimator:
- Estimate the whole traffic from obtained partial data of traffic by Bayesian estimation

$P(X_t)$ Current traffic

Predictor:
- Predict the future traffic from estimated current traffic by Bayesian estimation

$P(X_{t+k}|X_t)$ Future traffic

Controller:
- Route control to reduce the probability of congestion occurring
- Obtaining information whose uncertainty is expected to have a large influence on control performance

Estimator

- **Estimate the whole traffic in the current network from the partially observed traffic information**
  - Bayesian estimation updates uncertain traffic amounts using the previously predicted value.

$$P(X_t|X'_{0:t}; O_{0:t}) = \frac{1}{P(X'_t)} P(X'_t|X_t; O_t)\ P(X_t|X'_{0:t-1}; O_{0:t-1})$$

The estimated distribution of the whole traffic ← Partially observed information about traffic amounts | The prior distribution of traffic amounts.

Supplement uncertain information

At time slot t ..
X_t: traffic rates of all flows, X'_t :the traffic observed, O_t : the set of the observed flows
$X_{t':t+k,} = (X_{t,}, X_{t+1,}, \ldots, X_{t+k,})$, $O_{t:t+k,} = (O_{t,}, O_{t+1,}, \ldots, O_{t+k,})$

Predictor

- **Predict the future traffic from the current some**
  - Controller obtains traffic amounts in the next time slots as a probability distribution by using time series data of previously estimated distribution.

$$P(X_{t+1:t+n}|X'_{0:t}; O_{0:t}, \theta) = P(X_{t+1:t+n}|X_{t-m:t}; \theta)\ P(X_{t-m:t}|X'_{0:t}; O_{0:t})$$

The predicted distribution of future traffic ← Predictive model ← Estimated distribution of the traffic amounts until now

Prediction based on prior knowledge

In Predictive model, noise increases as time passes. The larger the flow fluctuates, the larger the variance of the noise for the flow becomes.

At time slot t ..
X_t: traffic rates of all flows, X'_t :the traffic observed, O_t : the set of the observed flows
$X_{t':t+k,} = (X_{t,}, X_{t+1,}, \ldots, X_{t+k,})$, $O_{t:t+k,} = (O_{t,}, O_{t+1,}, \ldots, O_{t+k,})$

Route controller

- **Determine the future route using predicted distribution of traffic**
  - Controller calculates route which minimizes the objective function under while keeping the probability of congestion below a certain level.

$$minimize : \sum_{k=1}^{h} ||R_{t+k} - R_{t+k-1}||$$

$$(l \le k \le h, \forall l)$$
$$subject\ to: \mathrm{P}\Big[\textstyle\sum_{f,j} G^{l,j} R^{j,f}_{t+k} x_{t+k,f} \ \ge\ c_l \Big] \le p$$

$$\forall 1 \le k \le h, \forall i, \forall j, R^{i,j}_{t+k} \in [0,1]$$

$$\forall 1 \le k \sum_{i \in \vartheta(j)} R^{i,j}_{t+k} = 1$$

Route control to reduce congestion risk

$||R_{t+k} - R_{t+k-1}||$: the cost of changing routes
R: $R_{i,j}$ is the ratio of the traffic of flow j passing the route i.
G: $G_{i,j}$ takes 1 if the route j goes through the link i, 0 otherwise.
$\sum_{f,j} G^{l,j} R^{j,f} x_{t,f}$: The traffic passing link l at the time slot t can be obtained
$\mathrm{P}\Big[\sum_{i,l} G^{l,j} R^{j,f}_{t+k} x_{t+k,f} \ \ge\ c_l\Big]$: the probability that the rates of the traffic passing the link l exceeds c_l.
p: Acceptable probabilities of occurrence of congestion

Monitoring schedule controller

- **Select effective monitoring nodes under the constraints of limited observation resources.**
  - Controller selects monitoring nodes to optimize the optimum value of the constrained objective function in the route controller.

$$minimize : E_{p(X_{t+1})P(X'_t|O_t)}[f(X_{t+1}, R_{t+1}(X'_t|O_t))]$$

$$s.t.\ C(O_t) \le W$$

f is the optimum value of the constrained objective function in the route controller.

Assuming that future observed value is followed previous predicted distribution. ($x'_{t+1,f}$ for the flow f included in O_{t+1} is $E_{P(X_{t+1}|X'_{0:t}; O_{0:t})}[X_{t+1,f}]$)

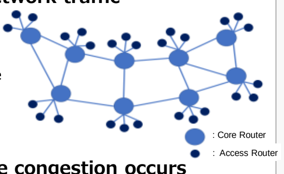
$$minimize : \sum_{k=1}^{h} ||R_{t+k} - R_{t+k-1}||$$
$$(l \le k \le h, \forall l)$$
$$subject\ to: \mathrm{P}\Big[\textstyle\sum_{f,j} G^{l,j} R^{j,f}_{t+k} x_{t+k,f} \ \ge\ c_l \Big] \le p$$

At time slot t ..
O_t : the set of the observed flows

X_t: traffic rates of all flows, $X_{t,f}$: the traffic rates of flow f, X'_t :the traffic observed
R_t: the route at time slot t, $x'_{t,f}$: the element of X'_t corresponding to the flow f

Performance evaluation

- **Purpose**
  - We demonstrate that our method reduces congestion by treating uncertainty of observed traffic and shortening control interval.
- **Network topology and Network traffic**
  - The backbone network topology and traffic trace data of Internet2 (It has 9 PoP routers).
  - To evaluate in larger network, we expanded the original topology. The expanded topology has 27 access routers (monitoring routers).



- **Metric: rate of links where congestion occurs**
  - $M = \frac{\sum_{t,l} g(y^l_t)}{TL}$

s.t. $g(y^l_t) = \begin{cases} 1 & (y^l_t > c^l) \\ 0 & (otherwise) \end{cases}$

T: Number of time slots
L: Number of links
y^l_t: Link utilizations of link l at time slot t

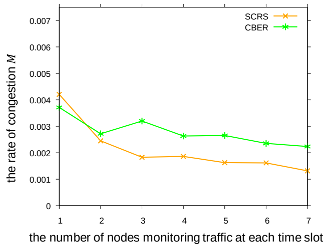
Compared method

- **By comparing these methods, we demonstrate 3 points.**
  - The impact of considering the probability distribution of traffic amounts.
  - The impact of selecting the monitoring nodes considering performance.
  - Shortening the control interval reduces congestions in spite of the uncertainty of observed traffic.

The method name	Consider Probability distribution	How to determine the monitoring nodes	Control interval
SCCU (our method)	Yes	Considering Performance	10 seconds
SCRS	Yes	Random	10 seconds
CBER	No	Random	10 seconds
LongTerm	No	-	Control after acquisition of all information

Impact of considering probability distribution

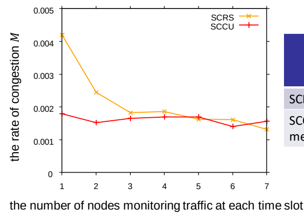
- **SCRS achieves smaller M than CBER unless the number of monitoring nodes is few.**
  - This is because SCRS allocates the resources, considering the probability distributions.



	Consider Probability distribution of traffic
CBER	No
SCRS	Yes

Impact of selecting monitoring nodes

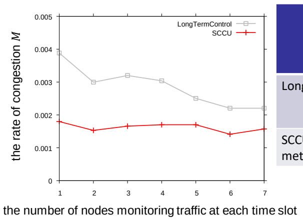
- **SCCU achieves small M even when the number of monitoring nodes is few.**
  - This is because SCUU selects the monitoring nodes that can monitor the flows whose uncertainties has the large impacts on the TE.



	Determine observed information at next time slot
SCRS	Random
SCCU(our method)	Considering Performance

Impact of shortening control interval

- **SCCU achieves smaller M than the LongTermControl.**
  - This is because the method with short intervals detects the risk of congestion and changes the routes so as to mitigate the risk soon after the risk becomes large.



	Control interval	The number of monitoring nodes
LongTerm	Control after it obtains all information	27 nodes (Constant)
SCCU (our method)	10 seconds (constant)	From 1 to 7

Summary and Futurework

- **Our proposed method**
  - The TE for the case that only a part of traffic information can be obtained at each time slot.
  - This framework was inspired by the human brain mechanism
- **Results**
  - Our method improves the performance of the TE even when only a part of the traffic information is monitored at each time slot.
  - Our method enable us to shorten the control interval.
  - Shortening the control interval improves the performance of the TE in spite of uncertainty of observed traffic.
- **Futurework**
  - The evaluation in an actual larger network
  - Discussion the parameter settings of our method for a larger network