# Framework for Traffic Engineering under Uncertain Traffic Information

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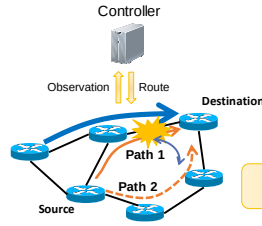
## Traffic Engineering

- Increasing the time variation of traffic in a backbone network
  - Deployment of streaming, cloud services, etc.
- Traffic Engineering(TE)
  - Periodical measurement of traffic and optimization of routes



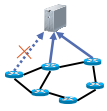

There is some uncertainty of traffic information



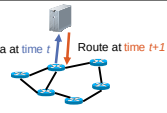
## Uncertainty of Traffic Information

- Causes of uncertainty

Lack in observation



Lag between observation and control




- Existing technology against the uncertainty in TE
  - Traffic monitoring[3]
  - Stochastic/Robust route decision[6]
  - Traffic estimation[2]
  - Traffic prediction[5]

Integrating these technologies is desired to overcome the uncertainty

[2] M. Roughan, Y. Zhang, W. Willinger, and L. Qiu, "Spatio-temporal compressive sensing and Internet traffic matrices (extended version)," IEEE/ACM Transactions on Networking, vol. 20, no. 3, pp. 662–676, Jun. 2012.
[3] H. Singhal and G. Michailidis, "optimal sampling in state space models with applications to network monitoring," in Proceedings of ACM SIGMETRICS, Jun. 2008.
[5] T. Otoshi, Y. Ohsita, M. Murata, Y. Takahashi, N. Kamiyama, K. Ishibashi, K. Shiomoto, and T. Hashimoto, "Traffic engineering based on model predictive control," IEICE Transactions on Communications, vol. E99-B, no. 6, pp. 996–1007, June 2015.
[6] T. Otoshi, Y. Ohsita, M. Murata, Y. Takahashi, K. Ishibashi, K. Shiomoto, and T. Hashimoto, "Traffic engineering based on stochastic model predictive control for uncertain traffic change," in Proceedings of The Seventh IFIP/IEEE International Workshop on Management of the Future Internet, May 2015.



## Difficulty in Integration

- Direct/Indirect interactions among different processes
  - Estimation accuracy directly depends on which data is monitored
  - Route decision indirectly depends on which data is monitored
  - etc.


- Only partial integrations in previous work
  - Traffic estimation and monitoring[2]
  - Traffic prediction and route decision[6]

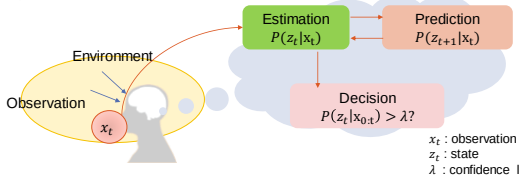
Integration of whole processes has not been achieved

[2] M. Roughan, Y. Zhang, W. Willinger, and L. Qiu, "Spatio-temporal compressive sensing and Internet traffic matrices (extended version)," IEEE/ACM Transactions on Networking, vol. 20, no. 3, pp. 662–676, Jun. 2012.
[6] T. Otoshi, Y. Ohsita, M. Murata, Y. Takahashi, K. Ishibashi, K. Shiomoto, and T. Hashimoto, "Traffic engineering based on stochastic model predictive control for uncertain traffic change," in Proceedings of The Seventh IFIP/IEEE International Workshop on Management of the Future Internet, May 2015.



## Bayesian Decision Making

- Decision making of brain under uncertainty
  - Estimates/Predicts state based on observation
  - Decides action with a certain confidence
- Bayesian decision model for brain[8]

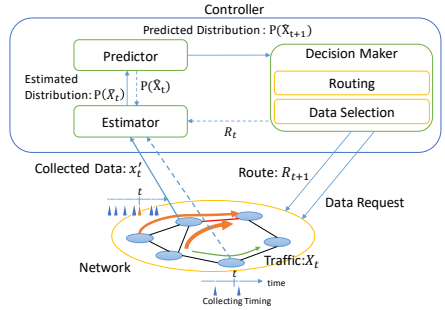



$x_t$ : observation
$z_t$ : state
$\lambda$ : confidence level

[8] S. Bitzer, J. Bruineberg, and S. J. Kiebel, "A bayesian attractor model for perceptual decision making," PLOS Computational Biology, vol. 11, no. 8, p. e1004442, Aug. 2015.

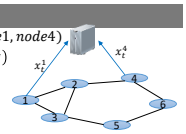


## Bayesian Framework for TE



# Estimator

e.g. $O_t = (node1, node4)$
$x'_t = (x^1_t, x^4_t)$



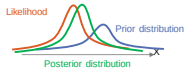

- Role
  - Estimating current traffic from partial data and previous prediction

$x'_t$ : data → estimator → $P(\bar{X}) = P(X_t|x'_t, O_t)$ : estimation

$O_t$ : data collection method
$P(\hat{X}_t)$ : prediction result at $t-1$

- Calculation

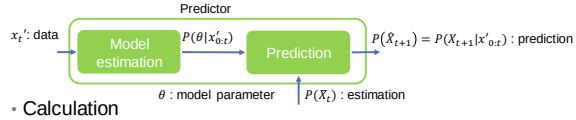
$$P(X_t|x'_t, O_t) \propto \underbrace{P(x'_t|X_t, O_t)}_{\text{Likelihood (from data)}} \underbrace{P(\hat{X}_t)}_{\text{Prior distribution (from prediction)}}$$






# Predictor

- Role
  - Estimating current traffic model which current traffic pattern follows
  - Predicting next traffic using model and estimated current traffic

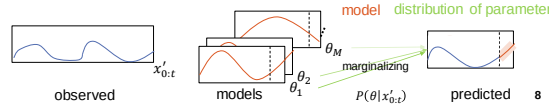



- Calculation

Model estimation: $P(\theta|x'_{0:t}) \propto P(x'_{0:t}|\theta)P(\theta)$

Prediction: $P(X_{t+1}|x'_{0:t}) = \sum_{\theta, X_t} P(X_{t+1}|X_{t-s:t}, \theta)P(\bar{X}_t)P(\theta|x'_{0:t})$

model distribution of parameter

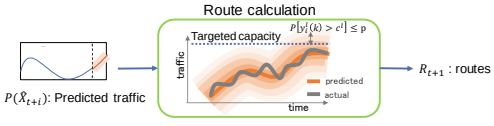





# Decision Maker – Route Decision

- Role
  - Setting routes to accommodate predicted traffic including errors
  - Keeping the probability of congestion lower than $p$ by SMP-TE[6]

Route calculation




- Calculation

cost : delay, loss, etc.

$$minimize: E\left[\sum_{k=t+1}^{t+h}\left((1-w)f(X_i, R_i) + w||\Delta R_i||^2\right)\right]$$
$$subject\ to: P\left[y^t_i(k) > c^t\right] \leq p$$

probability of congestion
routes change : $R_i - R_{i-1}$

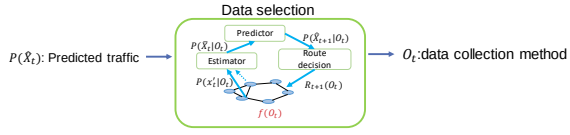
[6] T. Otoshi, Y. Ohsita, M. Murata, Y. Takahashi, K. Ishibashi, K. Shiomoto, and T. Hashimoto, "Traffic engineering based on stochastic model predictive control for uncertain traffic change," in Proceedings of The Seventh IFIP/IEEE International Workshop on Management of the Future Internet, May 2015.



# Decision Maker – Data Selection

- Role
  - Deciding which data to collect at next time
  - Considering how the new data affects on other processes

Data selection




- Calculation

$$minimize: E_{P(\hat{X}_{t+1})P(x'_t|O_t)}[f(X_{t+1}, R_{t+1}(x'_t, O_t))]$$
$$subject\ to: C(O_t) \leq W$$

cost : delay, loss, etc.
observation cost: bandwidth



# Summary and Future work

- Summary
  - Problem of existing approach in TE
    - Traffic uncertainty is separately tackled by different processes
    - Integrating the different processes is not completely achieved
  - Our proposal
    - Establishing a Bayesian framework of TE to handle the uncertainty
    - Considering how the decision affects the other processes in decision making

- Future work
  - Implementing the proposed framework with particular methods
    - Especially data selection
  - Evaluation for the effectiveness of the proposed framework