Real-time Adaptive Traffic Management

Kevin Tang
Cornell University
June 20, 2016

Goals

- Reliability:
  - Detection of fault conditions
  - Response to failure in the network
  - Network-wide reconvergence
- Performance and Efficiency:
  - Loss rate
  - Latency
  - Jitter
  - Link utilization

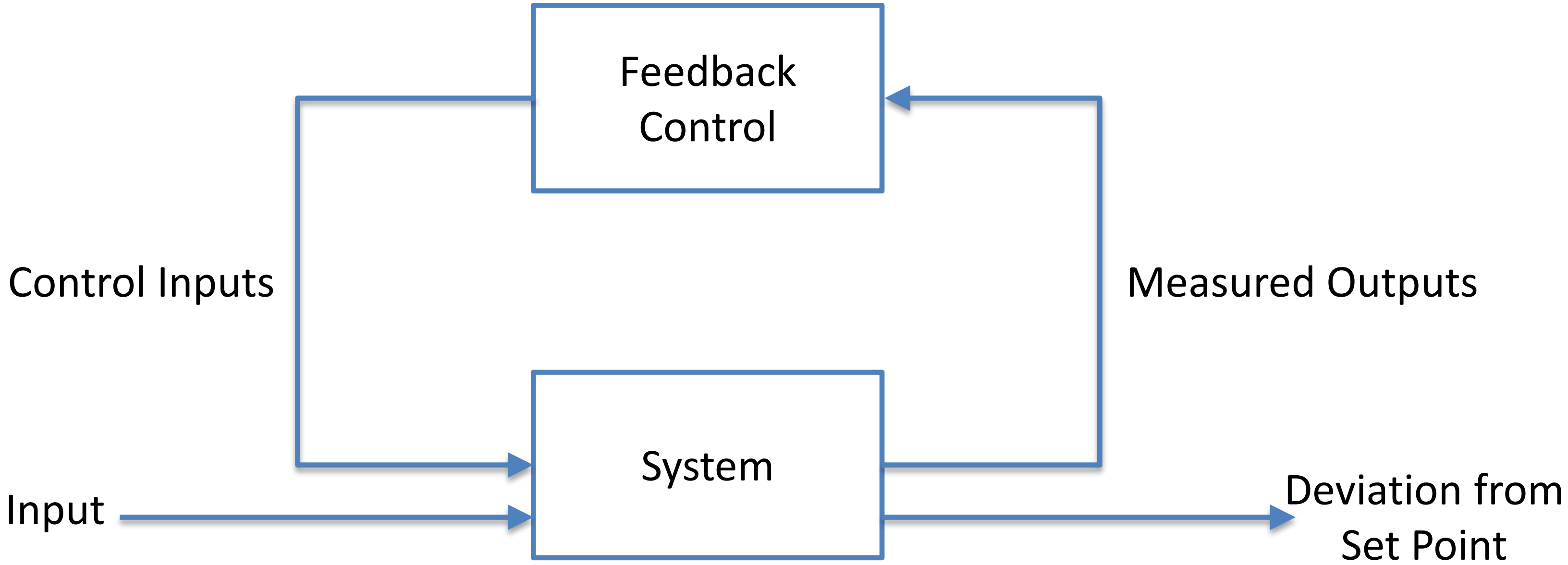
Approaches

- Static: significantly over-provisioning, huge redundancy
  - Conservative
  - Low average resource utilization

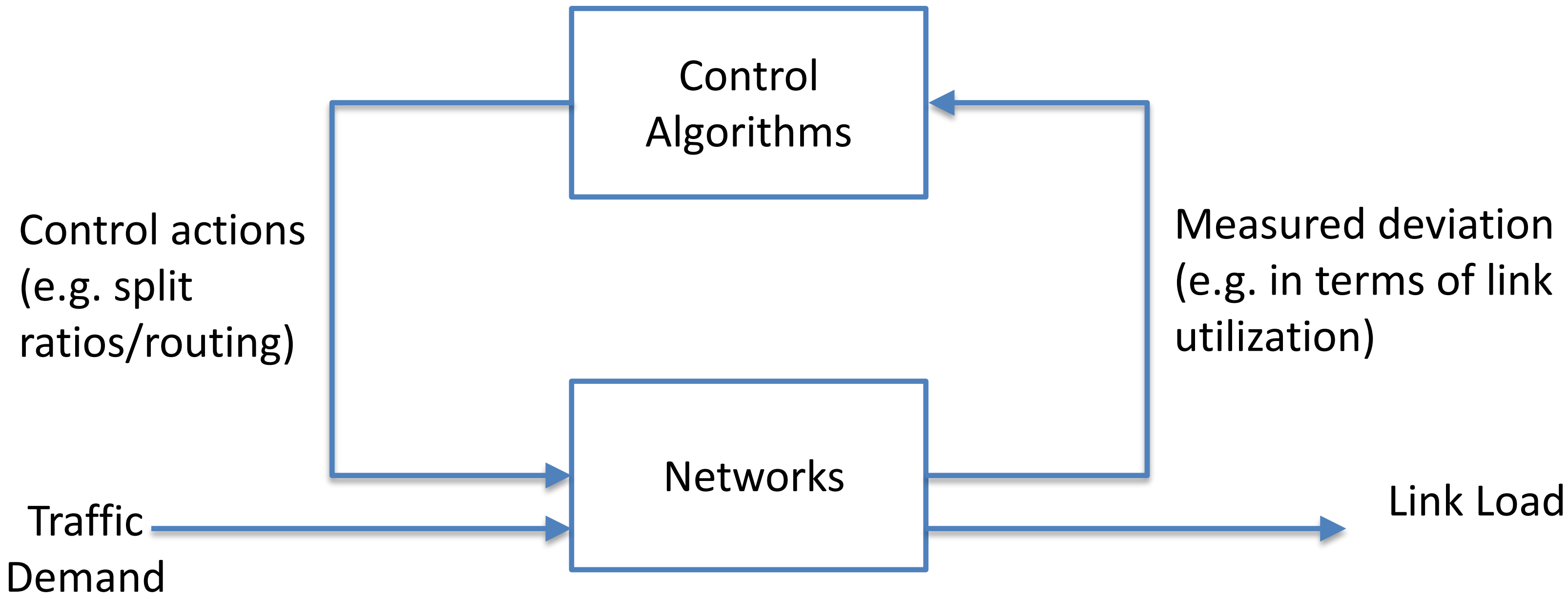
"WAN bandwidth remains a constrained resource that is economically infeasible to substantially overprovision" ---- BwE paper from Google, Sigcomm 2015

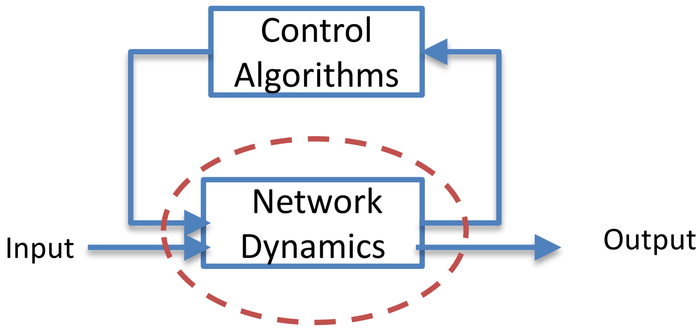
- Responsive: real-time adaptive traffic management
  - Update network configurations at a fast timescale
  - Best handle current demand given resource supply available
  - Adaptively balance the load among multiple paths
  - Adaptively use rate control to coordinate among different buffers

Feedback Control System



Feedback Control System





Modeling of Dynamics

- Level I: Static with out delay

$$y(t) = \alpha\ (t)x(t)$$

- Level II: Delay is included

$$y(t) = \alpha(t)x(t-\tau)$$

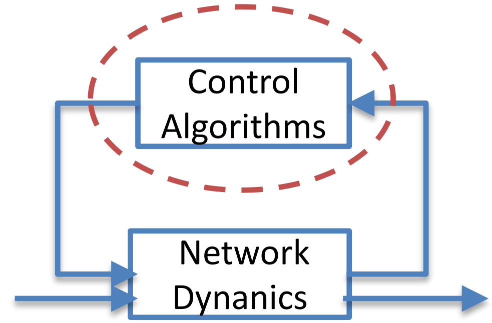
- Level III: A very detailed dynamic model at fast timescale

$$\dot{B}_l(t) = \left(\frac{f_l(t)-c_l}{c_l}\right)^{+}_{B_l(t)} = \begin{cases} \frac{f_l(t)-c_l}{c_l}, & B_l(t) > 0 \\ max\left(0, \frac{f_l(t)-c_l}{c_l}\right), & B_l(t) = 0 \end{cases}$$

$$g_l(t) = f_l(t) - (f_l(t)-c_l)^{+}_{B_l(t)} = \begin{cases} c_l, & B_l(t) > 0 \\ max(f_l(t), c_l), & B_l(t) = 0 \end{cases}$$

$$\sum_p g_{lp}(t) = g_l(t), \quad g_{kp}(t-t_k-t_v) = f_{lp}(t), \quad \sum_p f_{lp}(t) = f_l(t)$$

Control Algorithms



- MPLS: Path-based –
  - MATE: based on an estimate of LSP lengths by averaging over the past values (A. Elwalid et al 2001)

$$x_s(t+1) = [x_s(t) - \gamma\lambda_s(t)]^+$$
$$\hat{x}^l(t) = \sum_{t'=t-t_0}^{t} \sum_s \sum_{l\in p, p\in P_s} a_{lsp}(t',t)\, x_{sp}(t'), \sum_{t'=t-t_0}^{t} a_{lsp}(t',t) = 1$$
$$\lambda_{sp}(t) = \sum_{t'=t-t_0}^{t} \sum_{l\in p} b_{lsp}(t',t)\, C_l'\big(\hat{x}^l(t')\big), \quad \sum_{t'=t-t_0}^{t} b_{lsp}(t',t) = 1$$

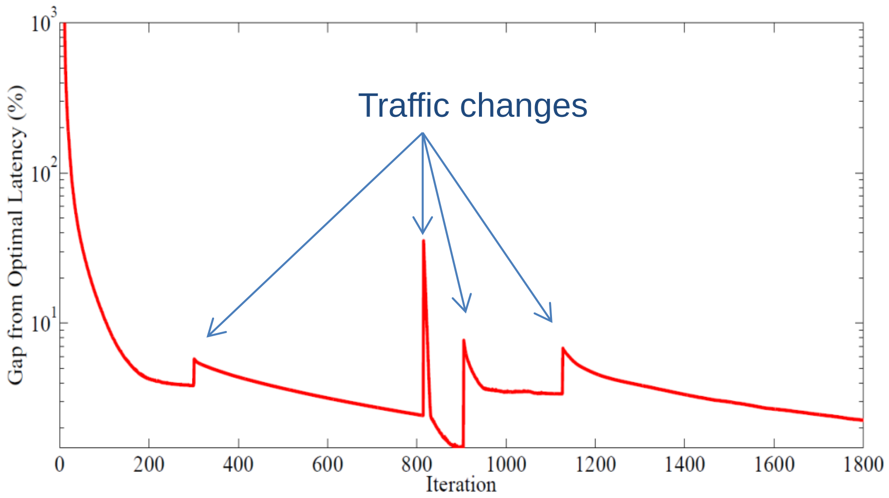
  - TeXCP: calculate new split ratios based on normalized average utilization (S. Kandula et al 2005)

$$\Delta x_{sp} = \begin{cases} \frac{r_{sp}}{\sum_{p'} r_{sp'}}(\bar{u}_s - u_{sp}), & u_{sp} > u_{min} \\ \frac{r_{sp}}{\sum_{p'} r_{sp'}}(\bar{u}_s - u_{sp}) + \epsilon, & u_{sp} = u_{min} \end{cases}$$

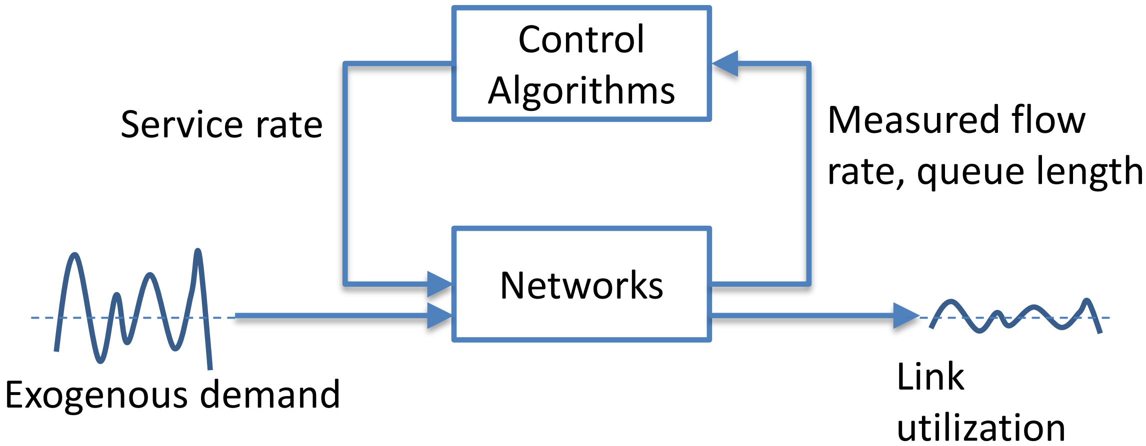
- IP: Hop-by-hop -- HALO: calculate split ratios based on current link rates (N. Michael et al 2015)

$$\dot{\alpha}^t_{u,v} = \begin{cases} -\frac{\alpha^t_{u,v}\delta}{\eta^t_u r^t_u}, & (u,v) \text{ not on shortest path} \\ -\sum_{v'\neq v} \dot{\alpha}^t_{u,v'}, & \text{otherwise} \end{cases}$$

Case Study 1: HALO - Hop-by-hop Adaptive Link-state Optimal

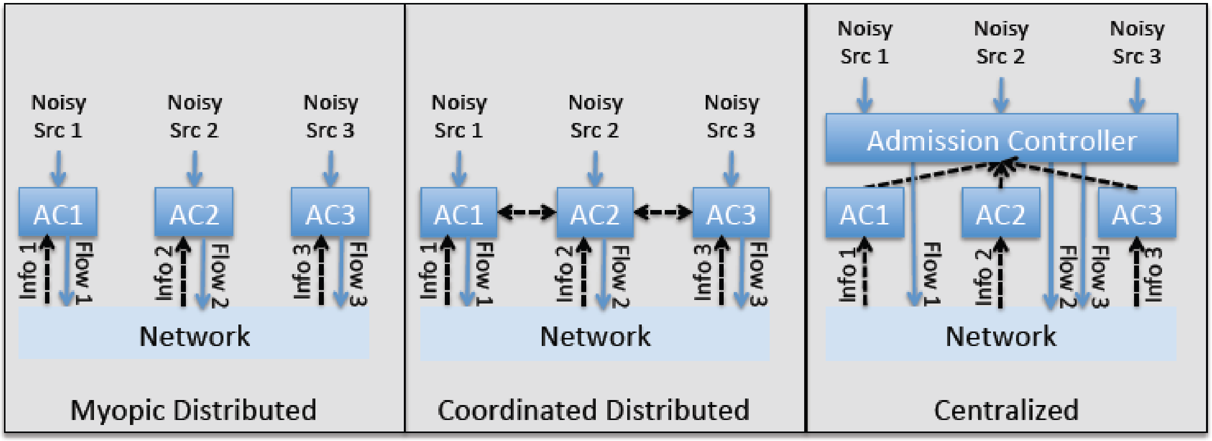


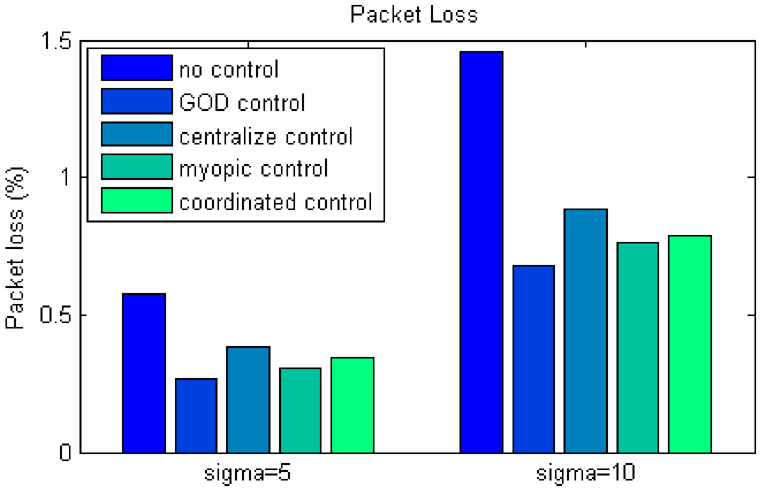
Case Study 2: HFTraC - High Frequency Traffic Control



	Traffic Engineering	HFTraC
Input	Average of Demand	Fluctuation of Demand
Output	Flow Routes	Service Rate
Resource	Link Bandwidth	Node Buffer
Timescale	Minutes to Hours	RTT (Milliseconds)

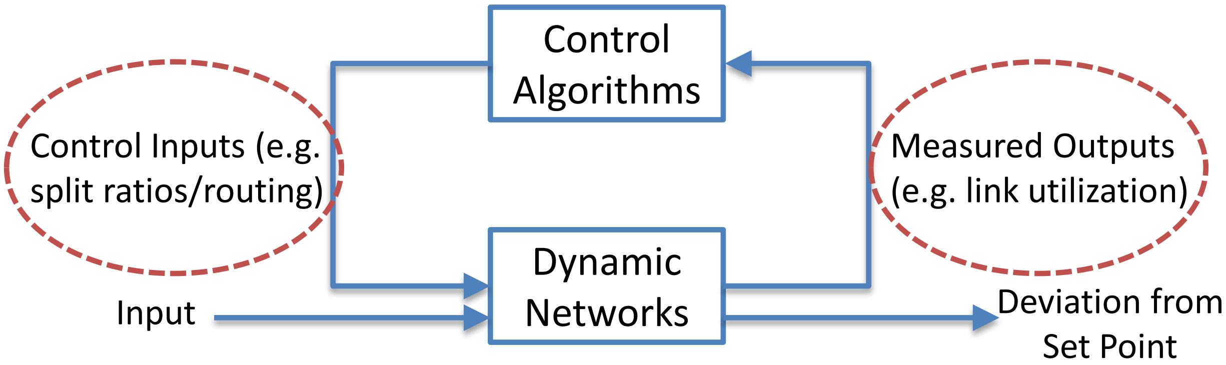
A good chance to have some rigorous discussion on architectures





Some Future Questions

- How to measure?
  - Time interval
  - Accuracy
  - Overhead
- How to control?
  - Granularity
  - Over commodity switches



- Good Control law with delay: develop proper (approximate) dynamics model, fast tracking with stability margin (both can be quantified)

It is time to bring real-time automatic control to network traffic management!