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On Attractor Perturbation through System-inherent Fluctuations and its Response

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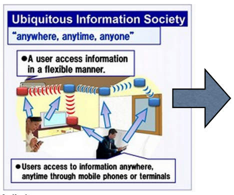
Ambient Networks

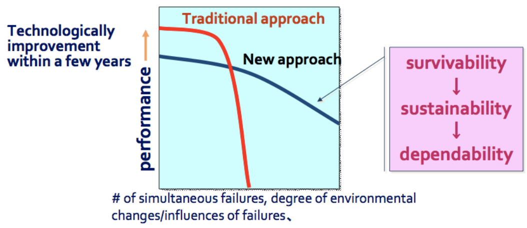
- In future networks we will have ubiquitous connectivity:
  - Increased diversity in (wirelessly connected) devices and services
  - Requirement of efficient cooperation and interaction of devices
  - Concept of "ambient networks" makes the device adapt to the situation and user's preferences



Network Traffic is not "Smooth"!

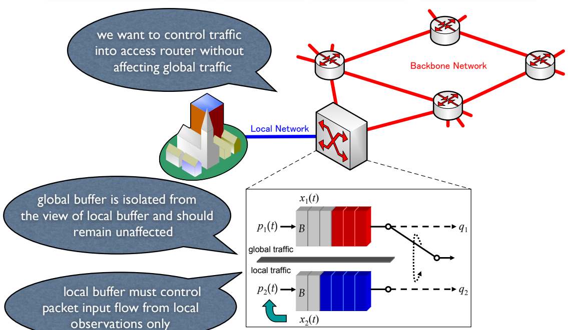
- However, network traffic is not smooth because:
  - Devices and services have different bandwidth requirements (browsing, VoIP, multimedia streaming, ...)
  - Background traffic from other users and external protocols (e.g. BGP routing updates) causes fluctuations in the perceived performance
- Therefore, it is necessary to apply new mechanisms that deviate from conventional teletraffic metrics in designing ambient network architectures
  - Focus is on including **robustness** and **adaptability** with traditional QoS measures, such as latency, jitter, etc.
  - We can take inspiration from dynamics found in biological systems

Why Use Robustness as Measure?

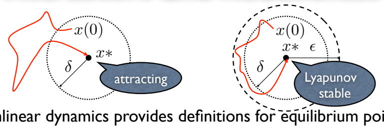


Self-organizing networks based on bio-inspired approaches
Principles: interaction, feedback, randomness

Considered Access Router Scenario

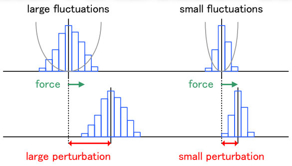


Attractors and Robustness



- Nonlinear dynamics provides definitions for equilibrium point $x*$:
  - $x*$ is **attracting** if any trajectory starting close to $x*$ will eventually converge to $x*$
  - $x*$ is **Lyapunov stable**, if all trajectories starting sufficiently close to $x*$ remain close to it
  - $x*$ is **asymptotically stable**, if it is both attracting and Lyapunov stable
- An **attractor** is an invariant closed set, which attracts all trajectories that start sufficiently near to it (basin of attractor)

Attractor Perturbation Concept



- Relationship between fluctuation and its response (Sato et al. 2003)
- System has measurable **variable** x (protein concentration) and **parameter** a (DNA sequence)
- Applying a **force** ($a \rightarrow a+\Delta a$) to the system results in a linear perturbation of μ (mean of x) proportional to σ^2 (variance of x before applying the force):

$$\mu_{a+\Delta a} - \mu_a = b\,\Delta a\,\sigma_a^2$$

Attractors vs. Distributions?

- Simple dynamic equation with attractor at x_0 given by

$$\frac{d}{dt}x(t) = -\rho\,(x(t) - x_0) + \eta(t)$$

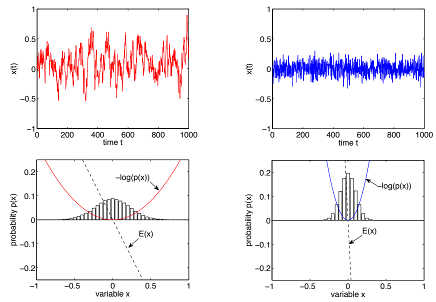
- The term ρ is the "softness" of control in the system and η is the constant background noise (Gaussian) with variance $2D$
- Noise follows a Gaussian distribution with pdf

$$p(x) = p(x_0)\exp\left(-\frac{(x-x_0)^2}{2\,\sigma^2}\right) \quad \text{with} \quad p(x_0) = \frac{1}{\sqrt{2\,\pi\,\sigma^2}}$$

- Taking the negative logarithm and deriving over x results in the energy potential function

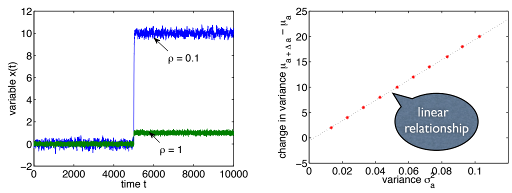
$$-\log(p(x)) = \frac{(x-x_0)^2}{2\,\sigma^2} - \log(p(x_0)) \quad \Rightarrow \quad E(x) = -\frac{\rho\,(x-x_0)}{D}$$

Influence of Control on Fluctuations



"Loose" control ($\rho = 0.1$) "Tight" control ($\rho = 1$)

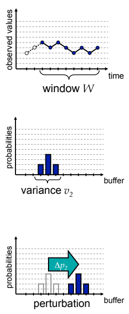
Dynamics of 1-Dimensional System



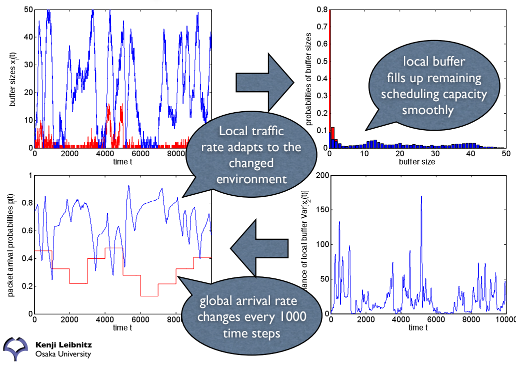
- Applying same force to system with different internal fluctuations results in different degrees of perturbations!
- So if we know the fluctuations (from measurements), we can directly compute the force necessary for "pushing" the system to a favorable operating region

Proposed Control Scheme

- Control of local arrival probabilities $p_2(t)$, only by measuring time series $x_2(t\text{-}W), \ldots, x_2(t)$ in a sliding window W
- Calculate variance over measured values as: $v_2(t) = \mathrm{Var}[x_2(t\text{-}W),\ldots,x_2(t)]$
- Update local probability $p_2(t)$ as follows:
  - Direction of adaptation: $\delta(t) = \mathrm{sign}(B/2 - x_2(t))$
  - Strength of adaptation: $s(t) = f(v_2(t))$ utilizes linear relationship of variance
- "Force" is adapted as: $p_2(t{+}1) = p_2(t) + \delta(t)\,s(t)$



Experimental Results



Conclusion

- Ambient networks are composed of many diverse devices and services → many internal fluctuations
- Application of biologically inspired concept to adaptive network control to improve robustness
- Attractor perturbation permits to compute the force necessary to "push" the system state to a good solution
- Simple example was shown for controlling local buffer at gateway router based on local information only
- Applicability of attractor perturbation to other applications in ambient networks are being studied
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