DOI: http://dx.doi.org/10.7551/978-0-262-33027-5-ch020

Dynamic Homeostasis in Packet Switching Networks

Mizuki Oka[1], Hirotake Abe[1] and Takashi Ikegami[2]
[1]Department of Computer Science, University of Tsukuba, Japan,
[2]Graduate School of Arts and Sciences, The University of Tokyo, Japan
mizuki@cs.tsukuba.ac.jp

Abstract

This is an extended abstract of a recent Adaptive Behavior paper (Oka et al., 2014) in which we investigate the homeostatic characteristics of the Internet using a packet switching network (PSN), the fundamental architecture of the Internet. We show that the adaptation introduced in PSN is interpretable as the self-organization of complex itinerant behavior among many quasi-attracting states and provides an example of Ashby's Law of Requisite Variety in action.

A Robust Yet Fragile Nature While the Internet exhibits a great deal of robustness, its fragility, too, has been discussed. Robustness refers to a generic property of stability against perturbation. Fragility, despite common perception, is not an opposite property. For example, in order to take in environmental information, a system should have fragility built into it. Taking in environmental information means lowering entropy of some sort, and doing this requires instability. In fact, the robustness of the Internet is derived from its fragility and it is called Robust Yet Fragile (RYF) characteristics of the Internet (Doyle et al., 2005).

A system would not function if the entire system became unstable due to the incorporation of fragility, thus some type of balancing mechanism such as *homeostasis* is required. How can the RYF property of the Internet can be explained in terms of homeostasis, is the theme of this research. We argue that this is made possible because the dynamical systems of the congestion window size (i.e., the maximum number of packets to be sent per unit of time from each computer), satisfies the Ashby's Law of Requisite Variety (Ashby, 1958). The law states that an active controller requires at least as many states as exist in the controlled system in order to be stable. It also attempts to demonstrate that the effective degrees of freedom of the system change adaptively in response to external perturbations in order to control a system.

To quantitatively study this notion of homeostasis using the Internet, we examine a PSN simulator called ns-2 and discuss its adaptability and robustness. PSNs constitute the fundamental mechanisms of the Internet, which provide adaptive dynamics to the system.

Results and Main Messages The complex dynamics of packet transmission are controlled by the congestion window size (cwnd), whose temporal behaviors change from fixed points to periodic, and finally to chaotic as the number of transmitted packets increases. This transition from a regular to chaotic state corresponds to where the congestion emerges. We further define the throughput as the overall percentage of successfully sent packets in the PSNs to evaluate the RYF nature of PSNs. By externally sending additional packets to perturb the system, we compared the dynamic state of PSNs and the throughput. A dynamical state of a PSN is defined by projecting the cwnd time series onto a reduced-feature vector space using principal component analysis.

As the input ratio increases, the number of dimensions required to reconstruct the original time series increases, leading to an increase in the number of system dimensions, which shows a state transition from a regular to chaotic. When the system's congestion increases, the system begins to generate a large number of states. Beyond a critical input ratio, the cwnd dynamic has no more attracting states. This analysis has been confirmed by applying the perturbation; there is almost no difference in the throughputs between with or without perturbations. The number of dropped packets increases as the input to the system increases due to the congestion, yet the throughput is kept high. This shows the robustness of the PSN system. We claim that this is the realization of Ashby's Law of Requisite Variety in action and RYF is confirmed at the level of PSNs.

Acknowledgements This work was supported by the Japan Society for the Promotion of Science Grant-in-Aid for Young Scientists (#25730184), partially by Grant-in-Aid for Scientific Research on Innovative Areas (#24120704), and partially by Grant-in-Aid for Scientific Research on Innovative Areas (#24650117). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

References

Ashby, R. (1958). Requisite variety and its implications for the control of complex systems. *Cybernetica*, 1(2):83–99.

Doyle, J. C., Alderson, D. L., Li, L., Low, S., Roughan, M., Tanaka, S. S. R., and Willinger, W. (2005). The robust yet fragile nature of the internet. *PNAS*, 102:14497–14502.

Oka, M., Abe, H., and Ikegami, T. (2014). Dynamic homeostasis in packet switching networks. *Adaptive Behavior*, 23(1):50–53.

Mizuki Oka, Hirotake Abe, Takashi Ikegami (2015) Dynamic Homeostasis in Packet Switching Networks. Proceedings of the European Conference on Artificial Life 2015, p. 80