# Developing Predictors of Failure Regimes in Real Communication Networks


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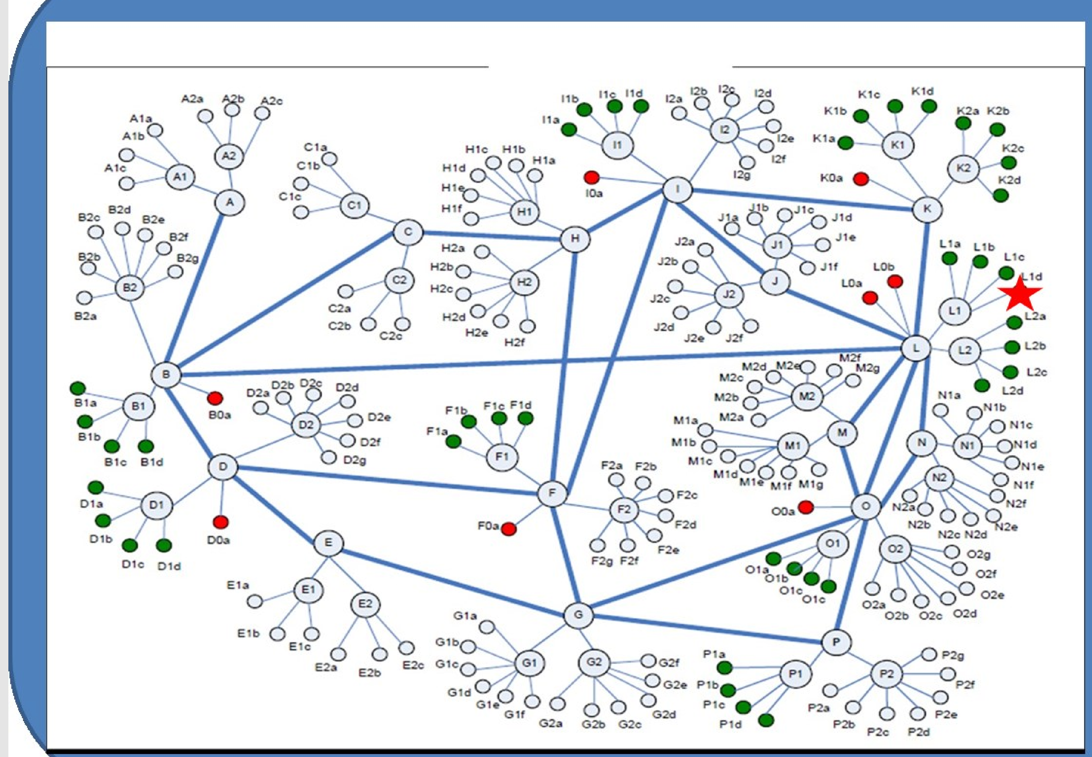
**Develop (1) design-time techniques for assessing vulnerabilities in networks being constructed thus improving reliability; and (2) run-time methods for predicting onset of congestion failure by detecting precursor signals prior to collapse of deployed networks. This will help industry to better build, monitor, and control networks.**

**APPROACH:**

- **Developed and evaluated five potential predictors of congestion failure in routers under: (1) *increasing load,* where packet injection, *p*, is raised to 300 packets / ms in the network; and (2) *steady load*, where *p* is held at 10 packets / ms. Results were simulated in a 218-router, single-ISP network with 258 158 nodes and realistic factors, such as TCP and variable router speeds.**
- **Detrended by subtracting system in steady load and smooth curves.**
- **For each router, computed if a precursor signal was real (i.e., not noise).**
- **If precursor signal was declared real, alarm could be raised.**



**Single-ISP router topology with 218 routers in which measures were developed and evaluated. Router L1c (see below) is starred.**

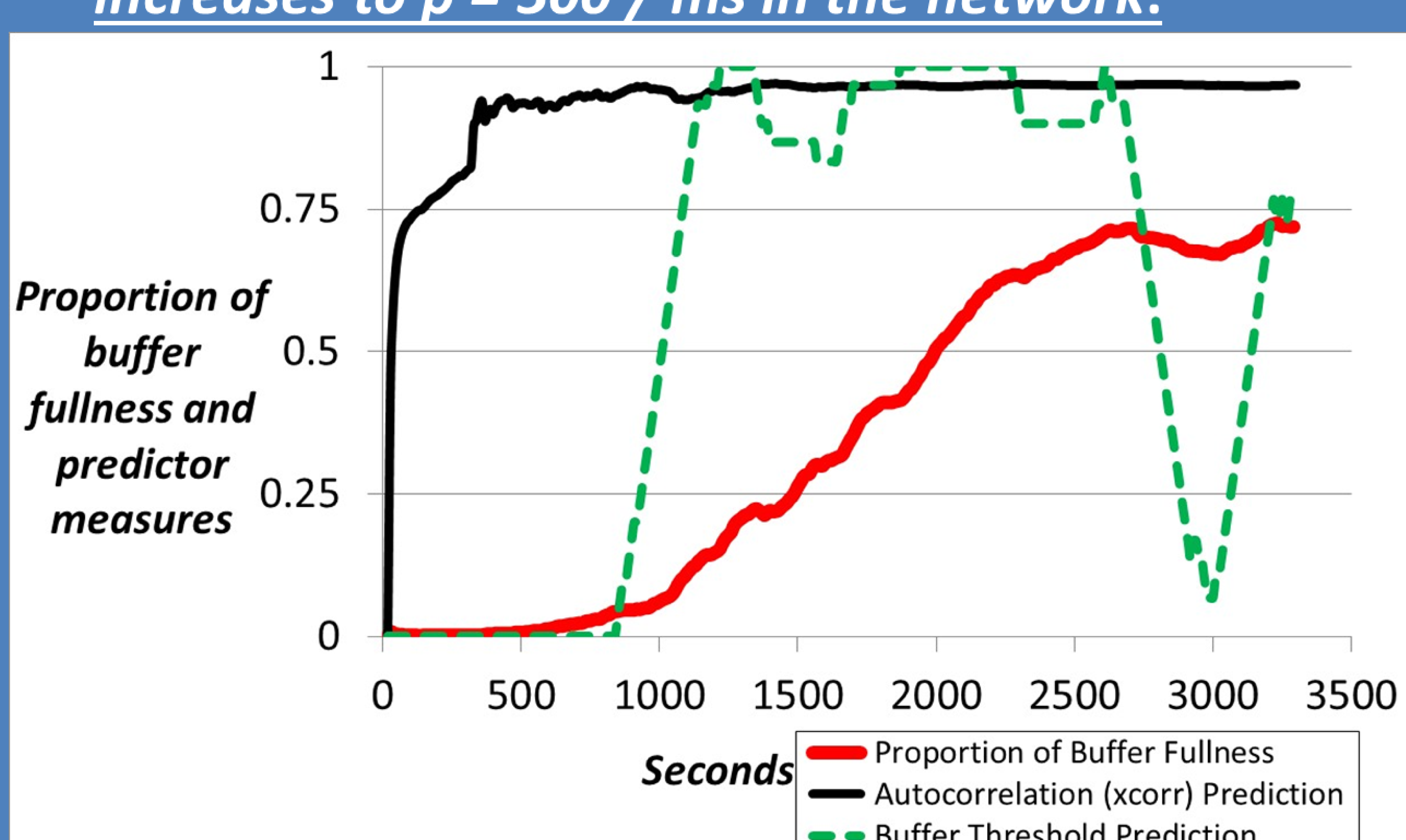
**RESULTS:** **As the packet injection rate *p* increased, packet queues at routers increased and transmission delays increased, degrading network performance. A *critical point* was said to be approached and a *phase transition* to a congested state occurred. When *p* was held steady, packet queues remained low and the phase transition never occurred. Of the five methods tested in the realistic, single-ISP network under both scenarios, three methods based on measuring the fullness of the 218 router buffers made successful predictions from 94.7% to 100%. However, two method (including Autocorrelation) predicted correctly at a lower rate, from 45.9% to 75.7%. For full results, see:** C. Dabrowski. And K. Mills. Evaluating Predictors of Congestion Collapse in Communications Networks. Submitted to *NOMS 2017,* October, 2017.

**EXAMPLE:** **Consider two potential predictors of congestion in router L1c: (a) autocorrelation, used as a predictor in many domains, measured by Matlab xcorr, and (b) a buffer threshold method which signals an alarm when the router packet queue reaches 25% of the router buffer (minus the router queue at steady load). Both Autocorrelation (a) and Buffer Threshold (b) alarm before router L1c congests (below left), but only Buffer Threshold *correctly* is zero and does not alarm when there is no congestion (below right). However, Autocorrelation (a) also alarms *incorrectly* and yields a false positive, when there is no congestion (right).**

## Predicting congestion in router L1c <u>*as p* *increases to p = 300 / ms in the network.*</u>

Buffer of router L1c fills as p is raised.

*Proportion of buffer fullness and predictor measures*



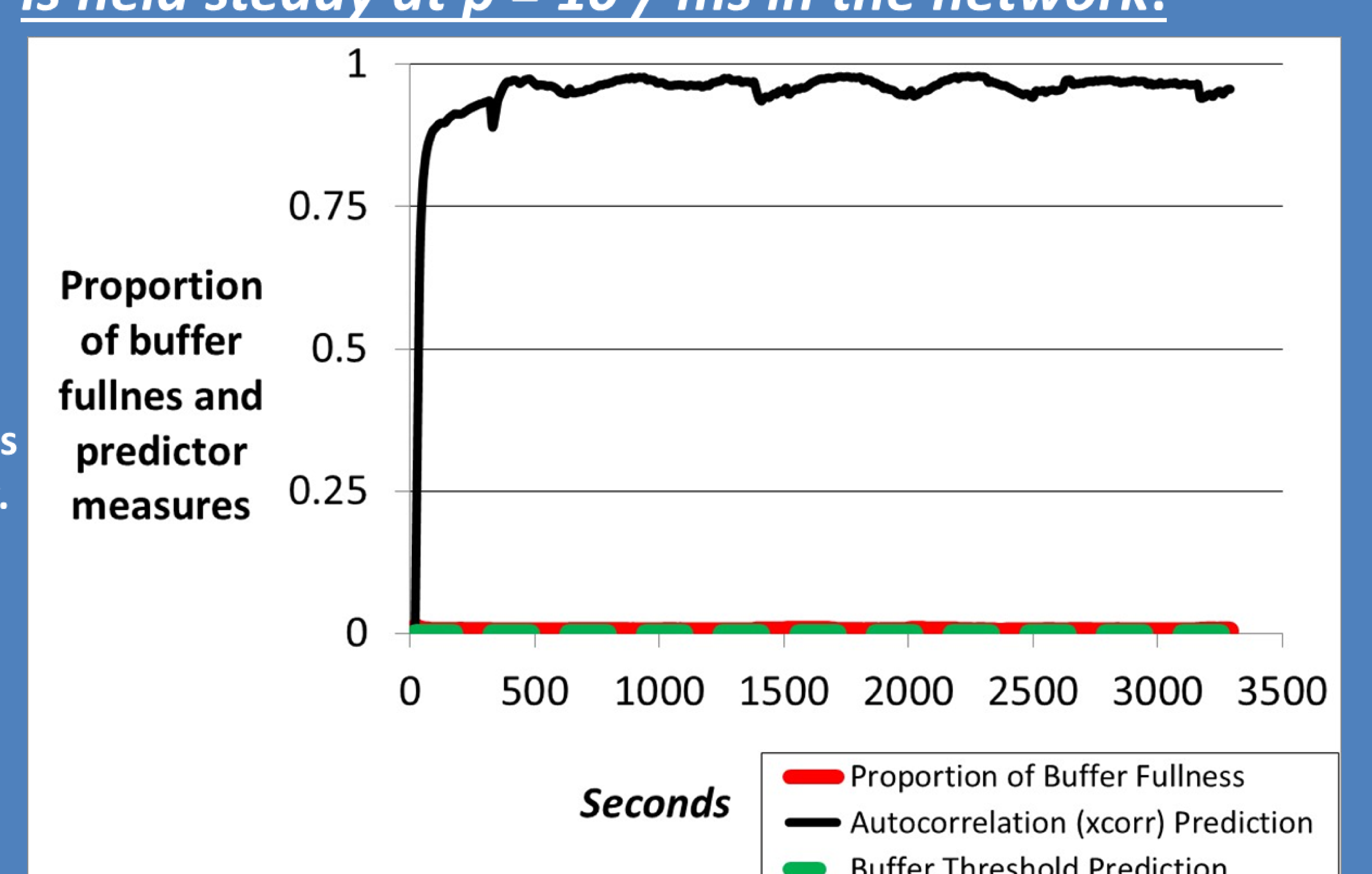

<u>Both Autocorrelation and Buffer Threshold successfully predict congestion when *p* is raised.</u>

*A sliding window of p=30 (750s) is used in all plots

## Predicting congestion in router L1c <u>*as p* *Is held steady at p = 10 / ms in the network.*</u>

Buffer of router L1c remains empty as p is held steady.

Proportion of buffer fullnes and predictor measures




<u>Buffer Threshold successfully predicts lack of congestion when *p* held steady. However, Autocorrelation signals nevertheless, because it measures *self-similarity*.</u>

*A sliding window of p=30 (750s) is used in all plots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K. Mills, J. Filliben, D. Cho, E. Schwartz and D. Genin. <u>Study of Proposed Internet Congestion Control Mechanisms</u>, NIST Special Publication 500-282, May 2010.

M. Scheffer, J. Bascompte, W. Brock, V. Brovkin, S. Carpenter, V. Dakos, H. Held, E. van Nes, M. Rietkerk, and G. Sugihara. Early warning signals for critical transitions. *Nature*. 461(53-59) 2009.

C. Dabrowski. Catastrophic Event Phenomena in Communication Networks: A Survey, *Computer Science Review*, 18(10-45), November 2015.


***http://www.nist.gov/itl/antd/emergent_behavior.cfm***