A FLOW-BASED ENTROPY CHARACTERIZATION OF A NATED NETWORK AND ITS APPLICATION ON INTRUSION DETECTION

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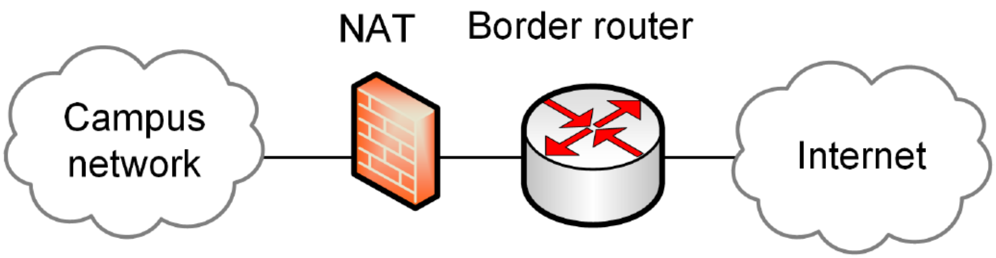
Agenda

- Motivation for a flow-based entropy characterization
- Overview of campus NATed networks
- Entropy of flow elements
- Results
- Conclusion

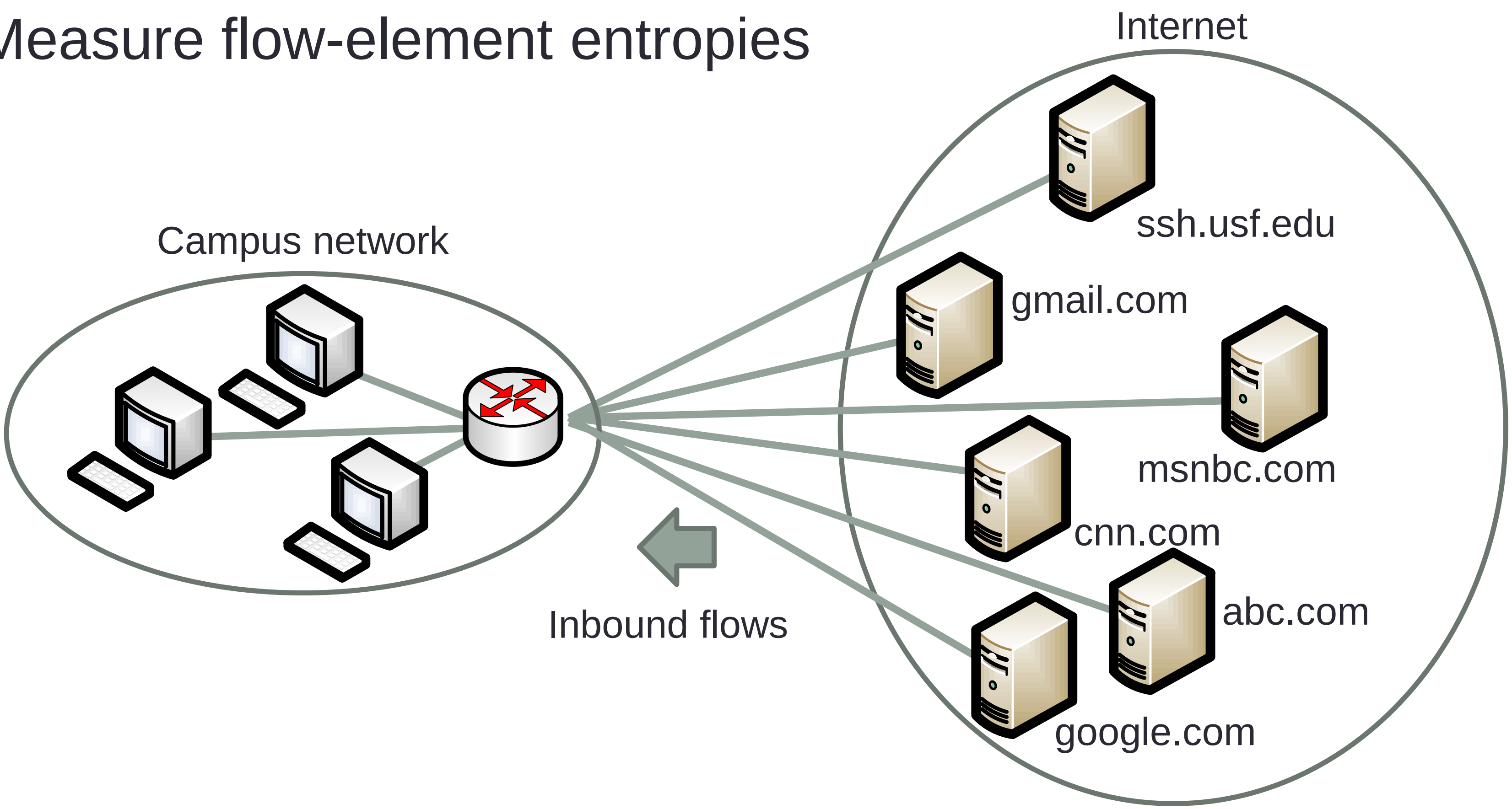
Motivation

- Most networks use Network Address Translation (NAT)
- Although NAT has been used since early 2000s, traffic behind NAT has not been characterized using entropy
- One approach for flow characterization is to measure the *randomness* or *uncertainty* of elements of a flow
- E.g., entropy of IP addresses, ports, and combinations
- Goal: characterize normal traffic behavior by using flow information only (no payload inspection) and entropy



Methodology

- A flow is uniquely identified by the external IP, campus IP, external port[1], campus port, protocol
- Measure flow-element entropies



1. Port refers to transport-layer port

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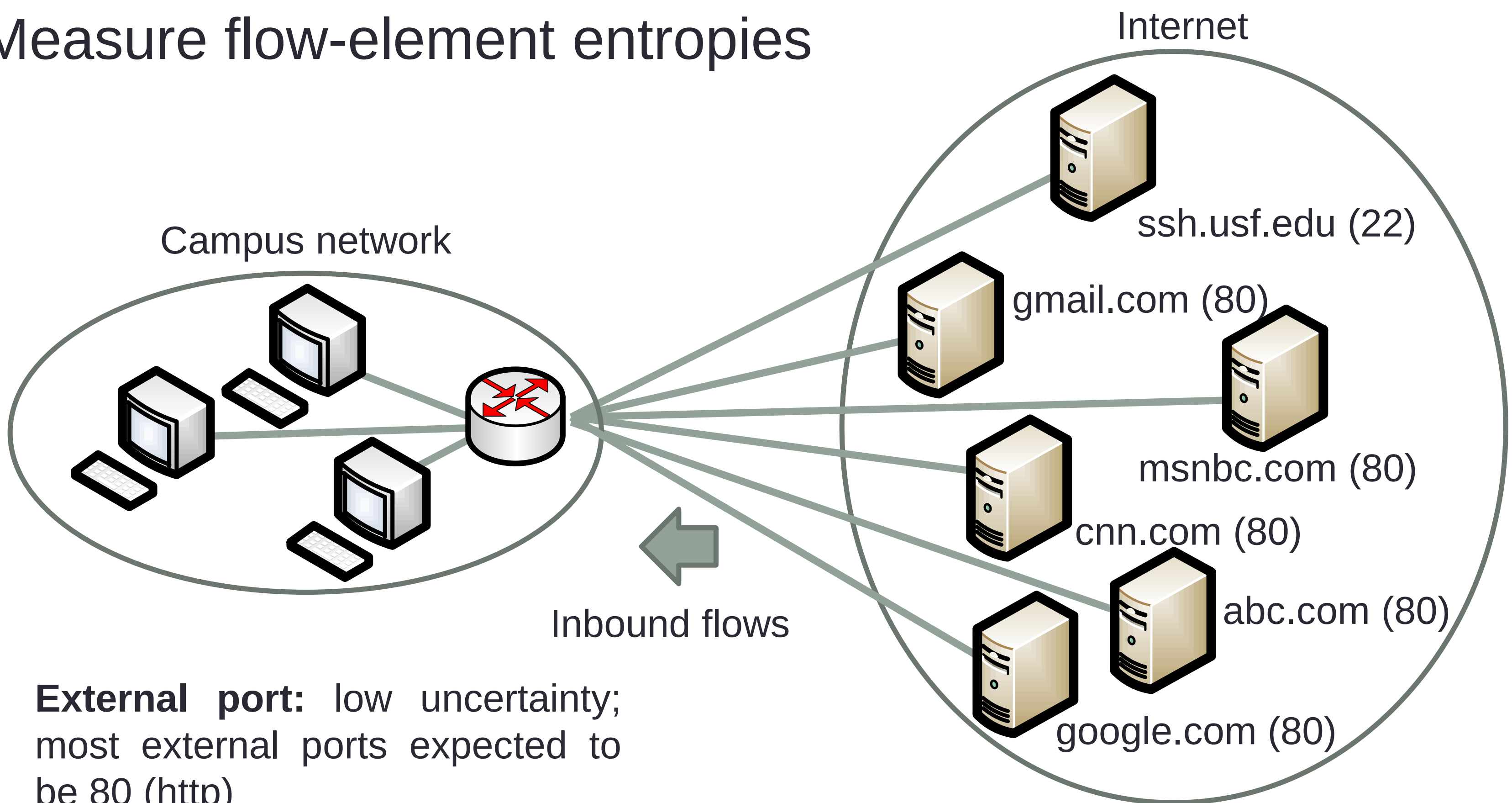
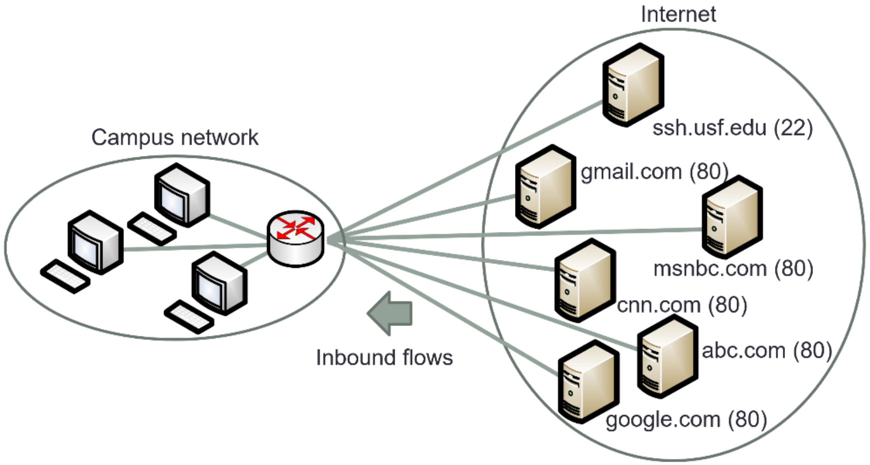


External port: low uncertainty; most external ports expected to be 80 (http)

Methodology

- Entropy provides a measure of randomness or uncertainty
- For a variable X, entropy of X = $\sum_{x \in X} p_x \log_2 \left(\frac{1}{p_x} \right)$
- For the previous port example, let *X* be the variable indicating the external port

$$X = \begin{cases} 80 \text{ with probability } p_1 = \frac{5}{6} \\ 22 \text{ with probability } p_2 = \frac{1}{6} \end{cases}$$



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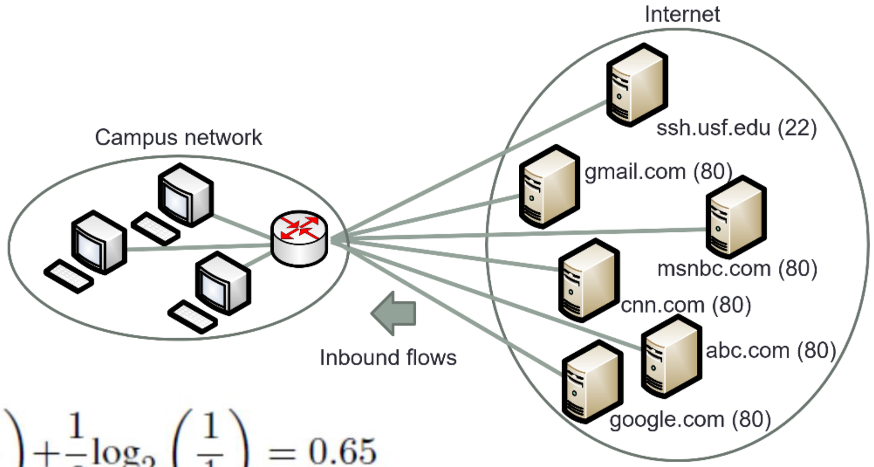
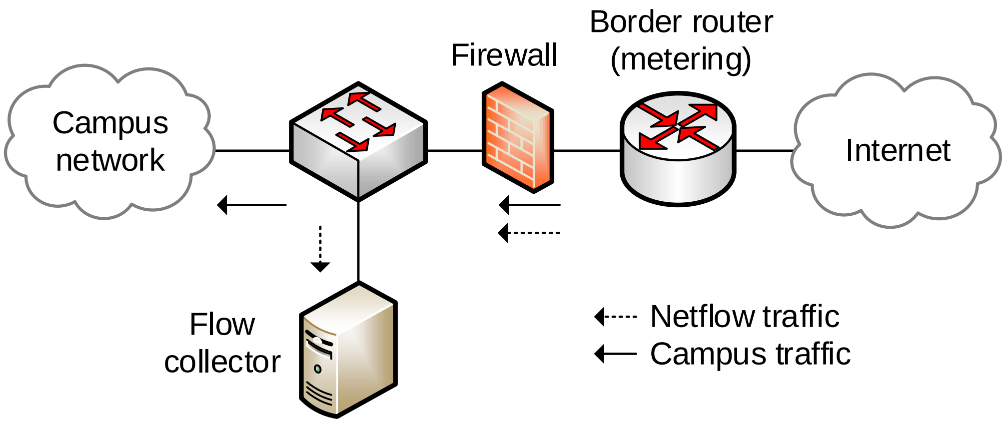


$$\text{Entropy External Port} = \sum_{i=1}^{2} p_i \log_2\left(\frac{1}{p_i}\right) = \frac{5}{6}\log_2\left(\frac{1}{\frac{5}{6}}\right) + \frac{1}{6}\log_2\left(\frac{1}{\frac{1}{6}}\right) = 0.65$$

Methodology

- Campus network with 15 buildings
- The collector organizes flow data in five-minute time slots
- Traffic data observed during a week is representative of the campus traffic



Methodology

- The entropy of a random variable *X* is:

$$H(X) = \sum_{i=1}^{N} p(x_i)\log_2\left(\frac{1}{p(x_i)}\right),$$

where $x_1, x_2, \ldots x_N$ is the range of values for *X*, and $p(x_i)$ is the probability that *X* takes the value x_i

- For each external (campus) IP address (port) x_i, the probability $p(x_i)$ is calculated as

$$p(x_i) = \frac{\text{Flows with } x_i \text{ as external (campus) IP addr. (port)}}{\text{Total number of flows}}$$

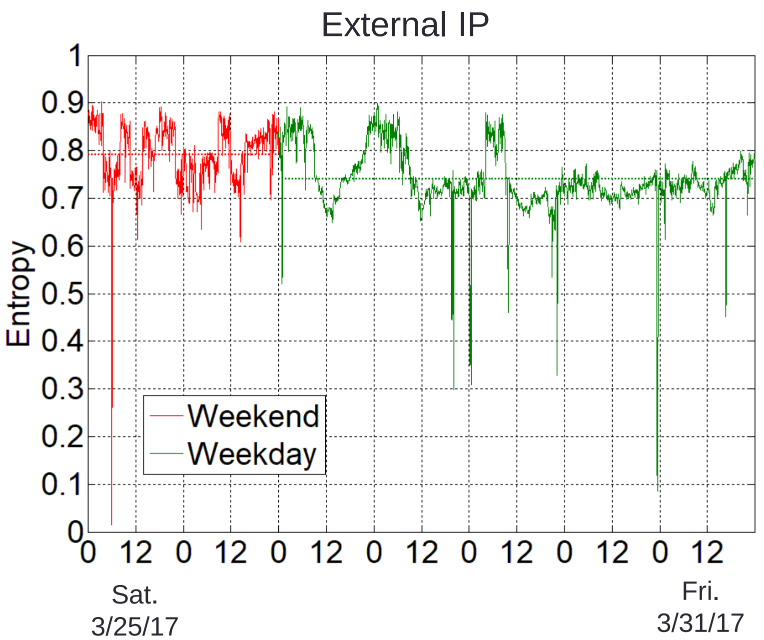
- Entropies are normalized to that of the uniform distribution

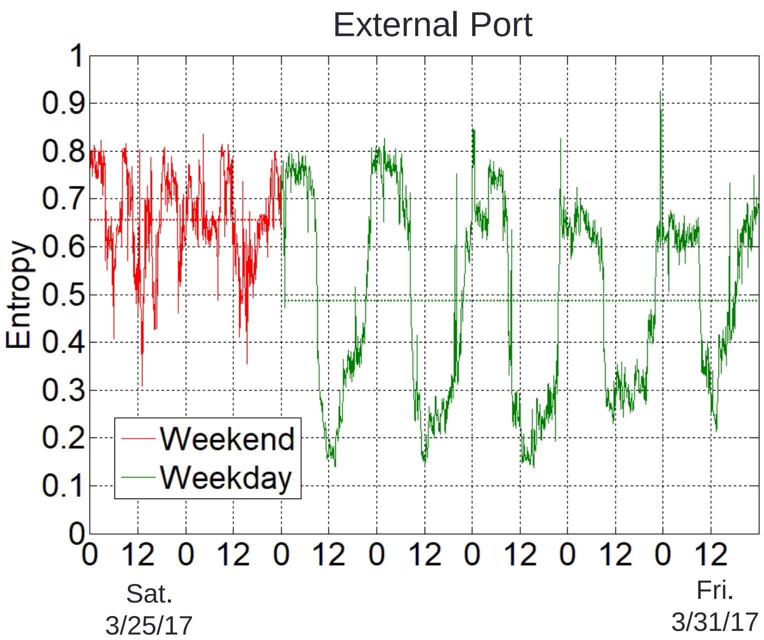
Methodology

- This paper also considers the entropy of the 3-tuple {external IP, campus IP, campus port}
- For a given 3-tuple x_i, the corresponding probability is calculated as

$$p(x_i) = \frac{\text{Flows with } x_i \text{ as 3-tuple}}{\text{Total number of flows}}$$

Results





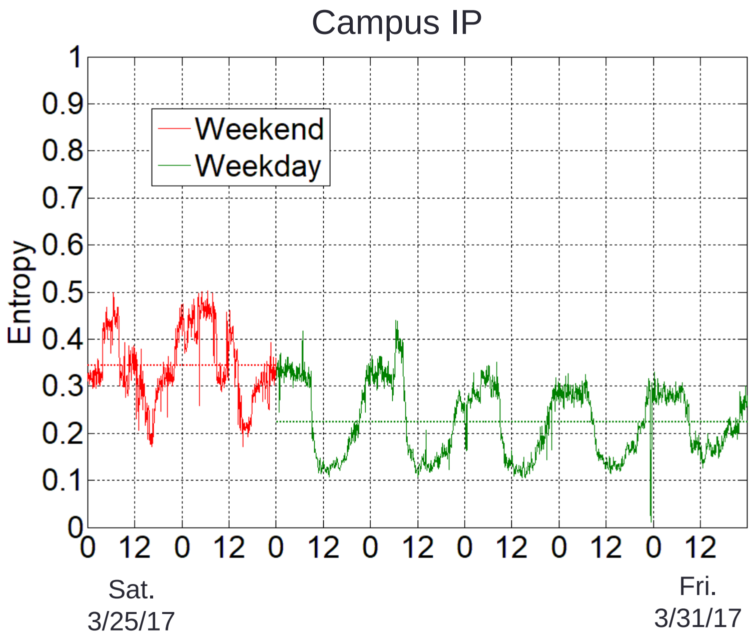
External IP

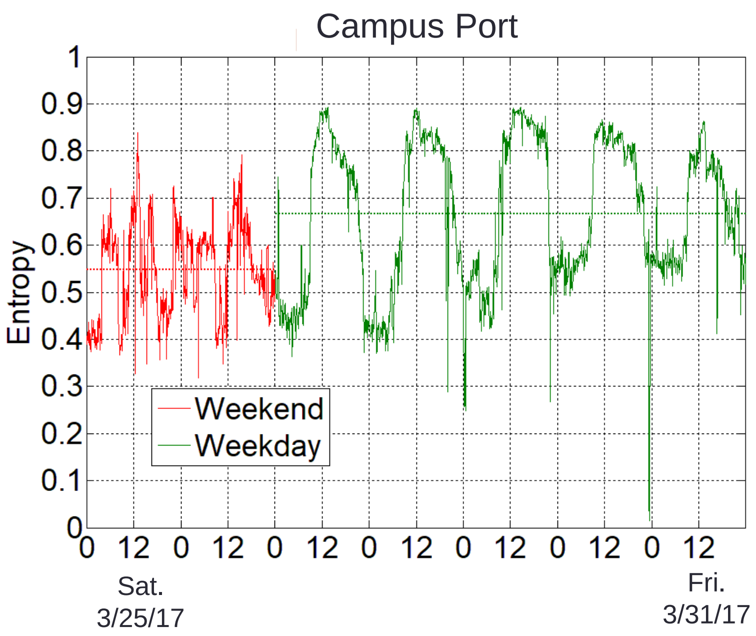
- In general, high entropy, ‘many’ external IP addresses
- External IPs dispersed in the Internet
- Abnormal low entropy points
- Entropy near zero (no uncertainty of the external IP address), or ‘very low’ level (few external IP addresses dominate the distribution)

External port

- Higher entropy during the night, weekends
- Low entropy during the day, noon
- Large volume of http flows when students are on campus (less uncertainty/entropy on external port)
- Abnormal high entropy points
- Entropy widely varies over ‘hours’ but not over very short time periods

Results





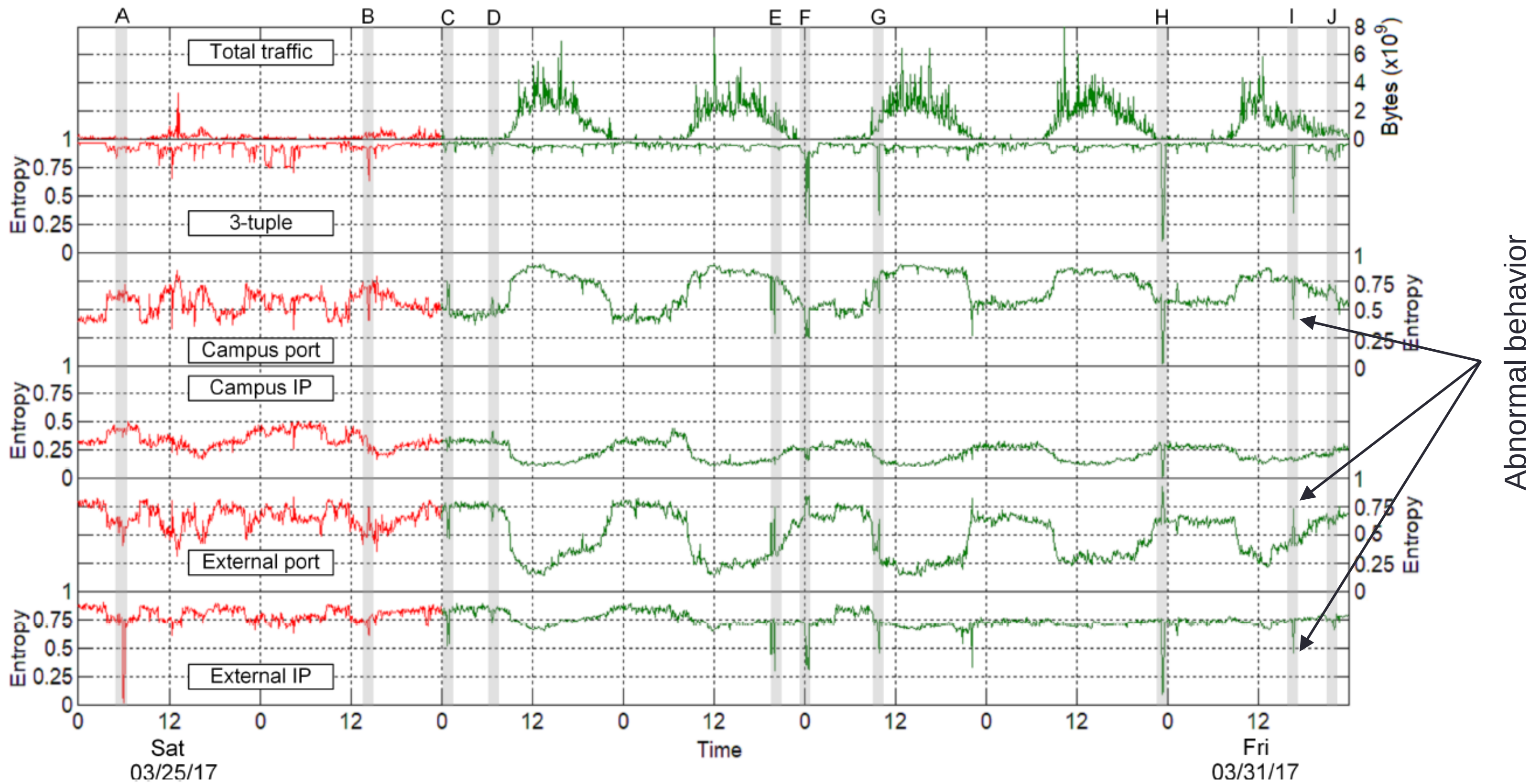
Campus IP

- In general, low entropy, 'few' IP addresses on campus
- A handful of public IP addresses used for regular Internet connectivity (NAT operation)
- Higher entropy on weekends and at night
- Lower entropy when students are on campus
- Entropy varies over 'hours' but not over very short time periods

Campus port

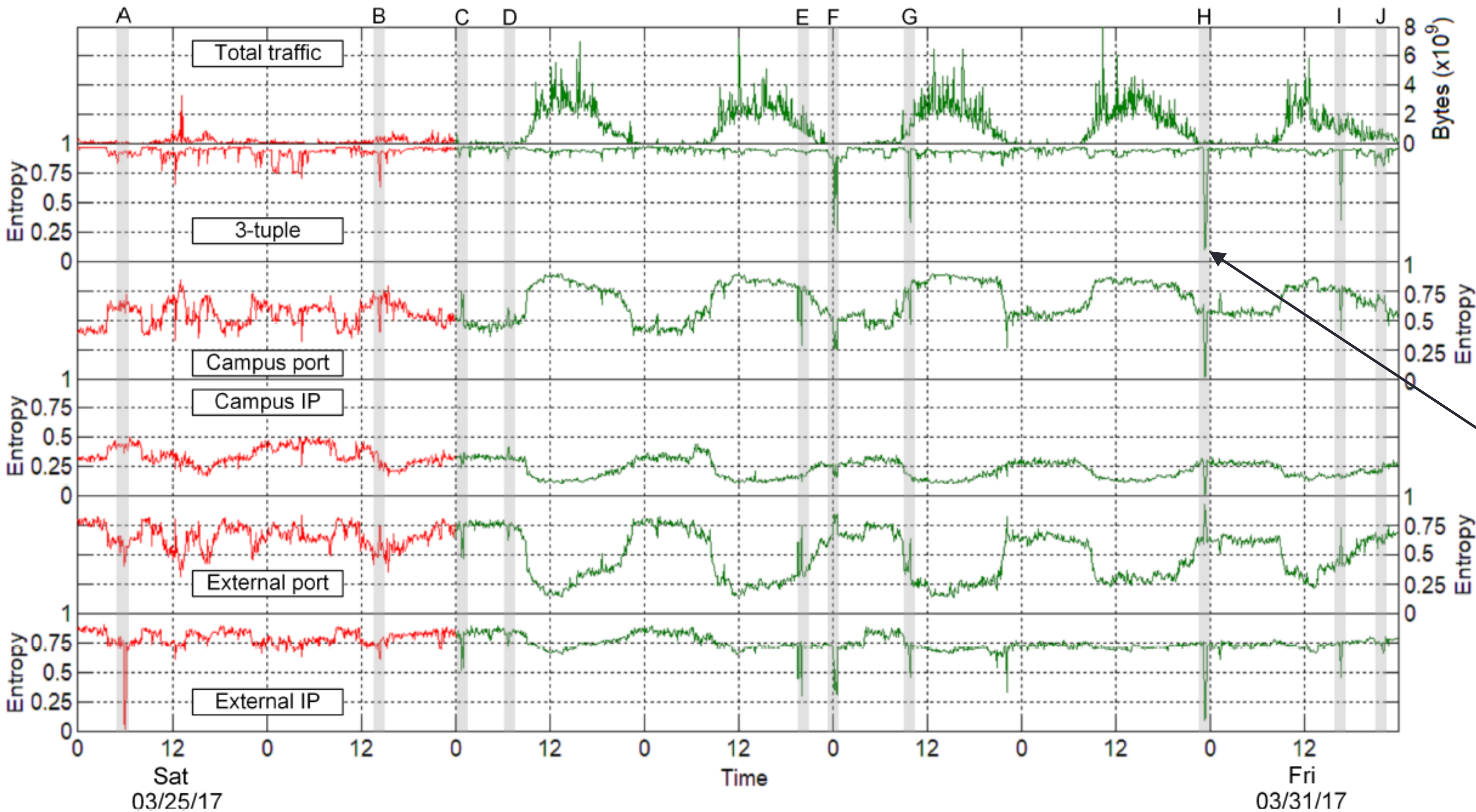
- Lower entropy at night
- High entropy (close to uniform distribution) at noon
- Dynamic / ephemeral ports used by browsers when students connect to the Internet
- Abnormal low entropy points
- Entropy widely varies over 'hours' but not over very short time periods

Results

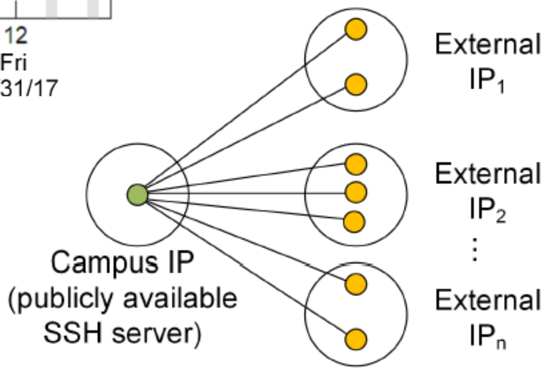


- Anomalies are detected by a single feature or by correlating multiple features
- E.g., event I: low campus port's entropy, high external port's entropy, low external IP's entropy

Results



Distributed brute force attack



Correlation of Entropy Time-series

- Campus IP – Campus port
  - The lower the number of campus IP addresses (most traffic coming from a NAT address), the higher the number of campus ports (ephemeral ports by browsers)

	Campus IP	Campus port	External IP	External port	Total traffic
Weekday					
3-tuple	0.23	0.1	0.6	-0.02	-0.05
Campus IP		-0.85	0.6	0.89	-0.8
Campus port			-0.37	-0.98	0.78
External IP				0.45	-0.36
External port					-0.81
Weekend					
3-tuple	-0.23	-0.12	0.56	0.06	-0.03
Campus IP		0.15	-0.38	0.06	-0.38
Campus port			-0.48	-0.93	0.31
External IP				0.48	-0.05
External port					-0.39

Correlation of Entropy Time-series

- Campus port – External port
  - The higher the number of campus ports (more connected students – more ephemeral ports), the lower the number of external ports (http / https)

	Campus IP	Campus port	External IP	External port	Total traffic
Weekday					
3-tuple	0.23	0.1	0.6	-0.02	-0.05
Campus IP		-0.85	0.6	0.89	-0.8
Campus port			-0.37	-0.98	0.78
External IP				0.45	-0.36
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Conclusion

- In a NATed environment, entropies may widely vary. E.g.,
  - External and campus ports vary from below 0.2 to above 0.8 (in a normalized entropy scale 0-1)
  - Campus IP address varies from 0.1 to 0.4
- Despite the wide range of values, building a granular (small time slots) entropy characterization helps to detect anomalies
- Strong correlation exists between entropy time-series
- Future work includes anomaly detection algorithms to exploit flow entropy characterization