Examples of Traffic

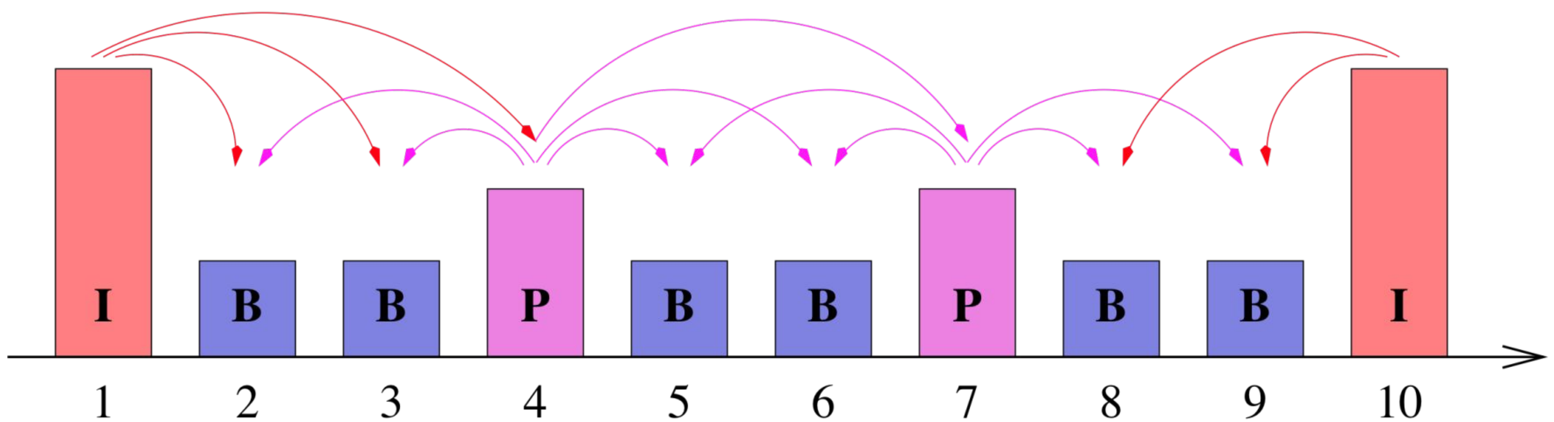
Video

- Video Traffic (High Definition)
  - 30 frames per second
  - Frame format: 1920x1080 pixels
  - 24 bits per pixel
- Required rate: 1.5 Gbps
- Required storage: 1 TB per hour

- Video uses compression algorithm to reduce bitrate

MPEG compression

- I frames: intra-coded
- P frames: predictive
- B frames: bi-directional



- Group of Pictures (GOP): IBBPBBPBB

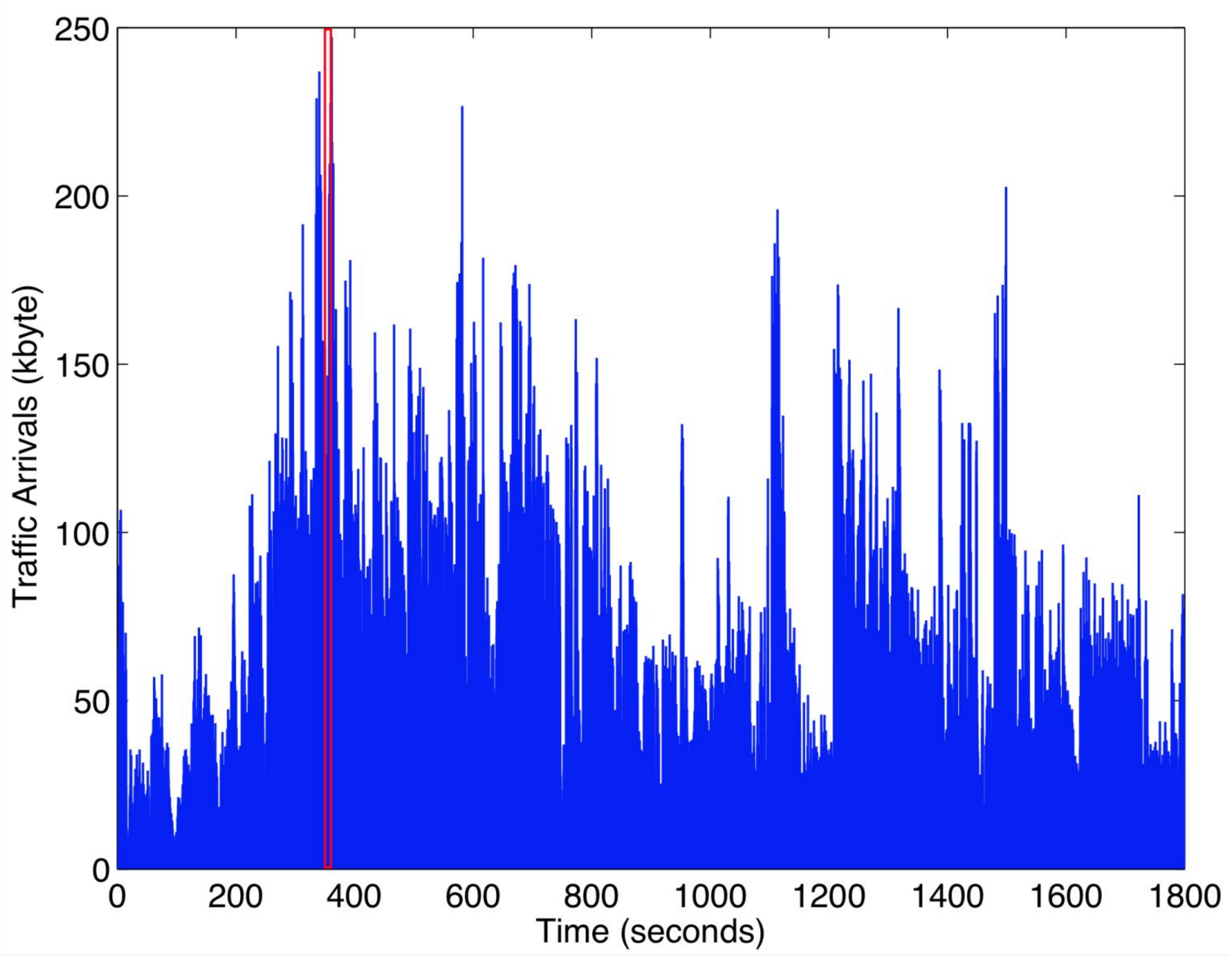
Example: Harry Potter

30 minutes of Harry Potter movie with HD encoding

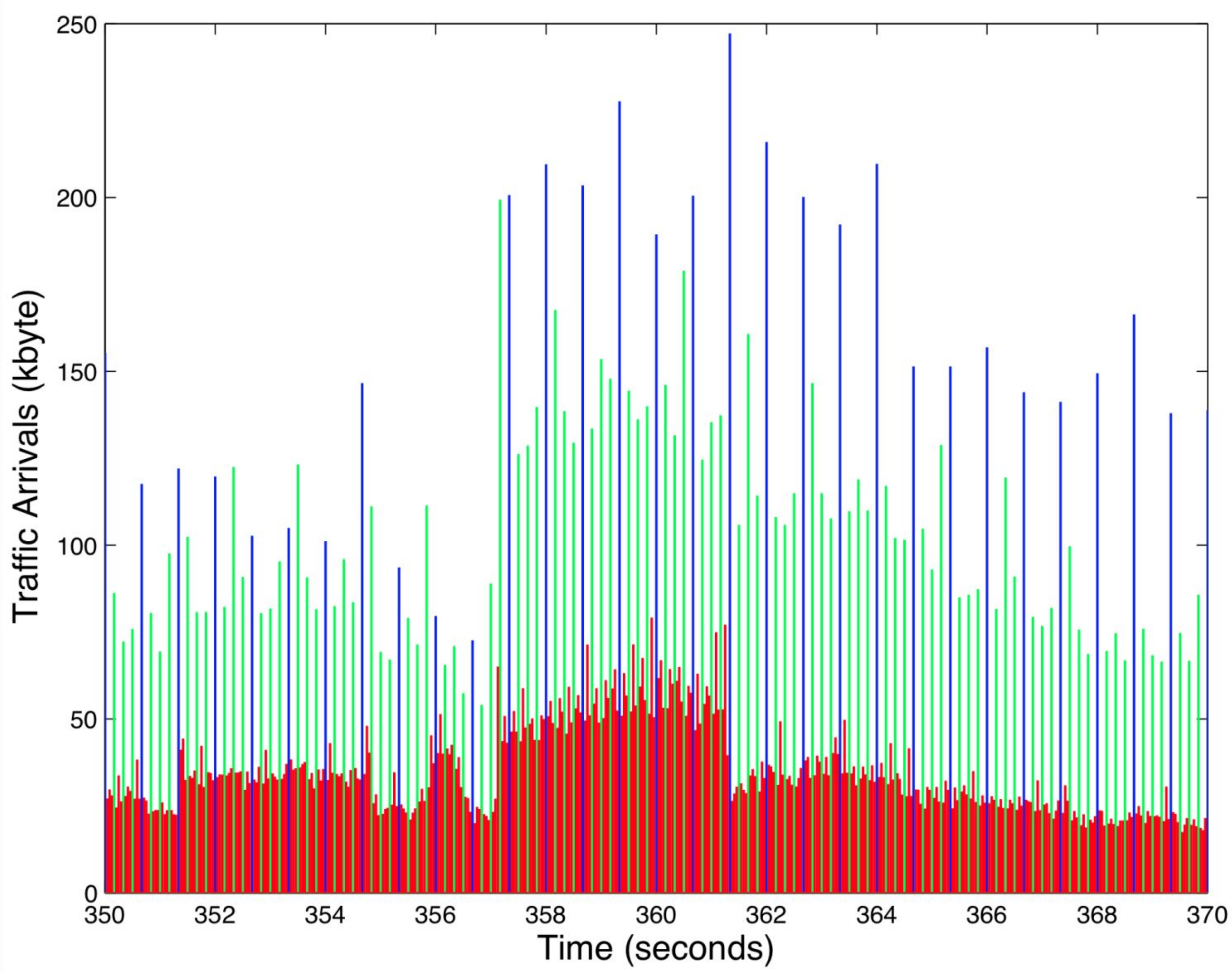
- Codec: H.264 SVC
- Resolution: 1920x1088
- Frames per second: 24 fps
- GOP: IBBBPBBBPBBBPBBB

- Frame size (Bytes):
  - Avgerage: 28,534
  - Minimum: 109
  - Maximum: 287,576
- Mean Frame Bit Rate (Mbps): 5.48
- Peak Frame Bit Rate (Mbps): 55.21

Harry Potter: 30 minutes

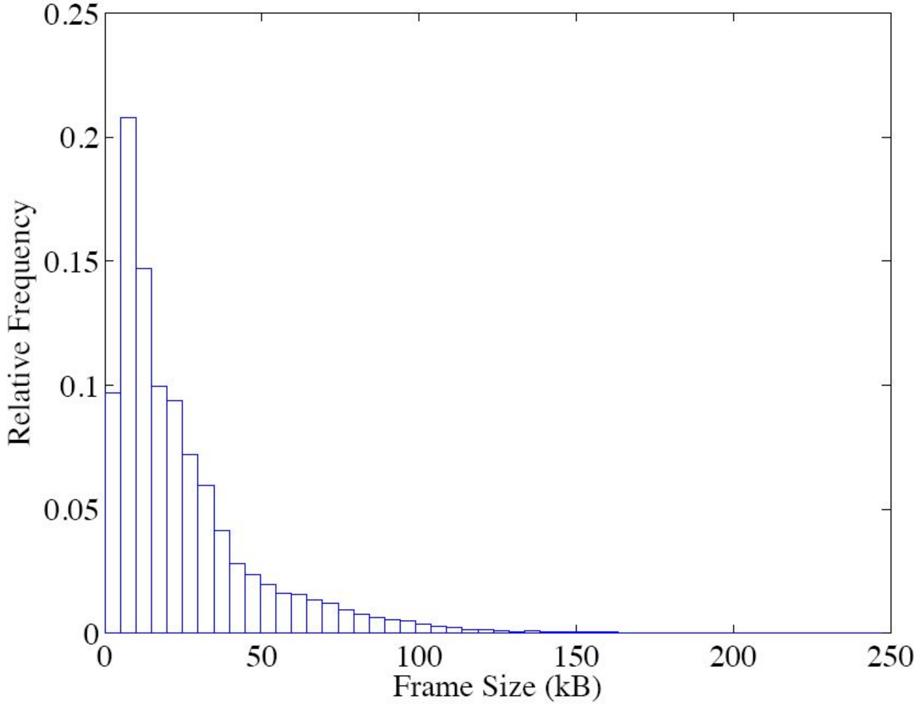


Harry Potter: 20 seconds

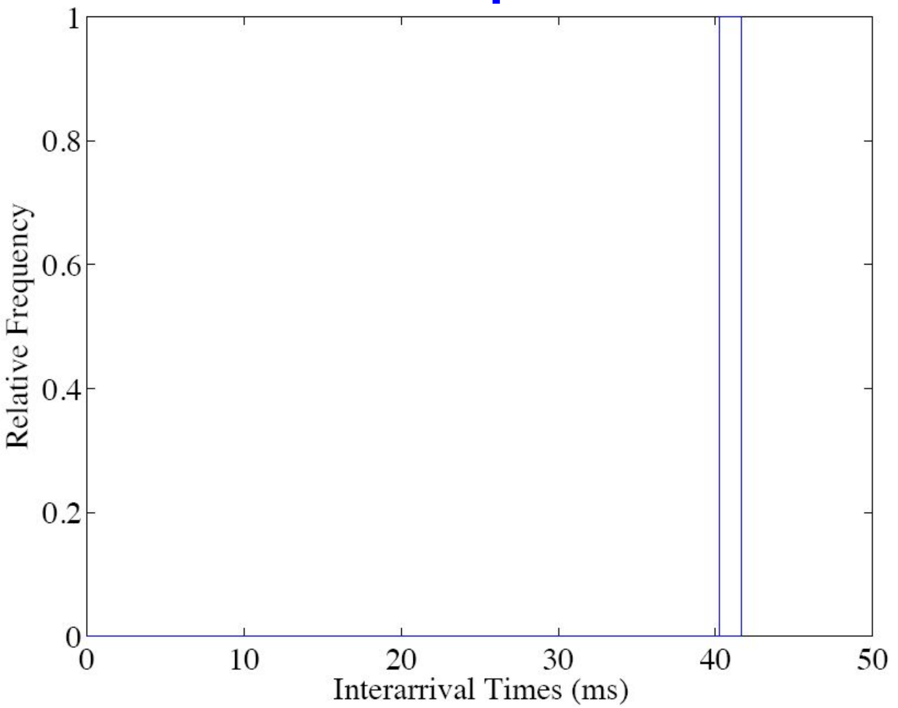


Harry Potter

Distribution of packet sizes



Distribution of time gap between packets

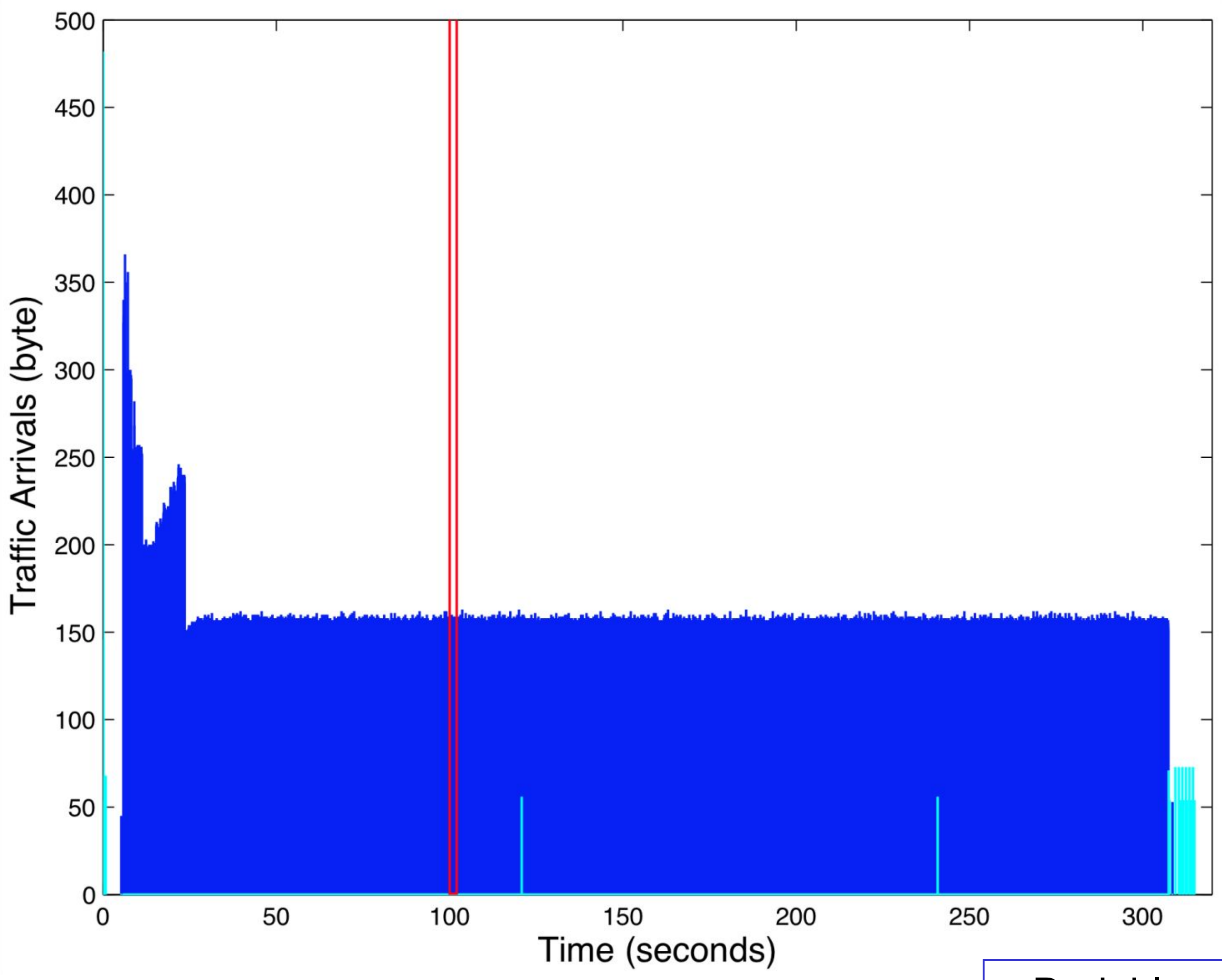


Voice

- Standard (Pulse Code Modulation) voice encoding:
  - 8000 samples per second (8 kHz)
  - 8 bits per sample
  - Bit rate: 64 kbps
- Better quality with higher sampling rate and larger samples
- CD encoding:
  - 44 kHz sampling rate
  - 16 bits per sample
  - 2 channels
  - Bit rate: 1.4 Mbps
- Packet voice collects multiple samples in once packet
- Modern voice encoding schemes also use compression and silent suppression

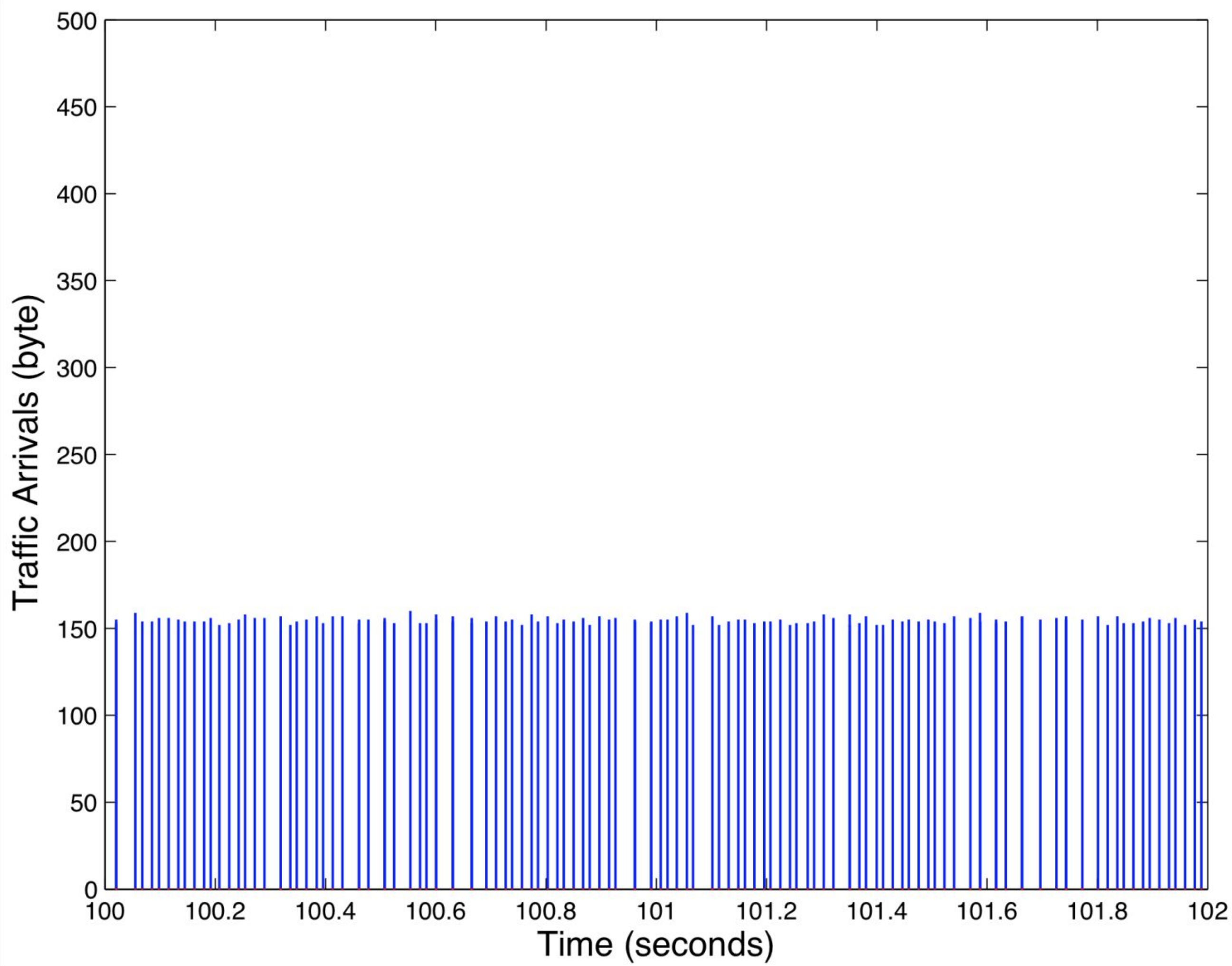
Skype Voice Call: 6 minutes

- SVOPC encoding, one direction of 2-way call



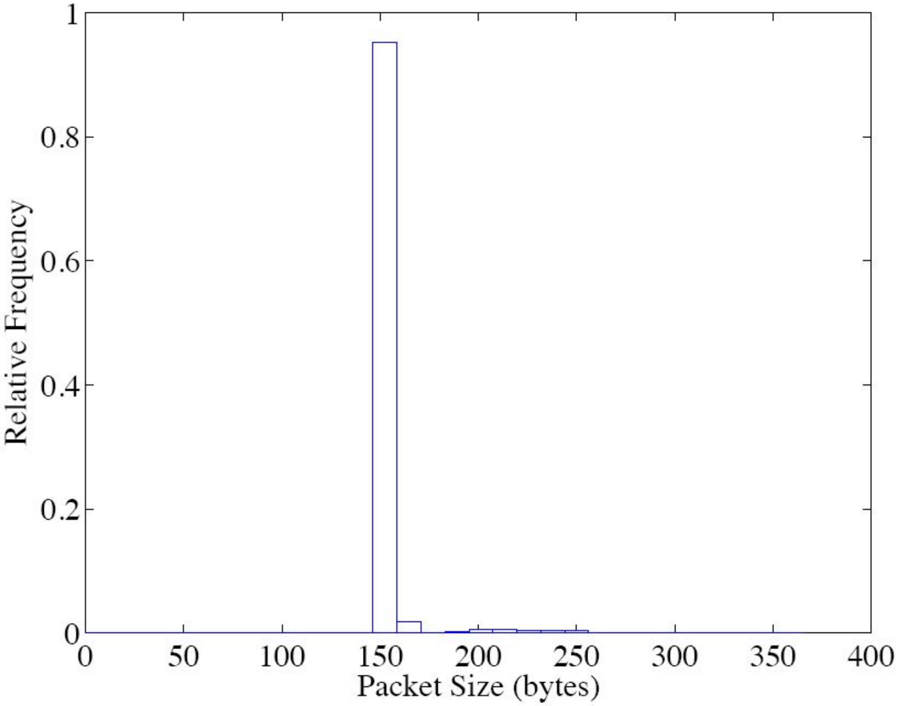
Dark blue: UDP traffic
Light blue: TCP traffic

Skype Voice Call: 2 seconds

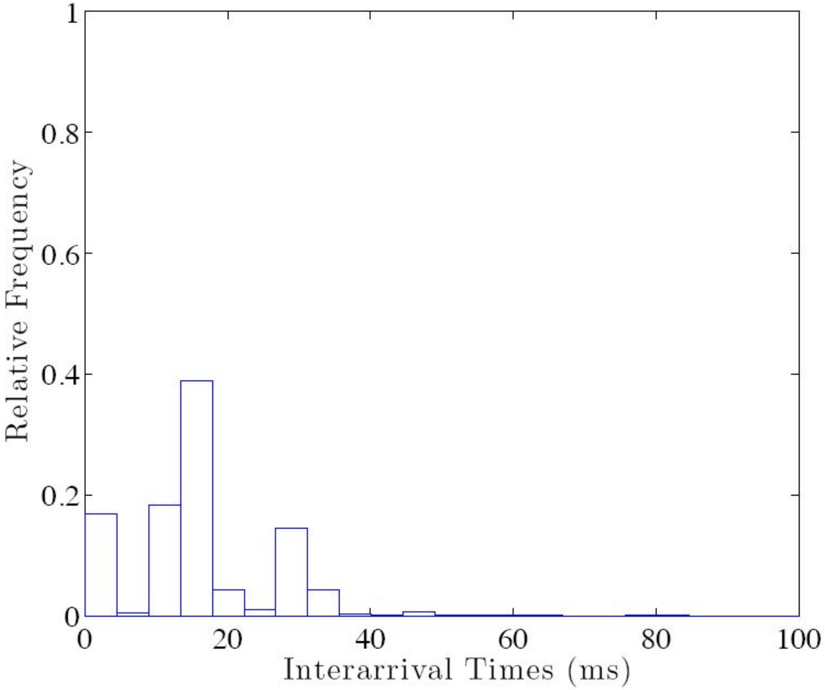


Skype (UDP traffic only)

Distribution of packet sizes



Distribution of time gap between packets



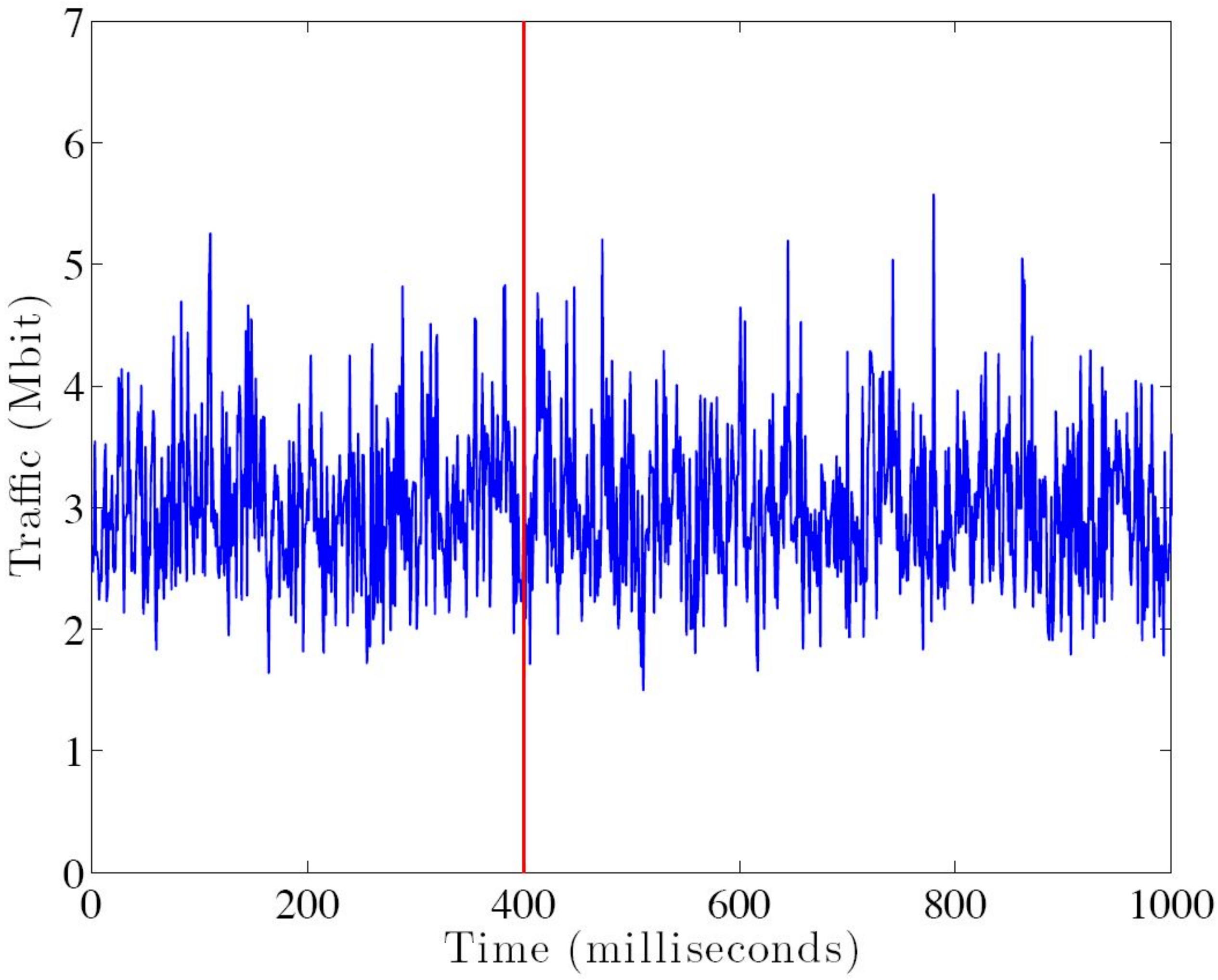
Internet Traffic: 10 Gbps link

- Data measured from a backbone link of a Tier-1 Internet Service provider
  - Link measured: Chicago – Seattle
  - Link rate: 10 Gbps (10 Gigabit Ethernet)
- Data measures total (aggregate) traffic of all transmissions on the network

- Data shown is 1 second:
  - ~430,000 packets packet transmissions
  - Average rate: ~3 Gbps
  - Avg. packet size: 868 Bytes
  - Min. packet size: 44 Bytes
  - Max. packet size: 1504 Bytes

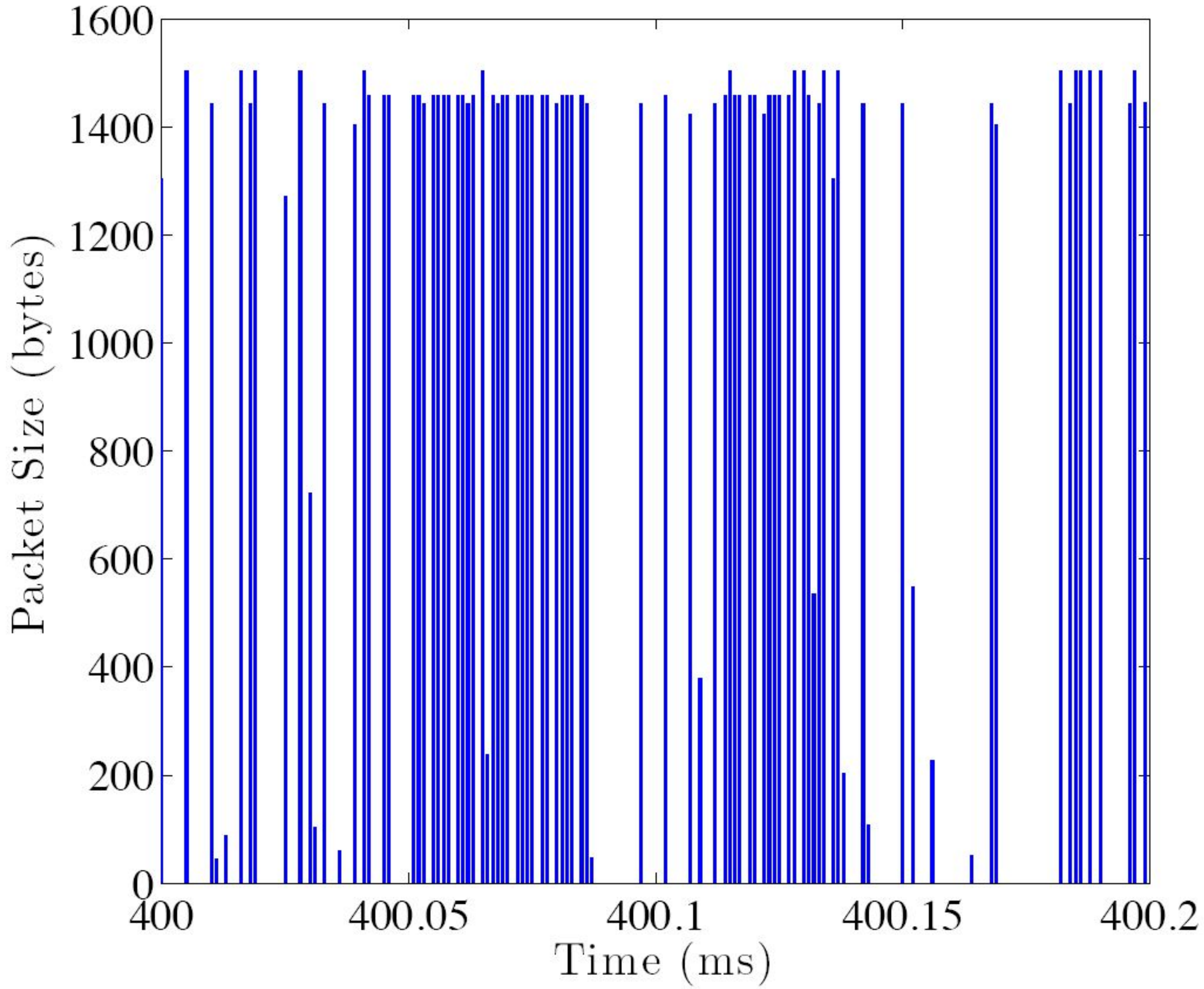
Internet Traffic: 10 Gbps link

- One data point is the traffic in one millisecond



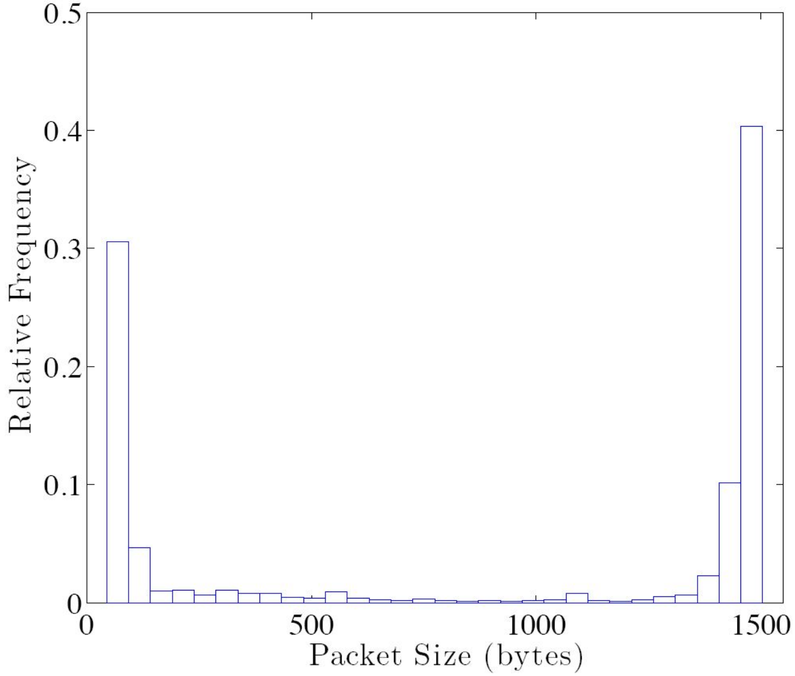
Internet Traffic

- Packet arrivals in a 2μs snapshot:

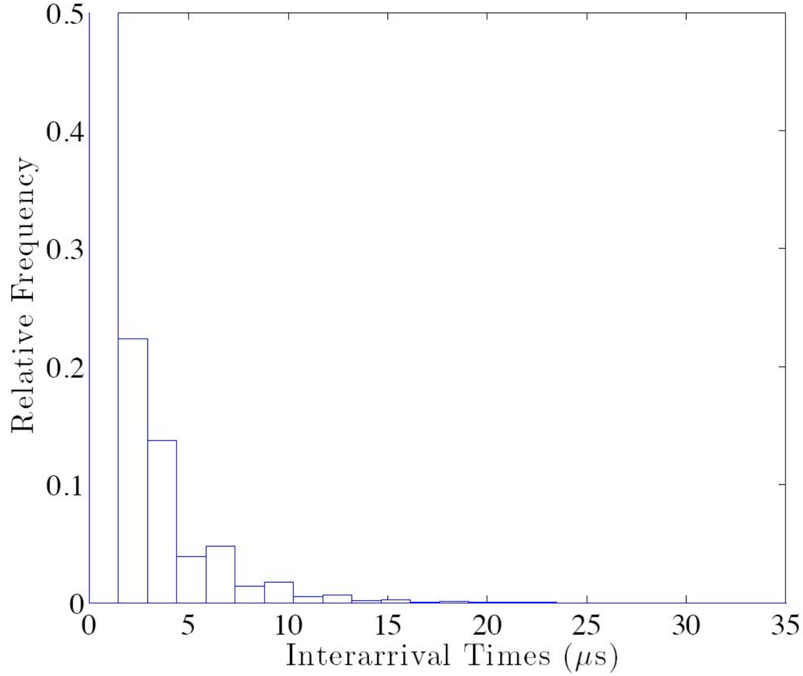


Internet Traffic: 10 Gbps link

Distribution of packet sizes



Distribution of time gap between packets



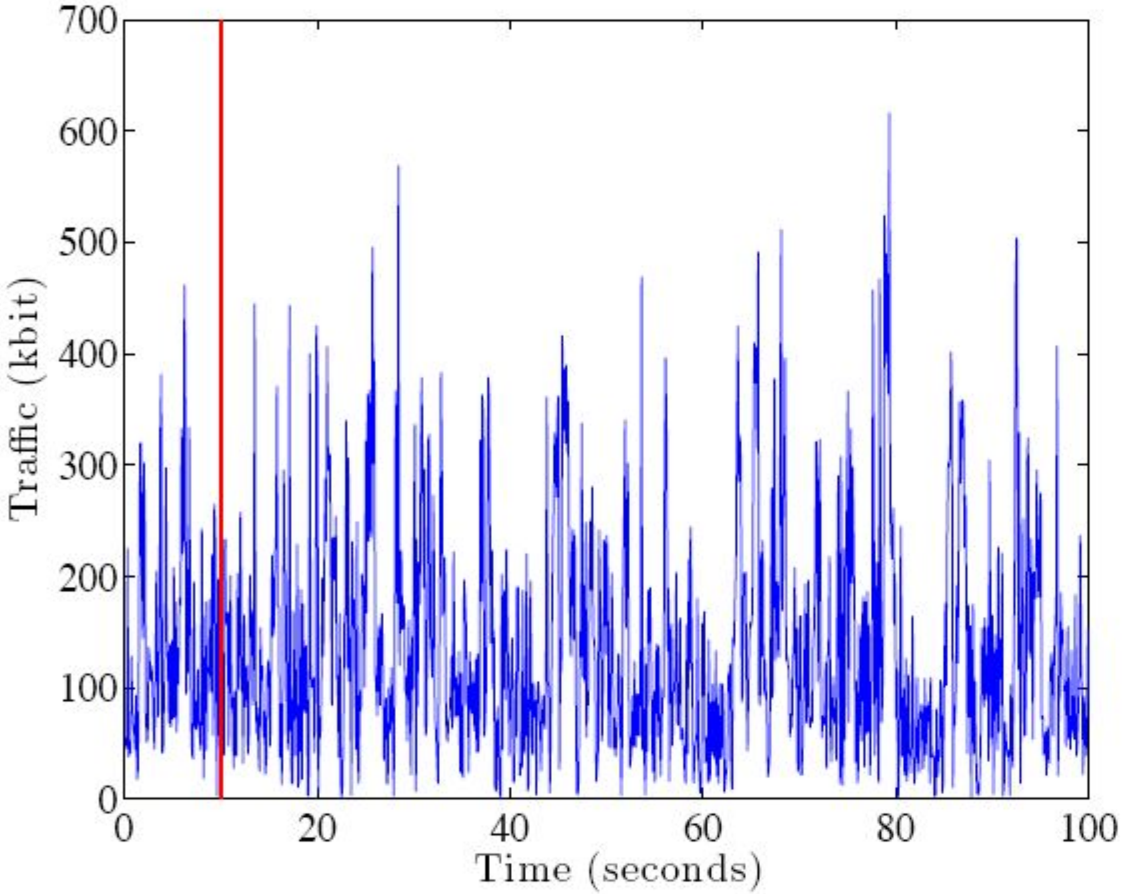
Data Traffic: “Bellcore Traces”

- Data measured on an Ethernet network at Bellcore Labs with 10Mbps
- Data measures total (aggregate) traffic of all transmissions on the network

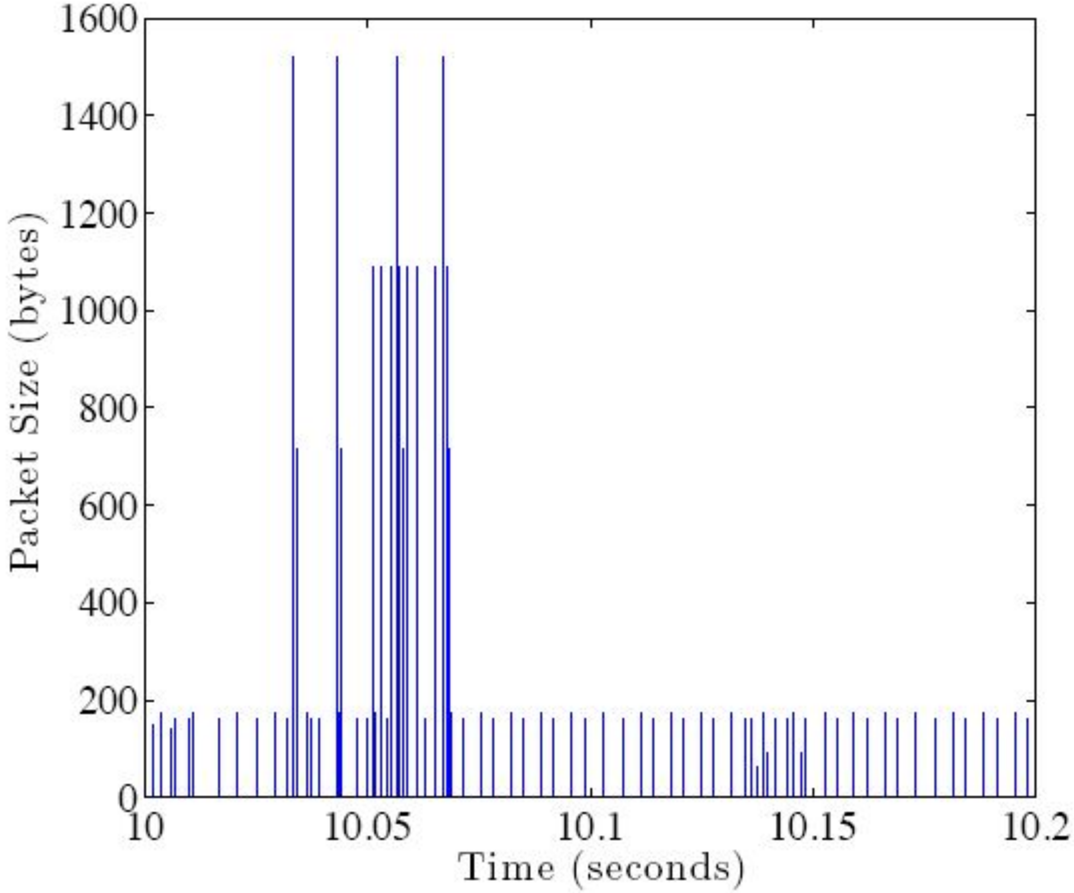
- Measurements from 1989
- One of the first systematic analyses of network measurements

Data Traffic: 100 seconds

- One data point is the traffic in 100 milliseconds

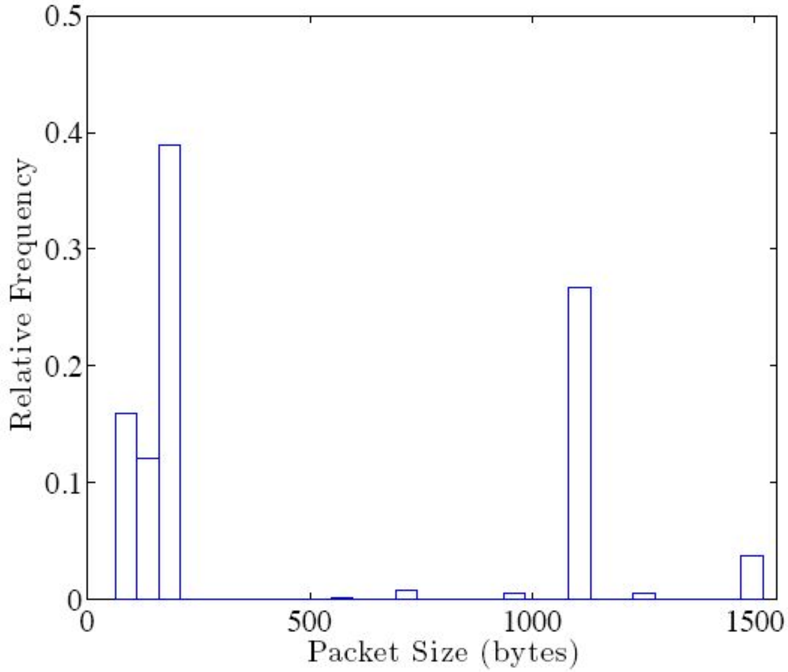


Packet arrivals: 200 milliseconds

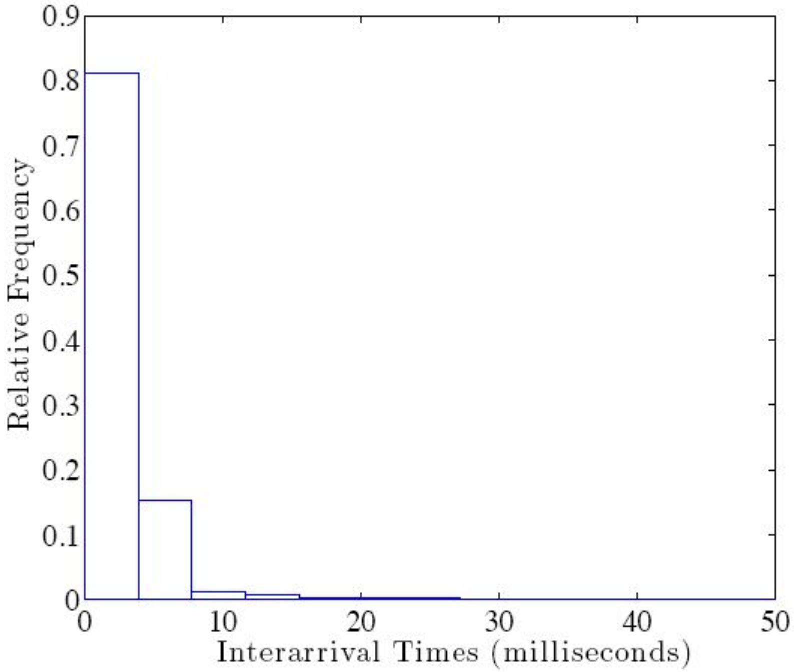


Bellcore traces

Distribution of packet sizes



Distribution of time gap between packets



Some background on Lab 1

Lab 1

- Lab 1 is about comparing a simple model for network traffic (Poisson traffic) with actual network traffic (LAN traffic, video traffic)

- Lab 1 retraces one fo the most fundamental insights of networking research ever:

"Typical network traffic is not well described by Poisson model"

Poisson

- In a **Poisson process** with rate λ, the number of events in a time interval *(t, t+τ],* denoted by *N(t+τ) – N(t),* is given by

$$P[N(t+\tau)-N(t)=k]=\frac{(\lambda\tau)^k}{k!}e^{-\lambda\tau} \qquad ,k=0,1,\ldots,$$

- In a Poisson process with rate λ, the time between events follows an **exponential distribution:**

$$P[\text{Time between two events} \leq X] = 1-e^{-\lambda X}$$

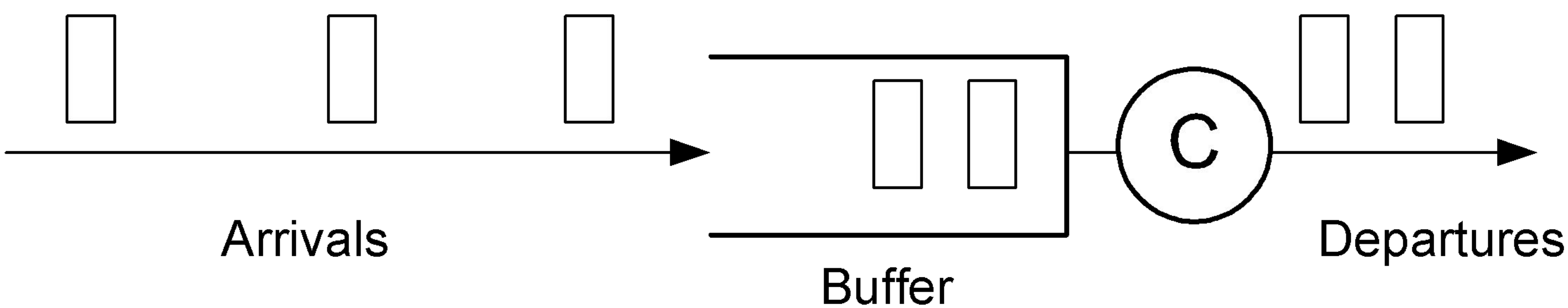
In the Past…

- Before there were packet networks there was the circuit-switched telephone network
- Traffic modeling of **telephone networks** was the basis for initial network models
  - Assumed Poisson arrival process of new calls
  - Assumed Poisson call duration

Source: Prof. P. Barford (edited)

… until early 1990's

- Traffic modeling of packet networks also used Poisson
  – Assumed Poisson arrival process for packets
  – Assumed Exponential distribution for traffic



Source: Prof. P. Barford (edited)

The measurement study that changed everything

- **Bellcore Traces**: In 1989, researchers at (Leland and Wilson) begin taking high resolution traffic traces at Bellcore
  - Ethernet traffic from a large research lab
  - 100 μ sec time stamps
  - Packet length, status, 60 bytes of data
  - Mostly IP traffic (a little NFS)
  - Four data sets over three year period
  - Over 100 million packets in traces
  - Traces considered representative of normal use

The data in part 3 of Lab 1 is a subset of the actual measurements.

Source: Prof. C. Williamson

Extract from abstract

Results were published in 1993

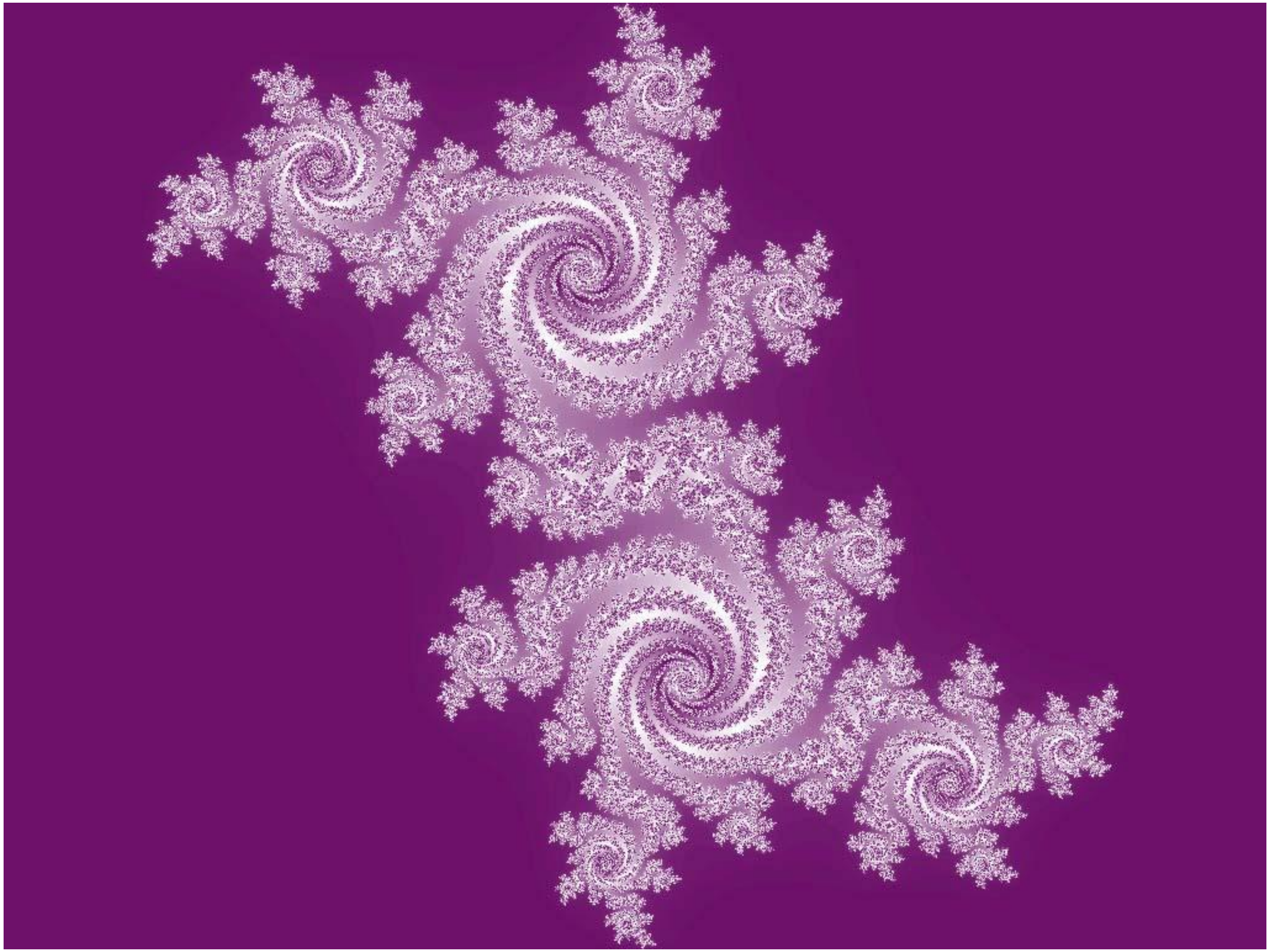
- **"On the Self-Similar Nature of Ethernet Traffic"**
  Will E. Leland, Walter Willinger, Daniel V. Wilson, Murad S. Taqqu

"*We demonstrate that Ethernet local area network (LAN) traffic is statistically self-similar, that none of the commonly used traffic models is able to capture this fractal behavior, that such behavior has serious implications for the design, control, and analysis of high-speed…*"

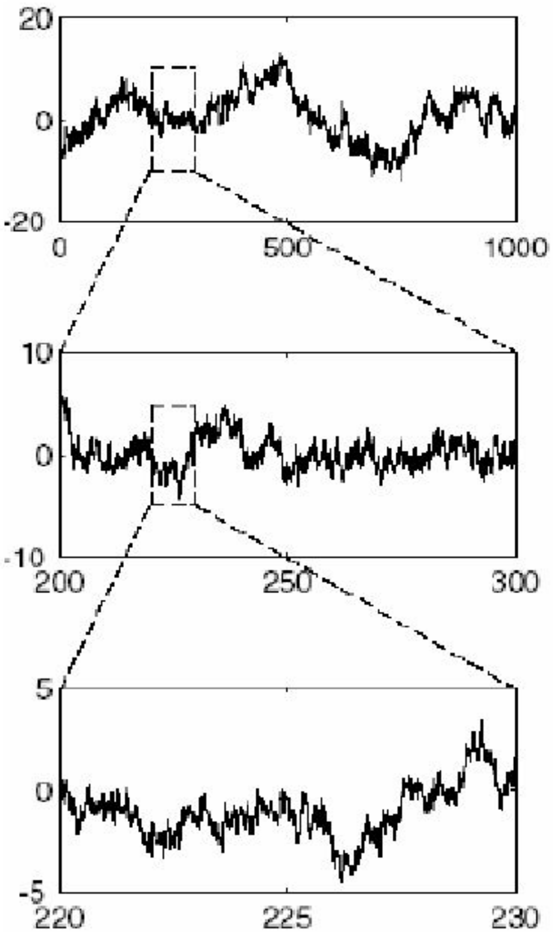
That Changed Everything…..

Source: Prof. V. Mishra, Columbia U. (edited)

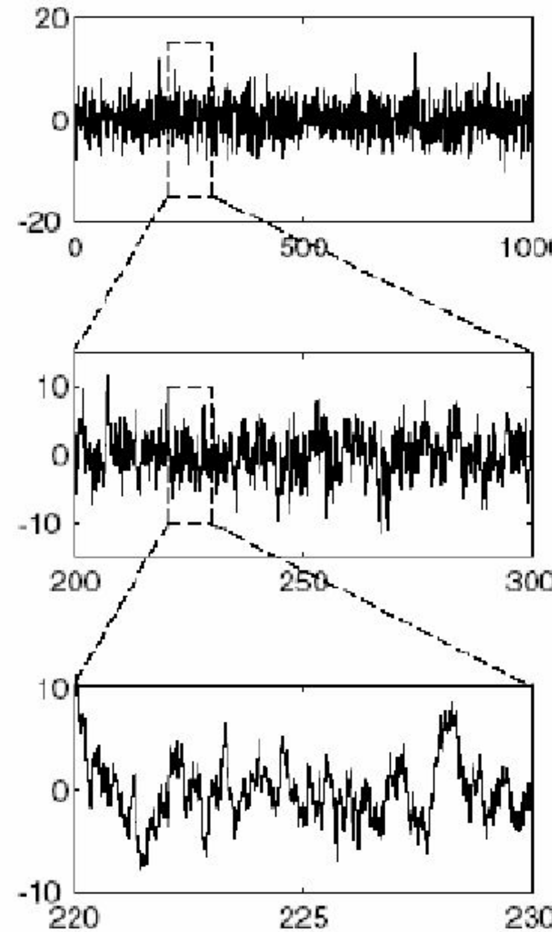
Fractals



Source: Prof. P. Barford, U. Wisconsin

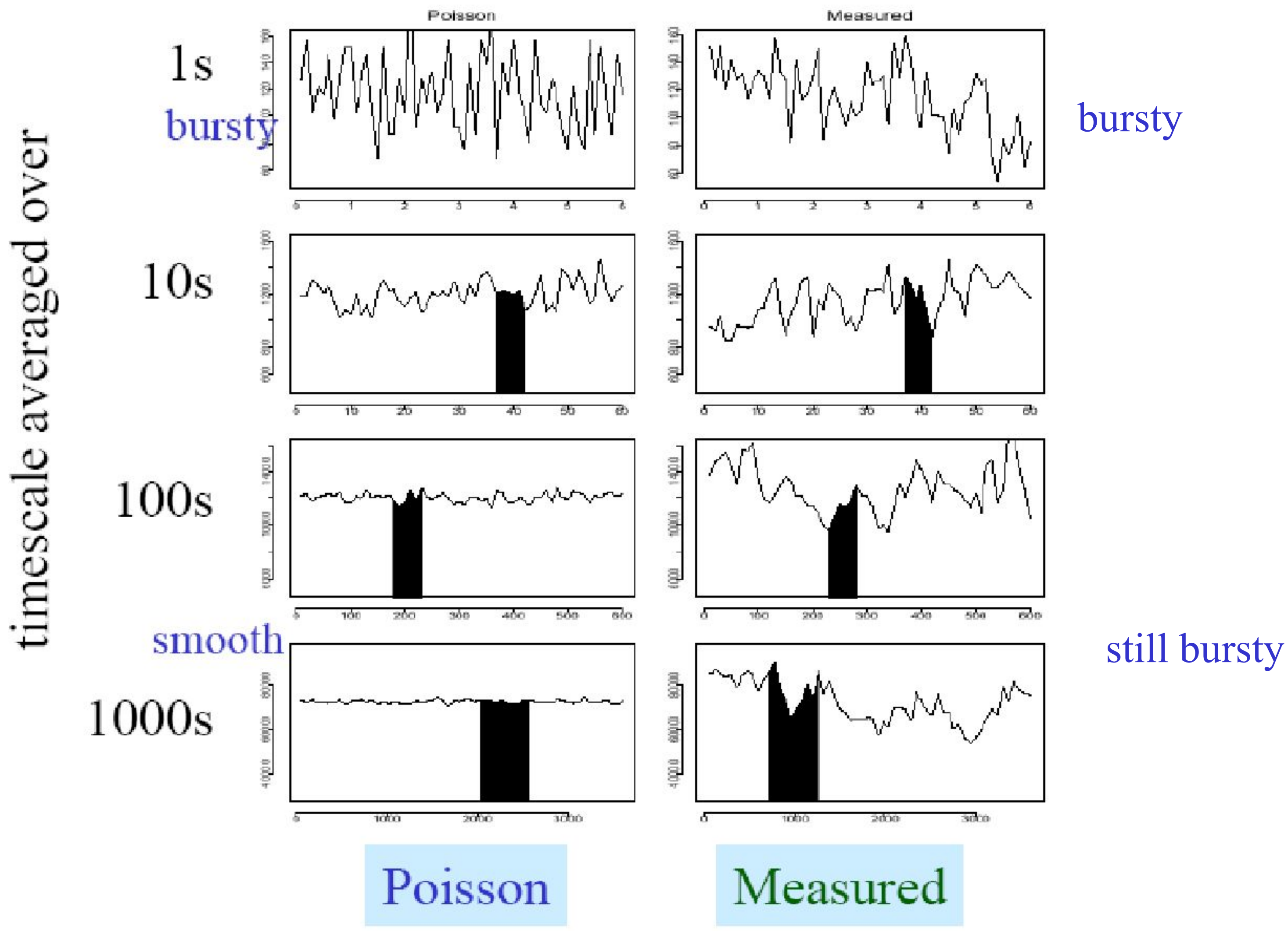


(a) Self-Similar Process

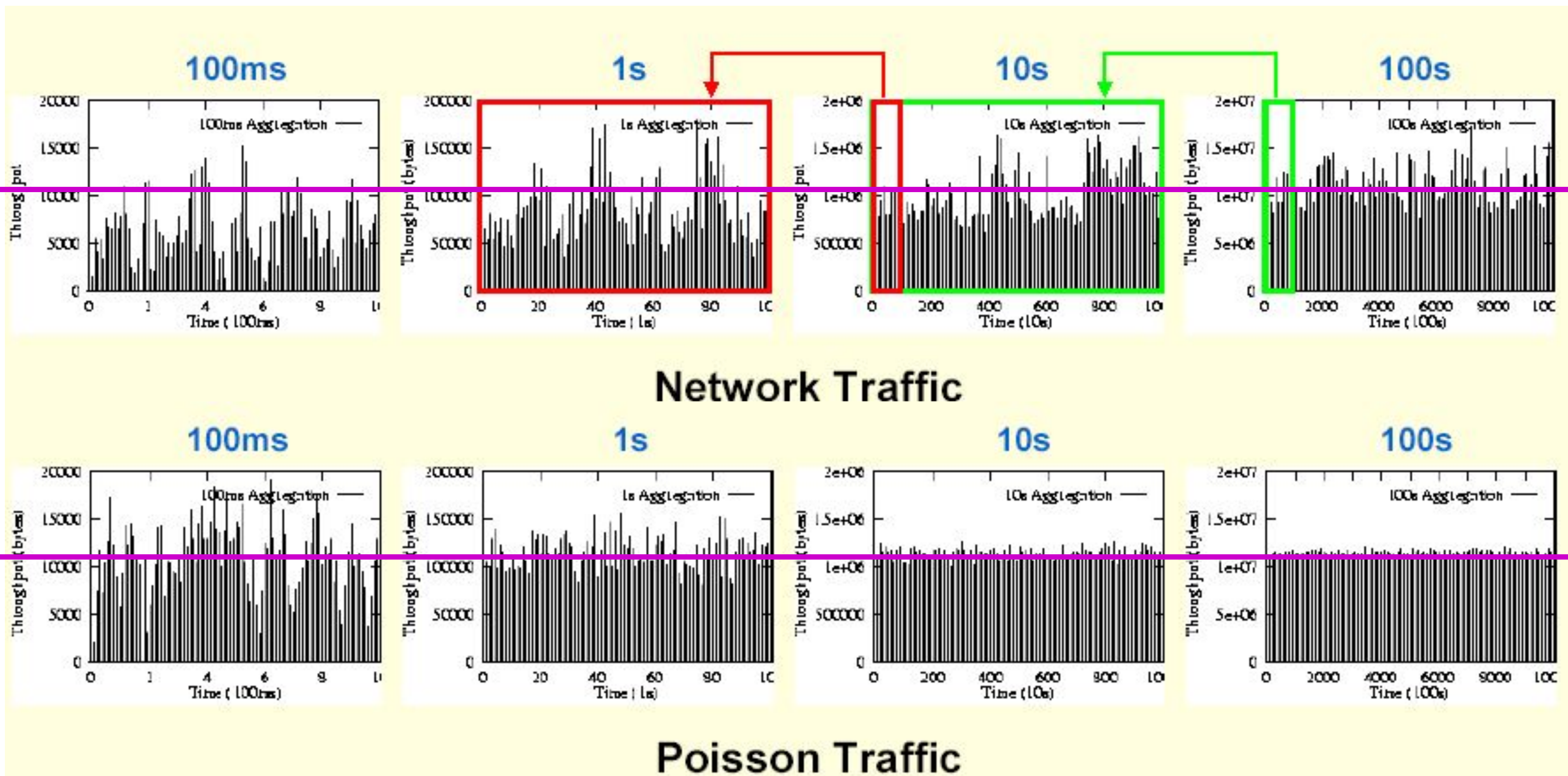


(b) Non-Self-Similar Process

Traffic at different time scales (Bellcore traces)



Source: Prof. P. Barford (edited)



Source: Prof. V. Mishra, Columbia U.

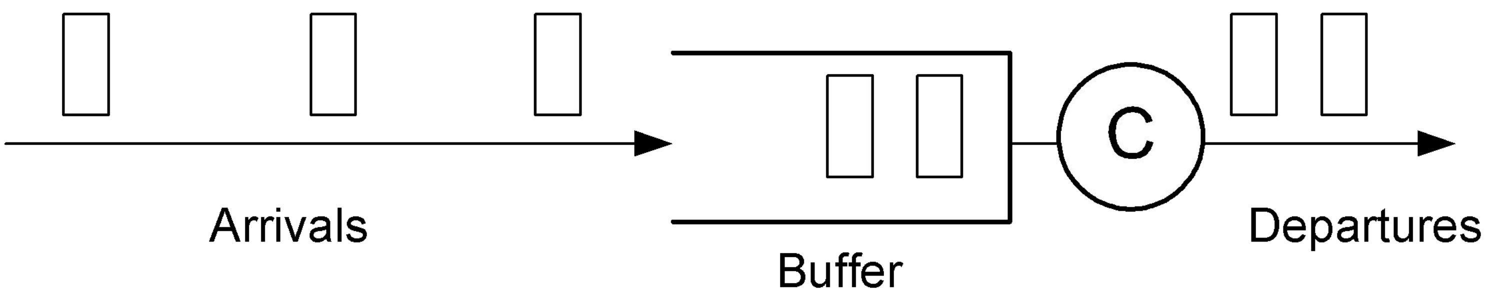
What is the observation?

- A Poisson process
  - When observed on a fine time scale will appear bursty
  - When aggregated on a coarse time scale will flatten (smooth) to white noise

- A Self-Similar (fractal) process
  - When aggregated over wide range of time scales will maintain its bursty characteristic

Why do we care?

- For traffic with the same average, the probability of a buffer overflow of self-similar traffic is much higher than with Poisson traffic
  - Costs of buffers (memory) are 1/3 the cost of a high-speed router !
- When aggregating traffic from multiple sources, self-similar traffic becomes burstier, while Poisson traffic becomes smoother
  -



Self-similarity

- The objective in Lab 1 is to <u>observe</u> self-similarity and obtain a sense.

- The challenge of Lab 1:
  - The Bellcore trace for Part 4 contains 1,000,000 packets
  - The computers in the lab are not happy with that many packets
  - Reducing the number of packets in plots, may reduce opportunities to discover self-similarity effect