Stability Study of TCP-RED System Using Detrended Fluctuation Analysis

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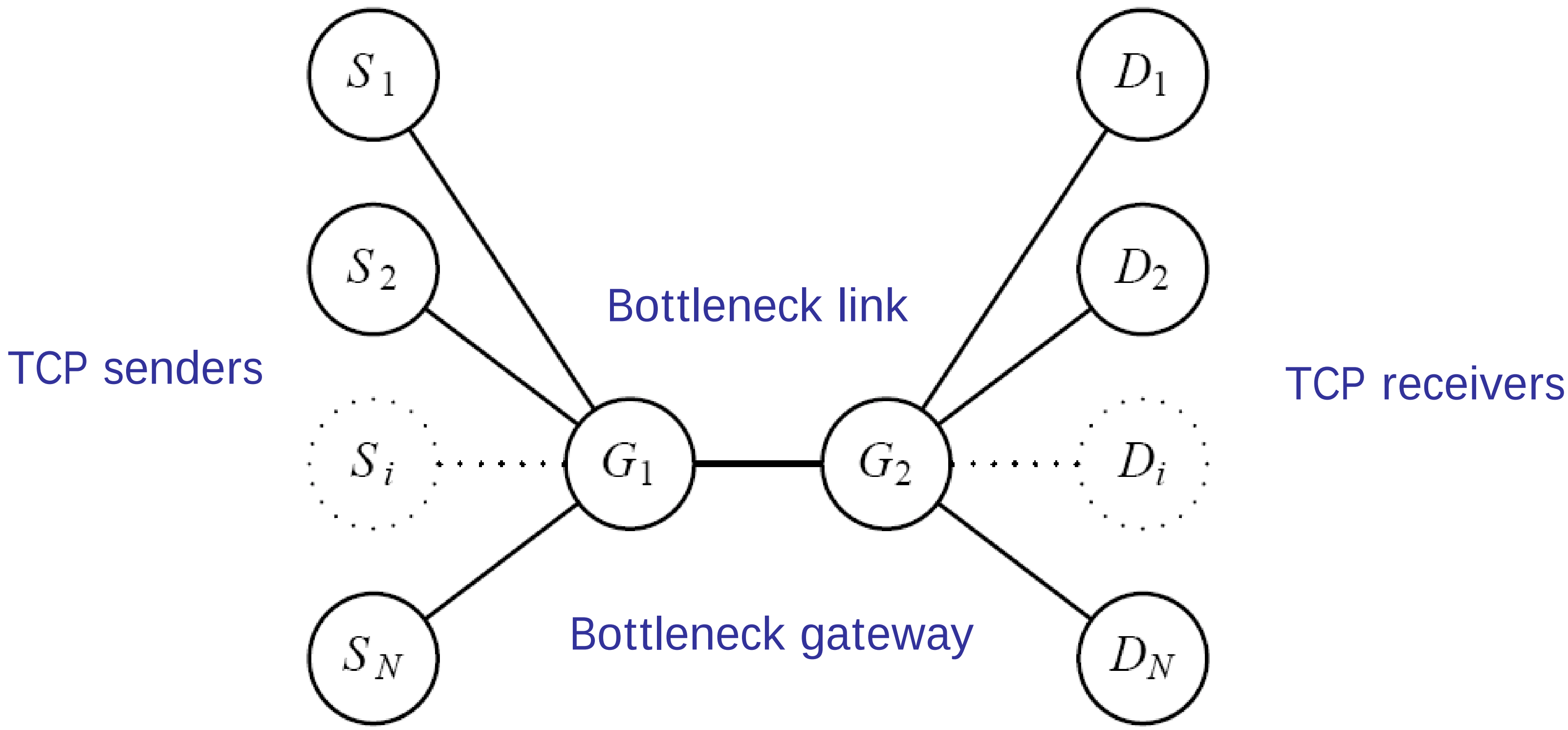
Outline

- Overview of TCP-RED (Random Early Detection) systems
- RED algorithm
- Self-similarity and detrended fluctuation analysis (DFA) method
- Interpretation from a waveform viewpoint
- Conclusions and future work

Overview



S_1
S_2
S_i
S_N
G_1
G_2
D_1
D_2
D_i
D_N
Bottleneck link
Bottleneck gateway
TCP senders
TCP receivers

TCP Window Congestion Control algorithm

Sender sends *W* packets at a time

Window size = *W*

- Additive increase (AI):
  if no loss, window size increases by one per round trip time
- Multiplicative decrease (MD):
  on detection of loss, window size decreases by half

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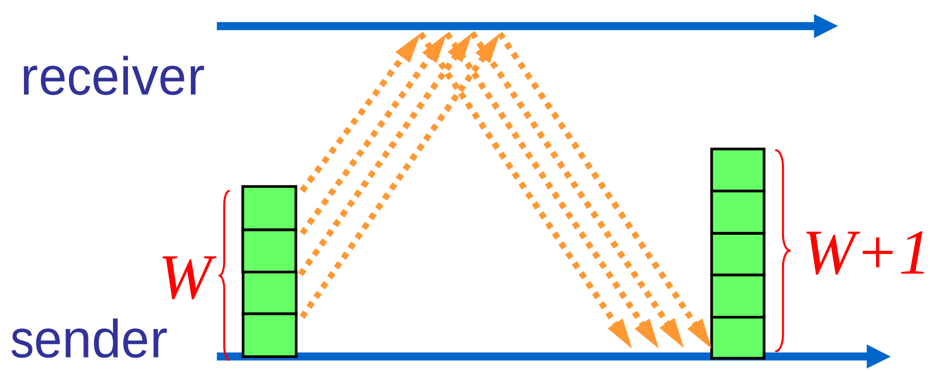

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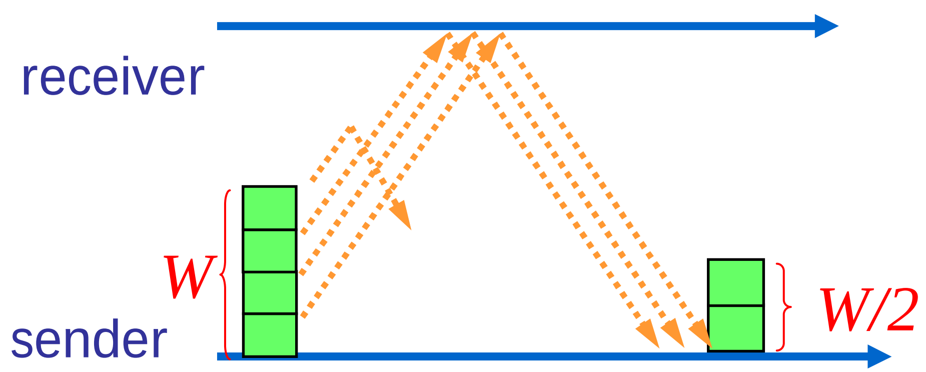
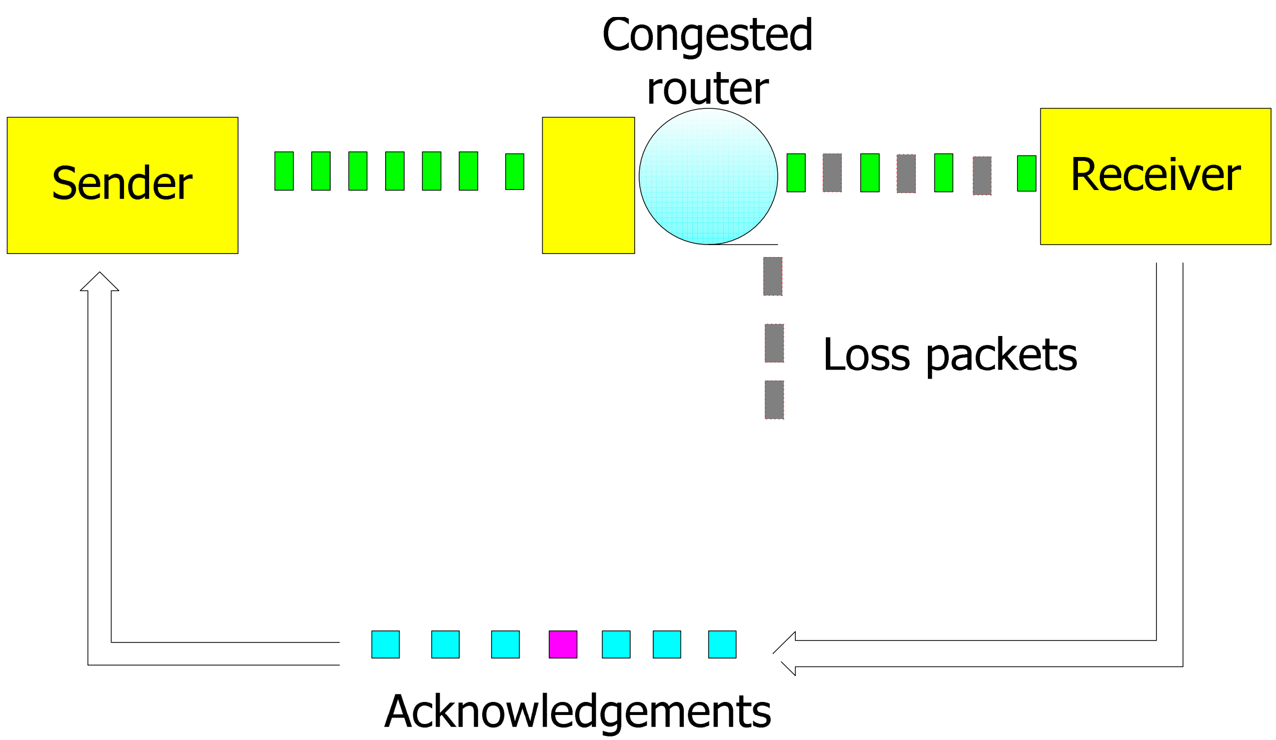
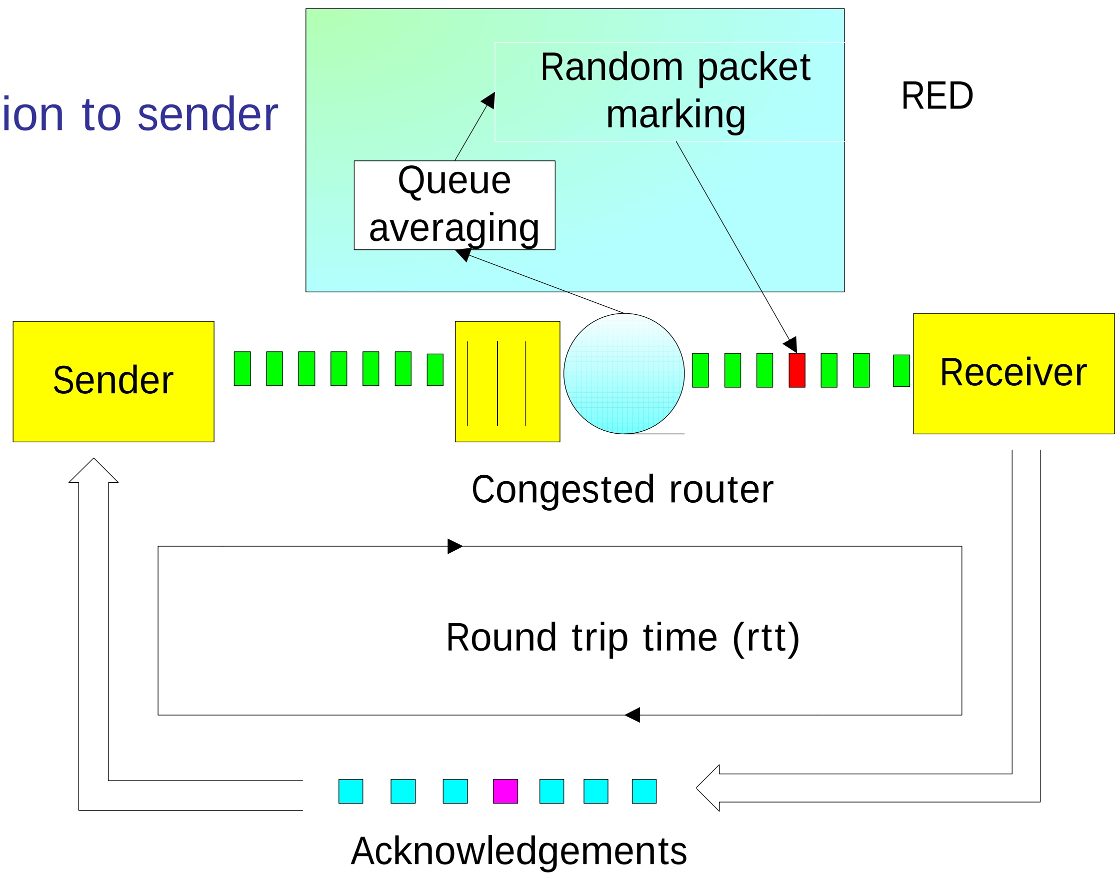


Sender-receiver connection without RED



Sender-receiver connection with RED

Early notification to sender



RED algorithm

Average queue length: $$x_k = (1-\alpha)x_{k-1} + \alpha q_k$$

α queue averaging weight $0<\alpha<1$

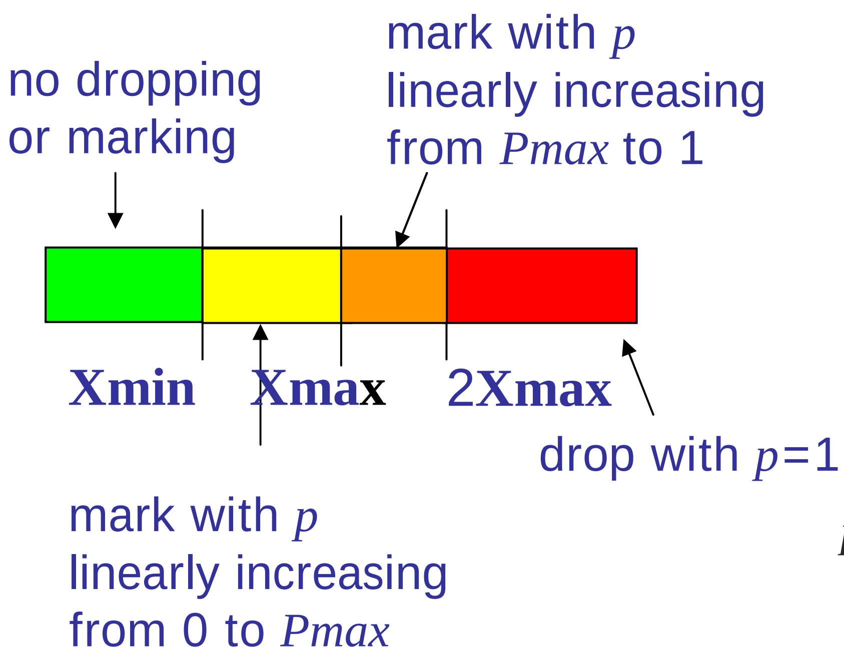
q_k: current queue size

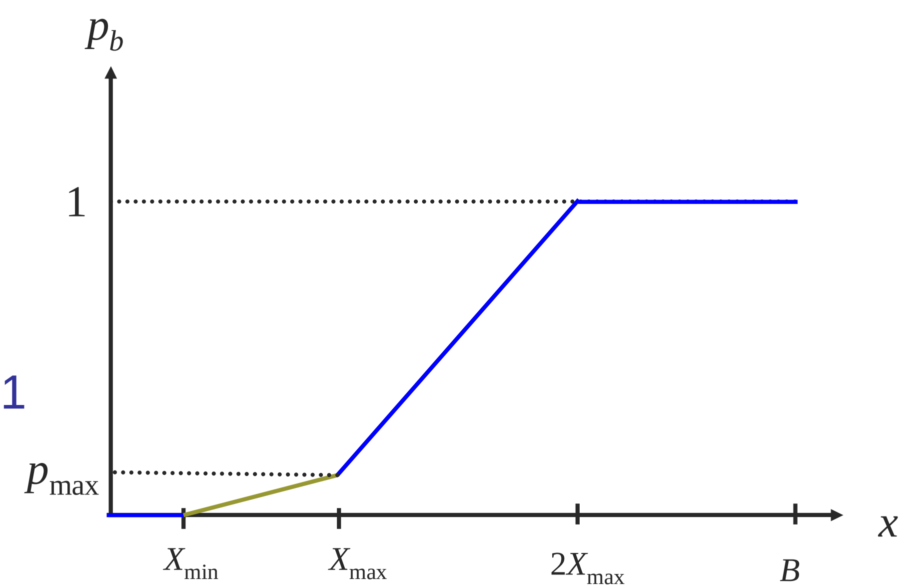
Marking/dropping probability:

$$p_b = \begin{cases} 0 & 0 \le x_k < X_{\min} \\ \dfrac{x_k - X_{\min}}{X_{\max} - X_{\min}} p_{\max} & X_{\min} \le x_k \le X_{\max} \\ p_{\max} - \dfrac{x_k - X_{\max}}{X_{\max} - X_{\min}}(1 - p_{\max}) & X_{\max} < x_k \le 2X_{\max} \\ 1 & 2X_{\max} < x_k \le B \end{cases}$$

$$p_k = \frac{p_b}{1 - c_m p_b}$$

RED marking/dropping probability

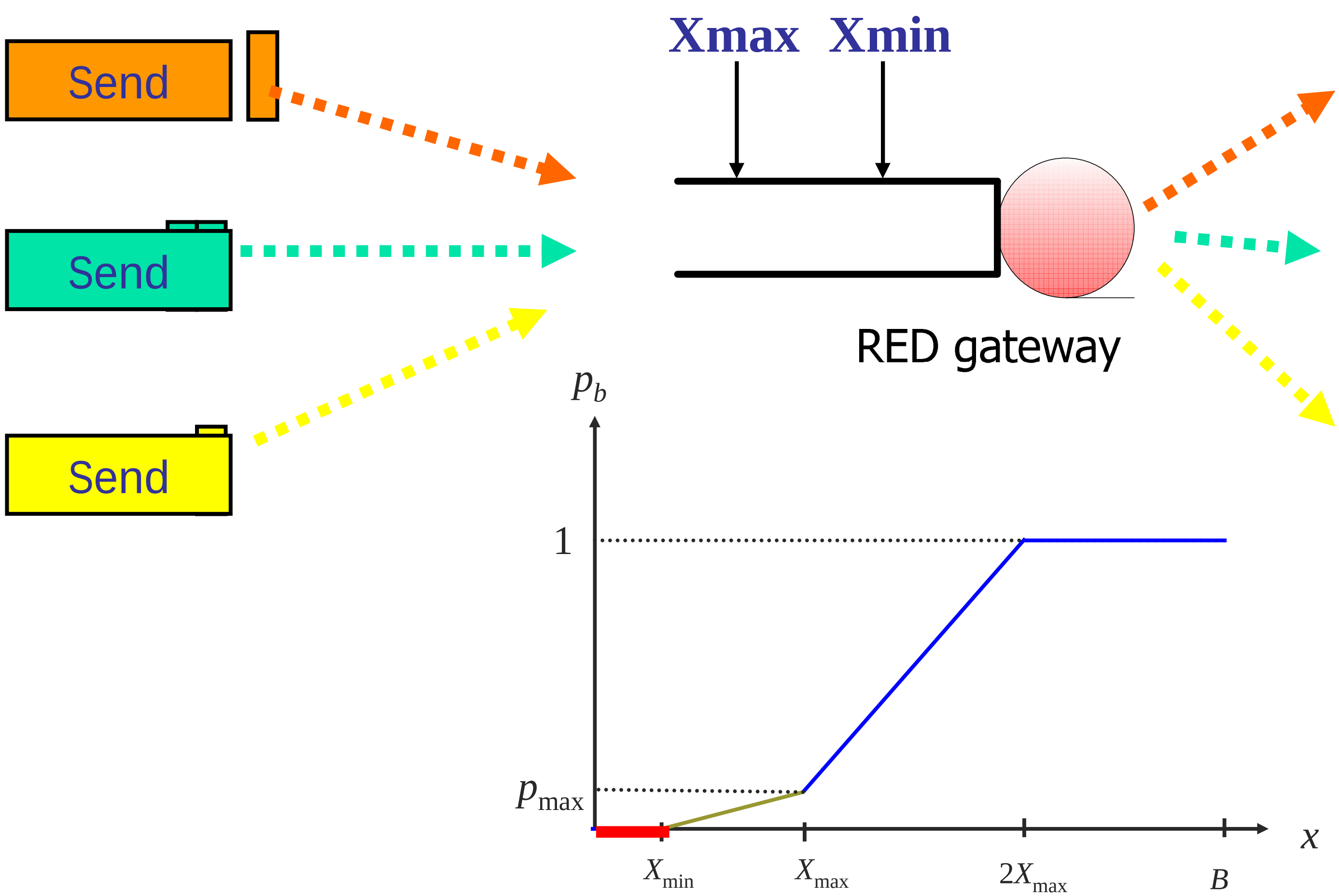




average queue length

drop probability *p*

RED gateway with small queue length



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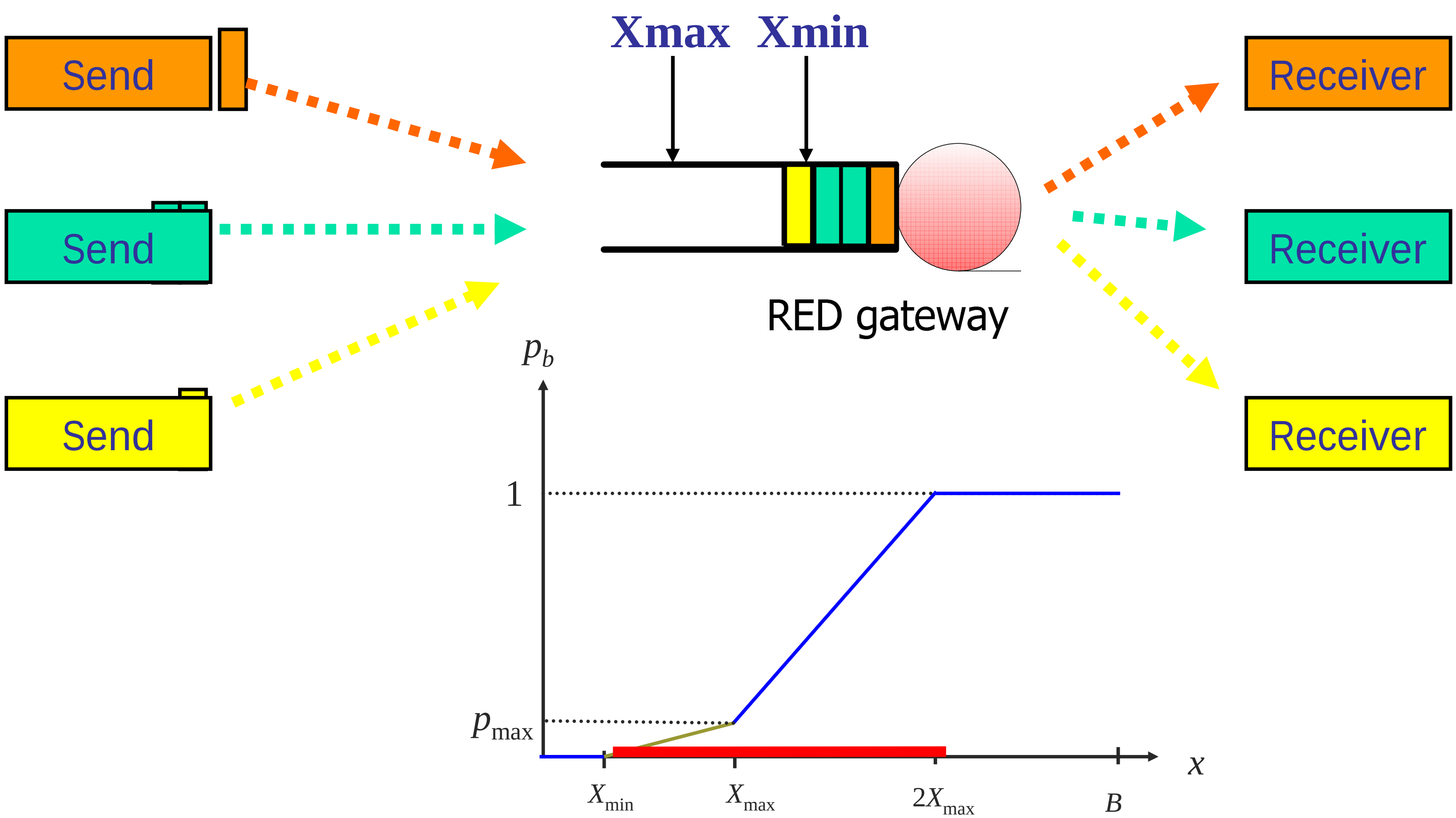
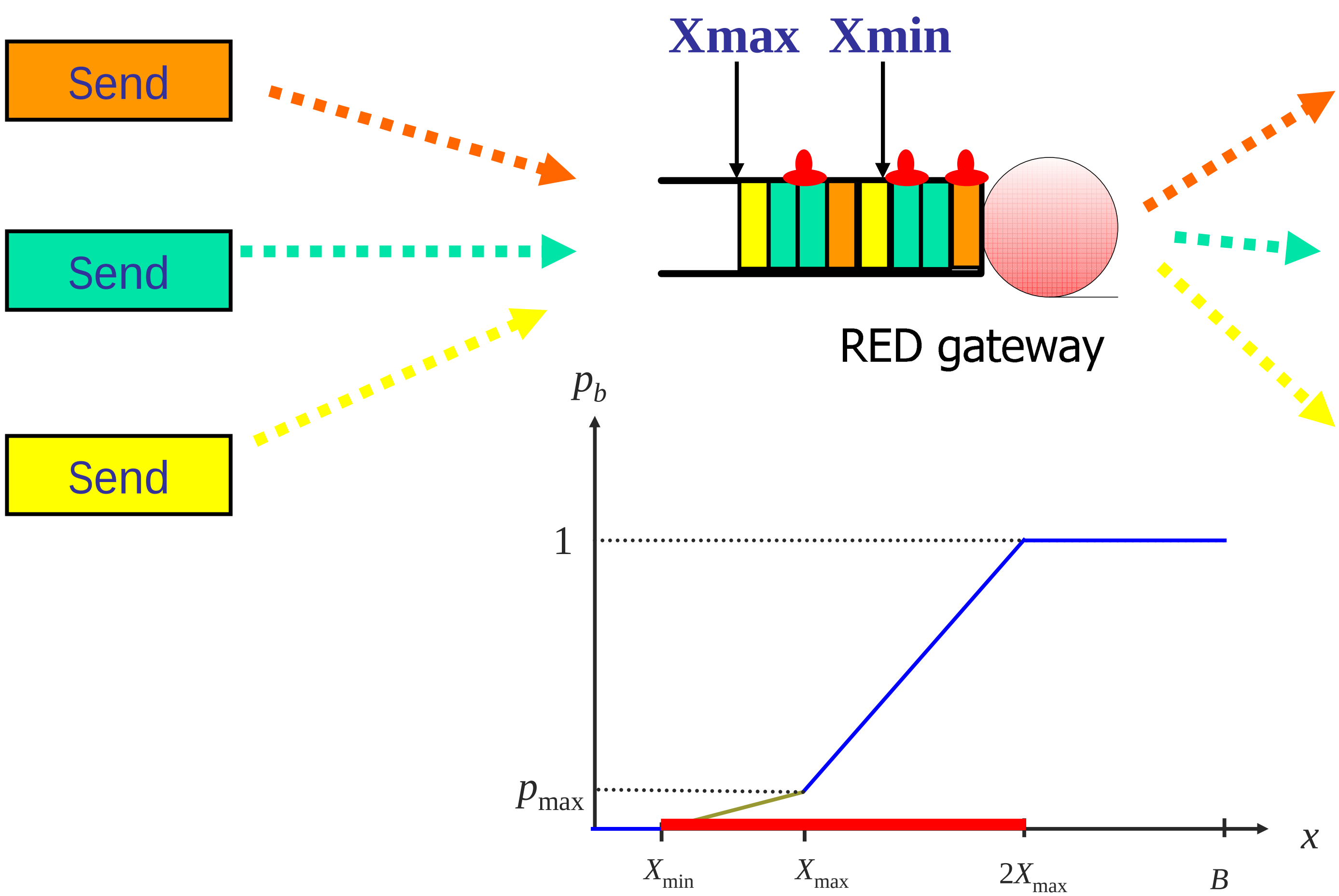
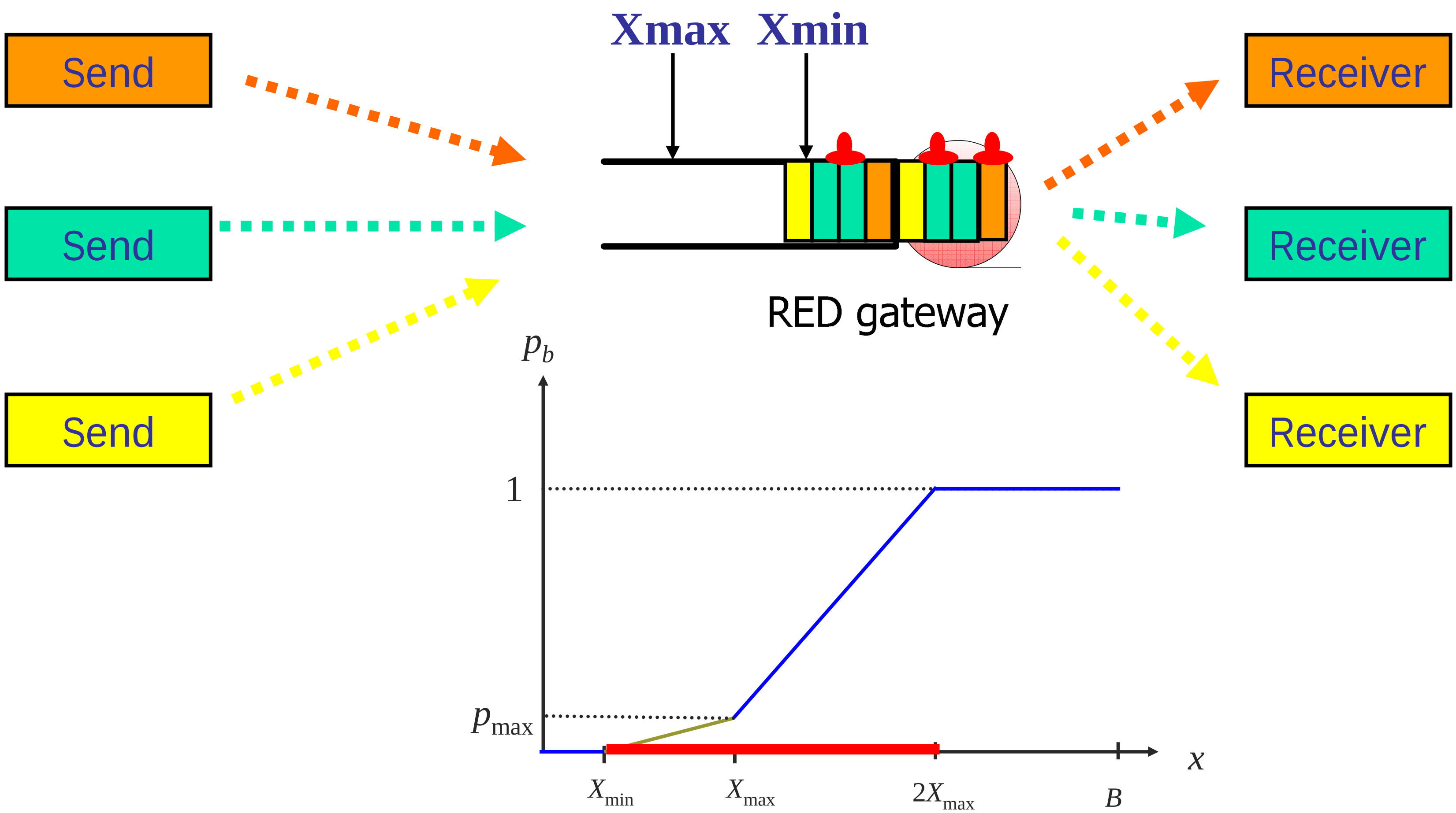


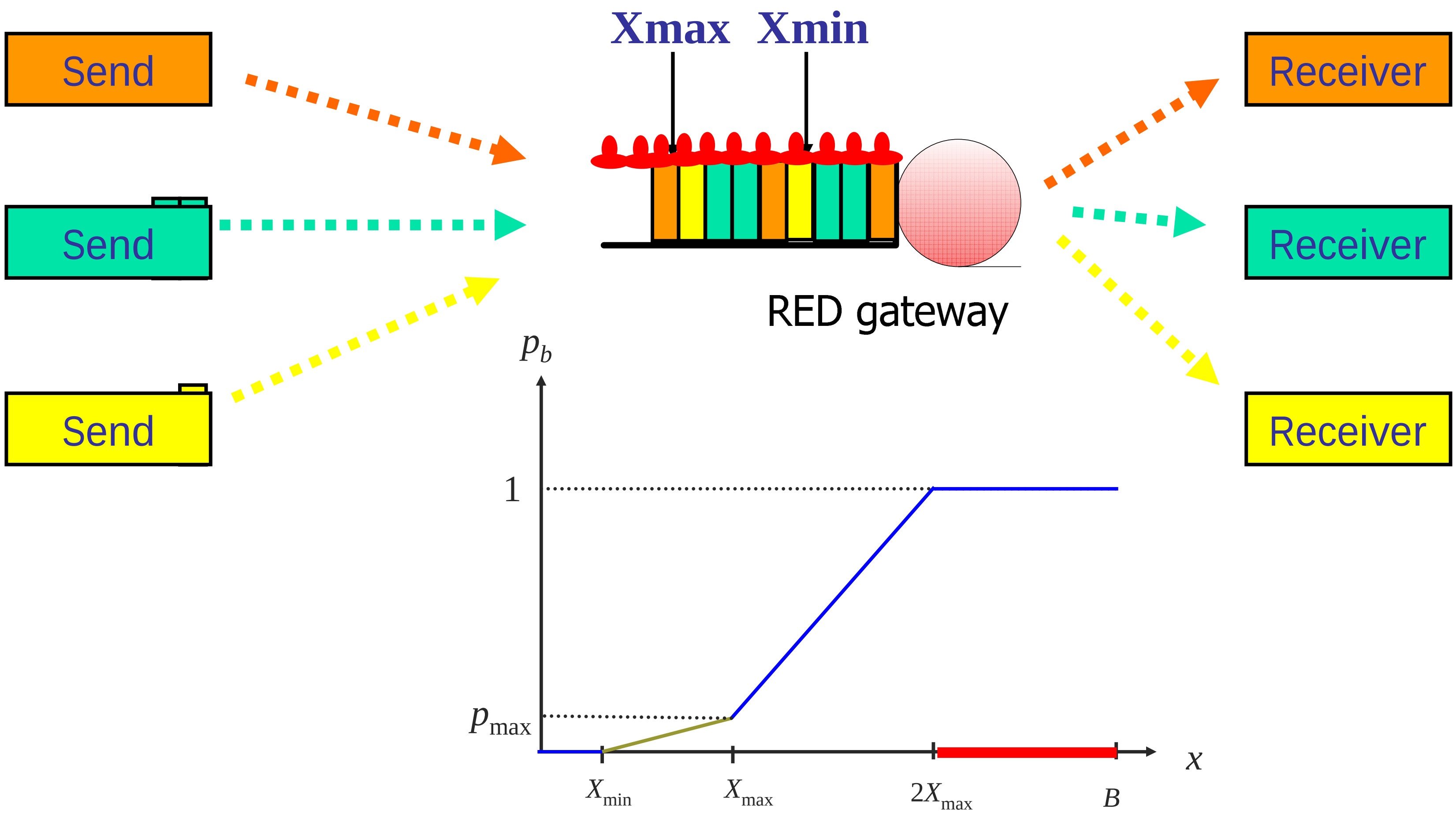
RED gateway with target queue length



RED gateway with target queue length



RED gateway with large queue length



Detrended fluctuation analysis (DFA)

DFA method:

- first proposed* for determining the statistical self-affinity of a signal.
- permits the detection of intrinsic self-similarity embedded in a seemingly nonstationary time series**, and avoids the spurious detection of apparent self-similarity, which may be an artifact of extrinsic trends.
- applied in the analysis of DNA nucleotides, fractals, electrocardiogram (ECG/ EKG), electroencephalography (EEG), climate, and stock market.

*C-K Peng, SV Buldyrev, S Havlin, M Simons, HE Stanley, and AL Goldberger, "Mosaic organization of DNA nucleotides," *Phys. Rev. E* 49: 1685-1689, 1994.

**A s*tationary* time series is characterized by its mean, standard deviation, higher moments, and correlation functions being invariant under time translation. Signals that are not stationary are *nonstationary*.

DFA computation

Consider signal s(i) of length of L

$$\bar{s} \equiv \frac{1}{L}\sum_{j=1}^{L}[s(j)]$$

Step 1: integrate s(i) and obtain $y(i) = \sum_{j=1}^{i}[s(j) - \bar{s}]$

Step 2: divide y(i) into boxes of equal length of l

Step 3: subtracting the local trend $y_l(i)$ for box of length l to detrended y(i):

$$Y_l(l) \equiv y(i) - y_l(i)$$

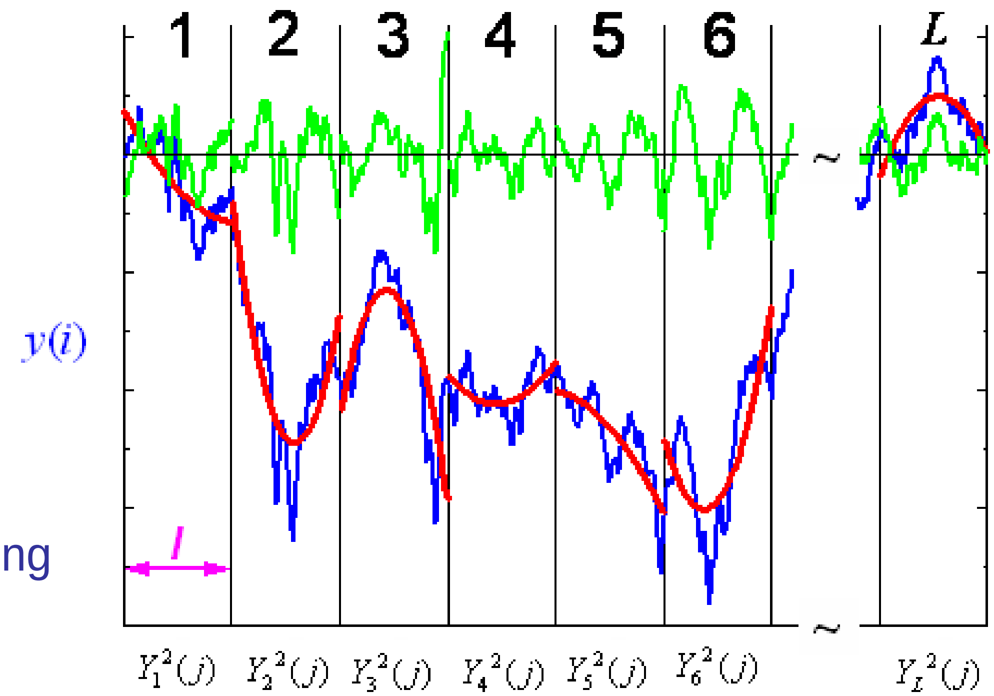
Step 4: for each box l, the characteristic size of fluctuation for the integrated and detrended time series is calculated by:

$$F(l) \equiv \sqrt{\frac{1}{L}\sum_{j=1}^{L}[Y_l(j)]^2}$$

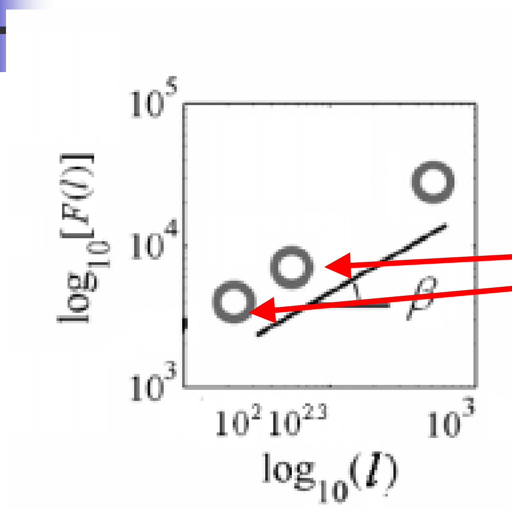
Repeat Steps 2 - 4 for several length of l (different scales)

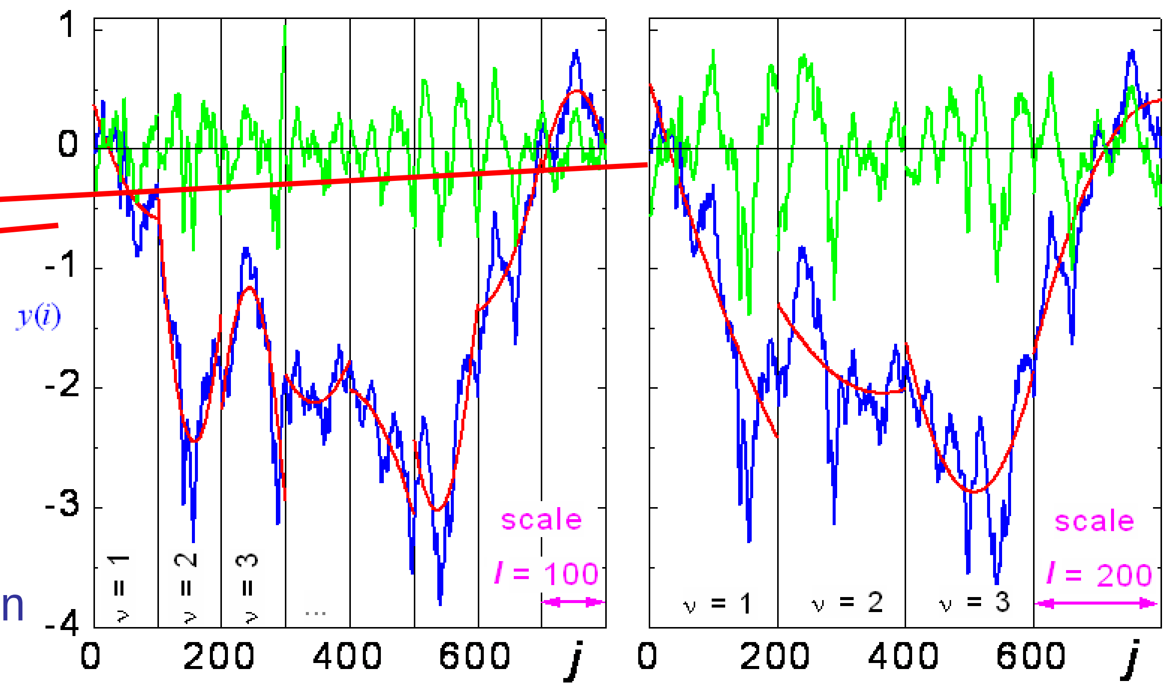
DFA method

1. Reconstruction of the **signal**
2. Splitting of the record into segments of **scale length *l***
3. **Regression** in each segment
4 Calculation of **variance** $Y(j)$ in each segment and then taking averaging to obtain $F(l)$



DFA method (cont.)





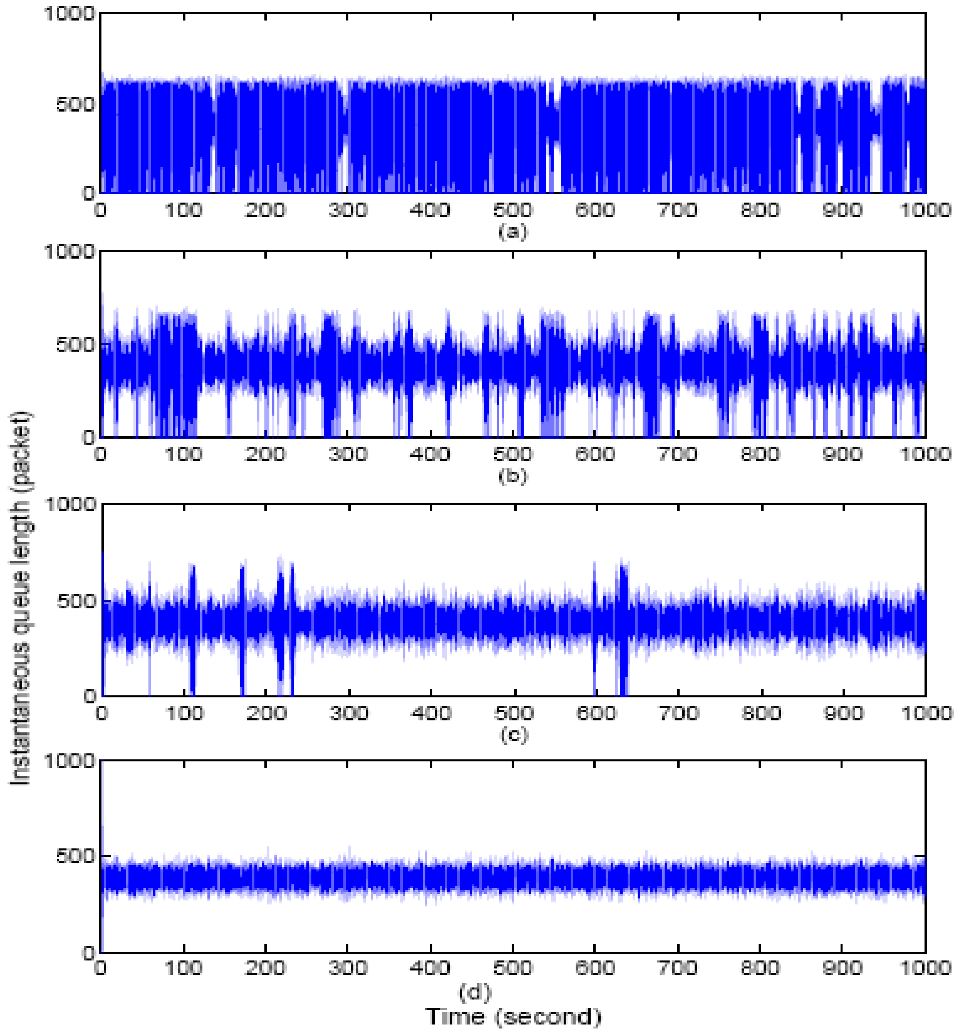
Scale invariant signals with power-law correlations between the scaling function F(l) and the scale l :

$$F(l) \propto l^{\beta}, \quad l \to \infty$$

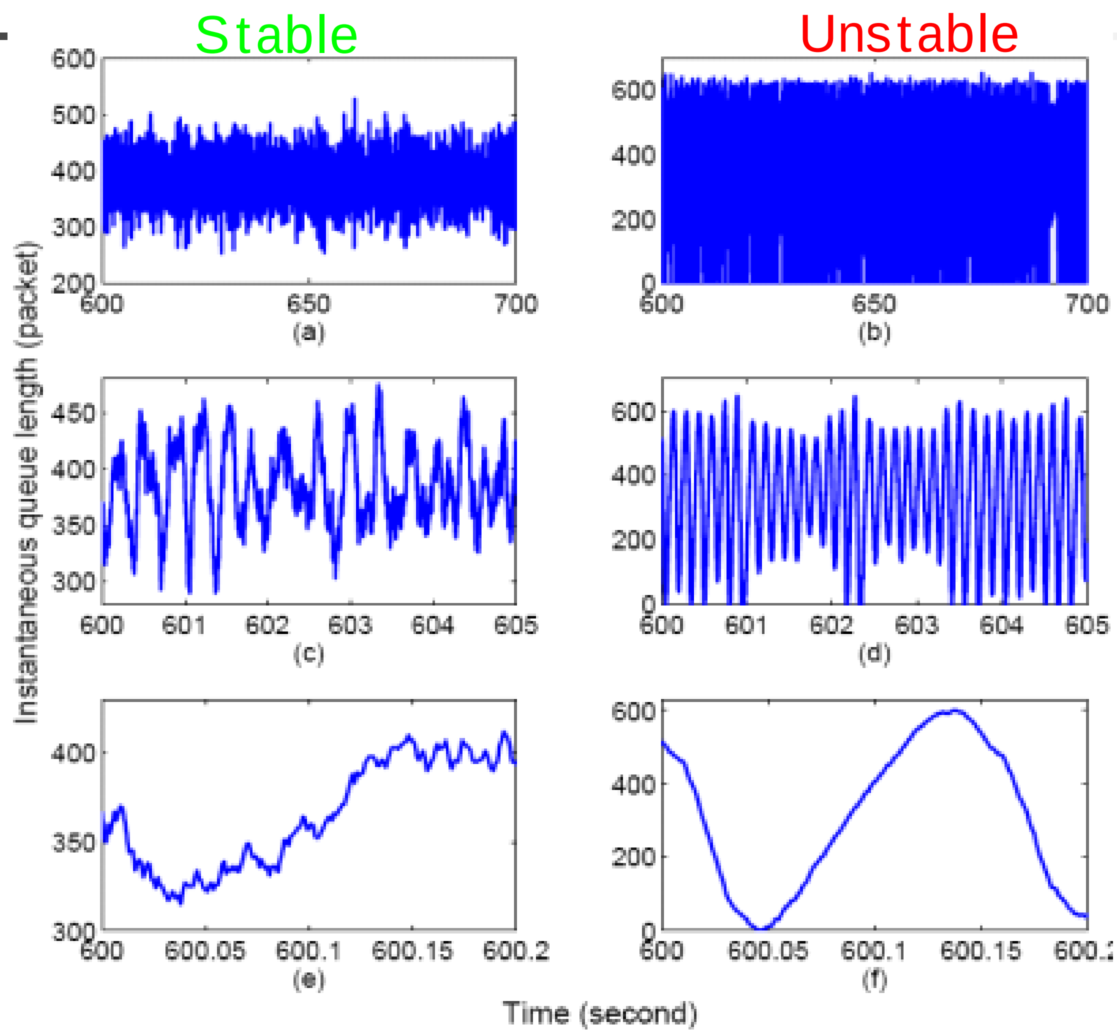
β represents the degree of the correlation.

Non stationarity and instability in TCP-RED system

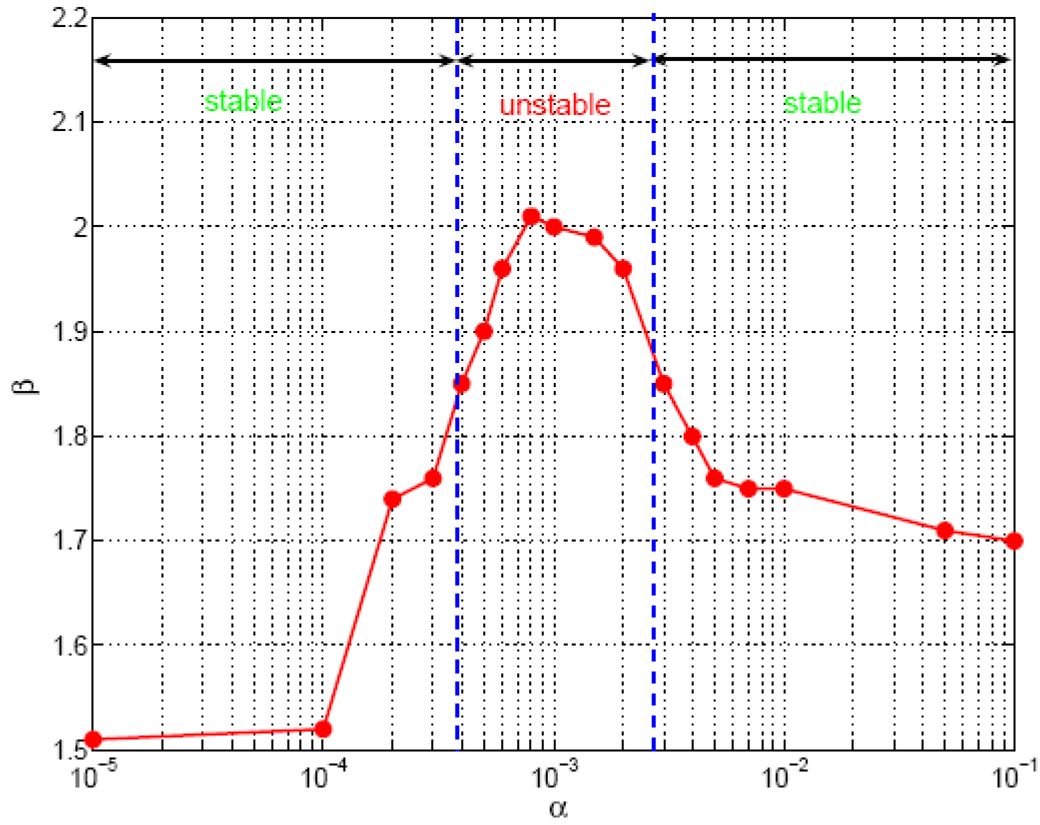
DFA method helps quantitatively describe the level of the instability of TCP-RED systems



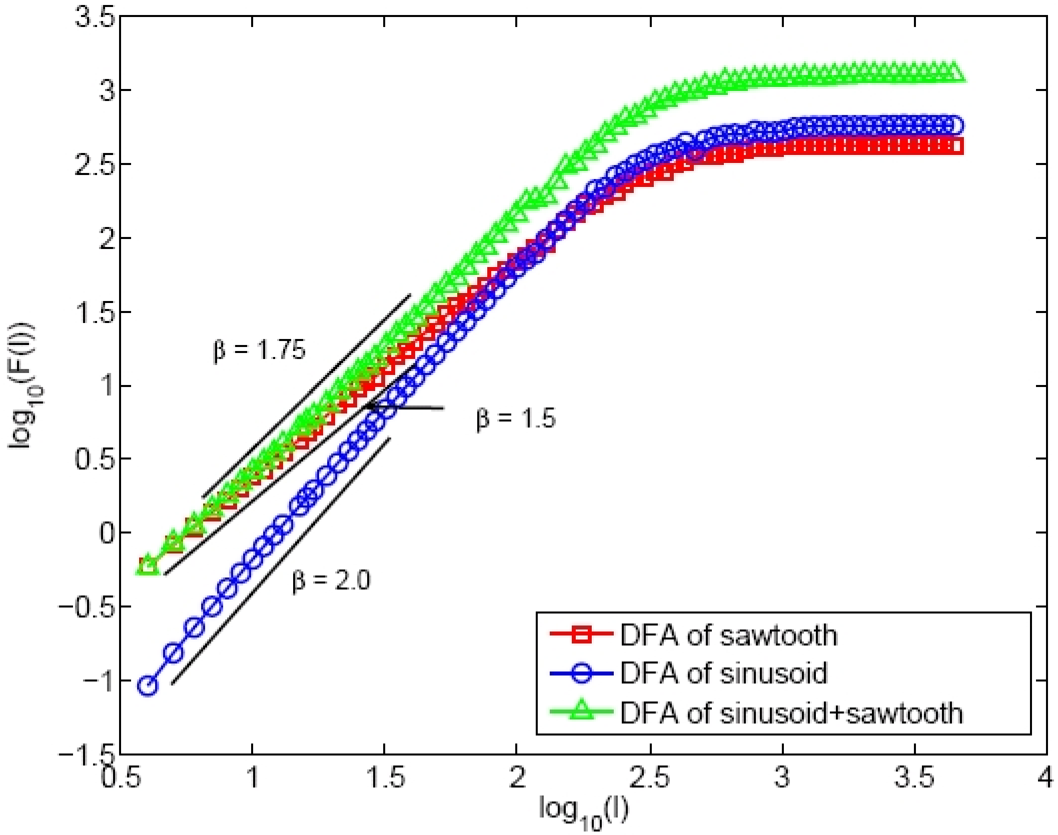
Self-similarity in TCP-RED system



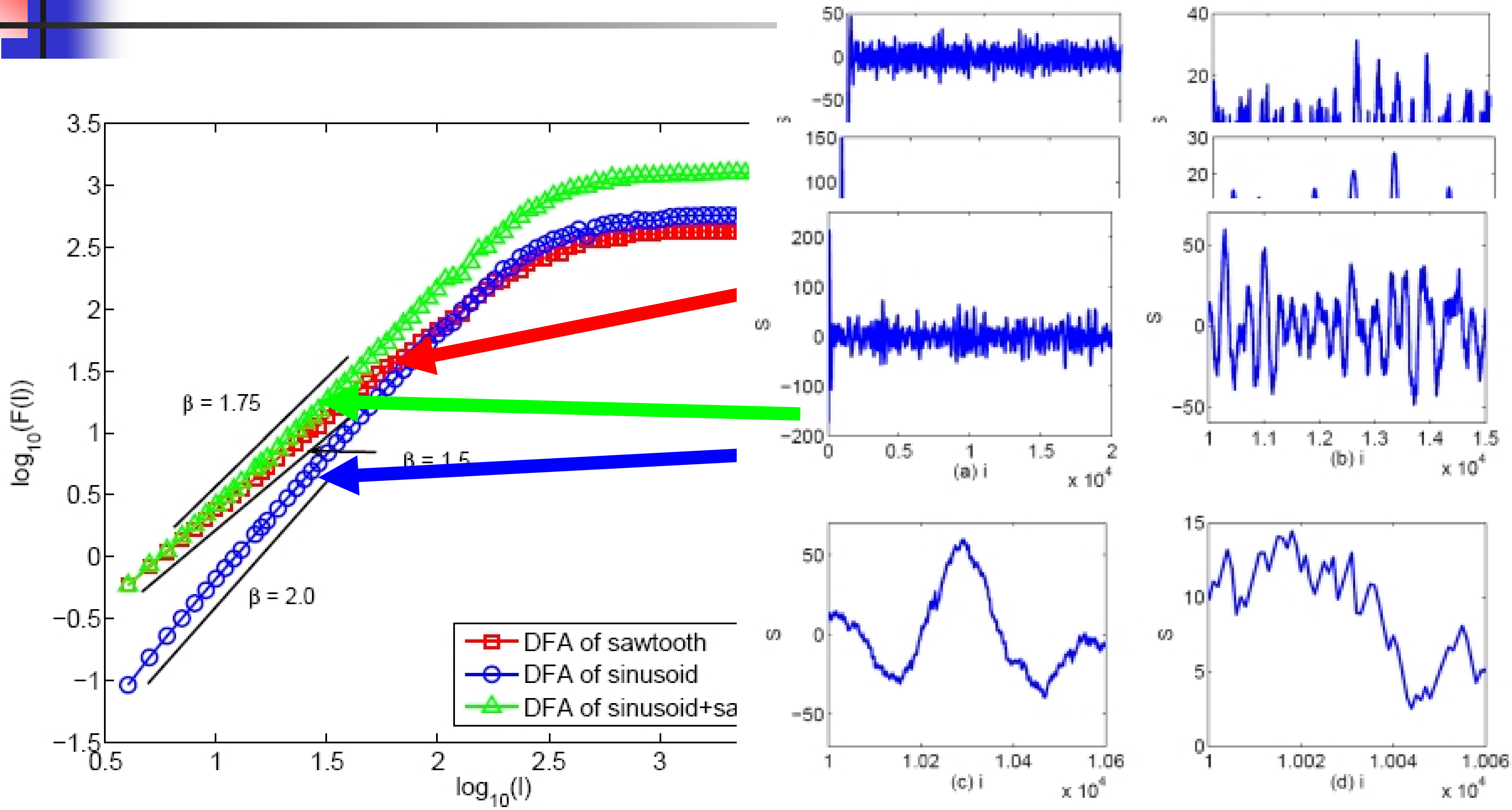
DFA results: instability



Interpretation of DFA: the waveform viewpoint



DFA exponents: sine and saw tooth



Conclusion

- Stability of the queue length has been explored using the DFA method
- The degree of instability can be described by DFA exponent, which varies with the relative stability of RED gateway
- We provided an interpretation of the relationship between the DFA exponent and the stability of RED system
- The DFA exponent may used as indicator for TCP-RED system and thus control the stability of the system