EXPERIMENTAL WIRELESS CHANNEL MODEL DERIVATION

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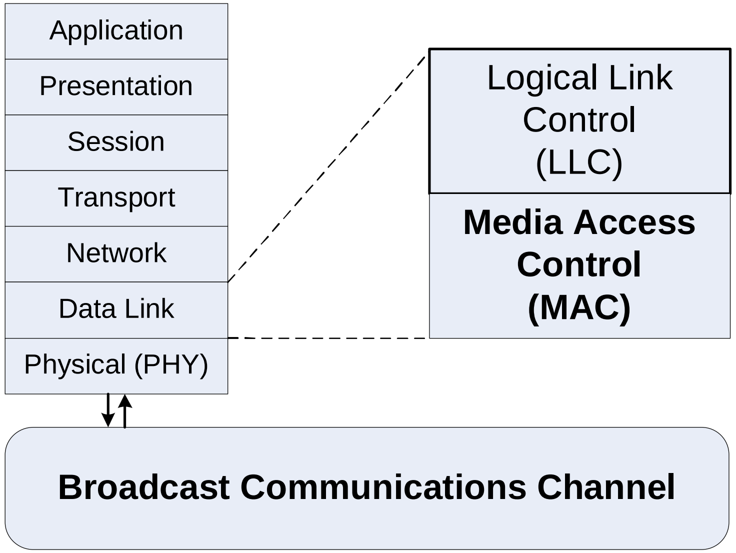
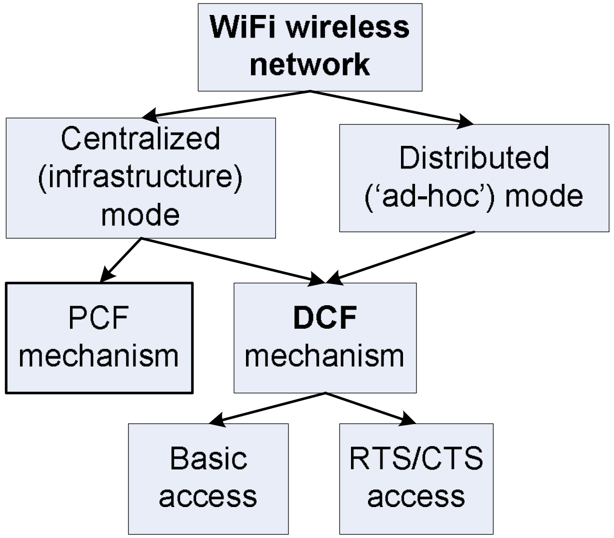
Session Outline

- Research Focus
- MAC Throughput Measurement
- Packet Error Rate Measurement
- Hidden Markov Models Summary
- Appropriate State Space Selection
- 2-state Model Description
  and Parameters Derivation
- Conclusion

Research Focus

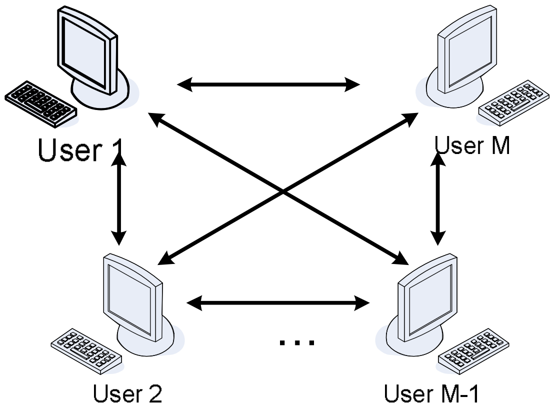
OSI Layers



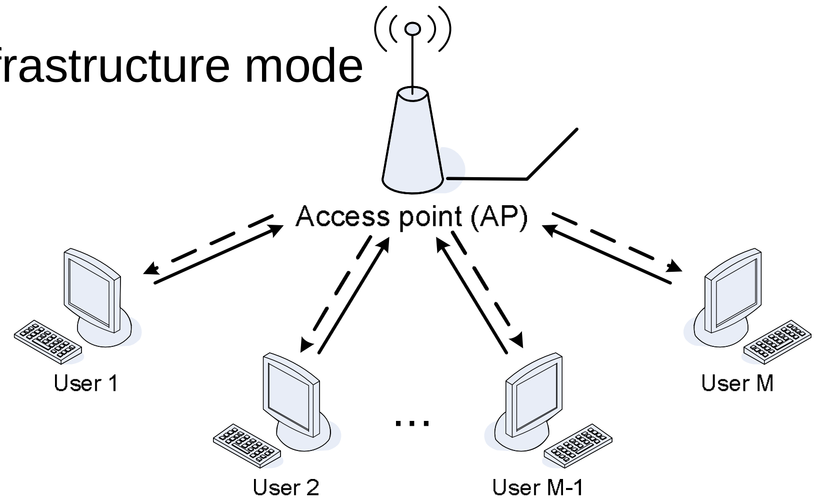


Consider IEEE 802.11g (WiFi) telecommunications standard

'Ad-hoc' mode

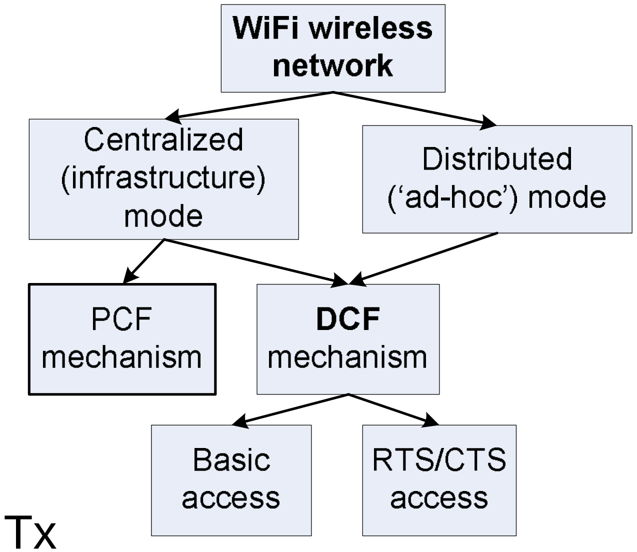


Infrastructure mode

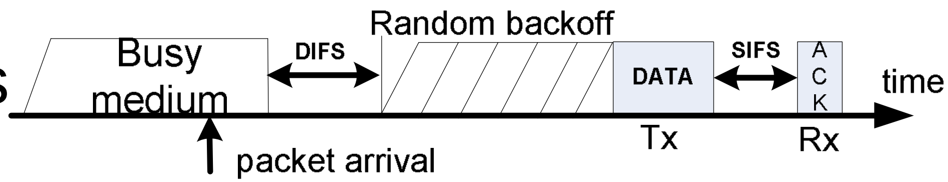


DCF Mode Operation

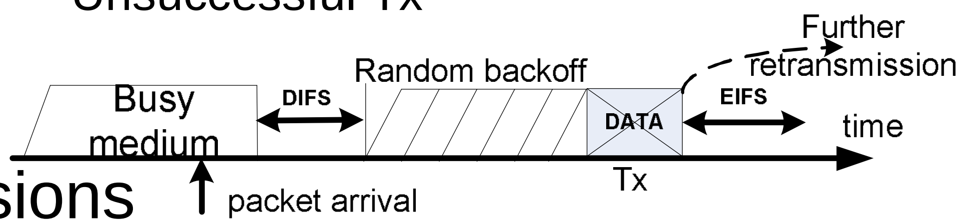
- Distributed Coordination Function (DCF) is a **randomized** channel access **scheme**
- **Packet corruption** and **collisions** are handled by Automatic Repeat reQuest (ARQ) mechanism that relies on packet **retransmission**
- Retransmission **obscures** real channel situation for the upper layers as the actual number of retransmissions is a **random variable**



Successful Tx



Unsuccessful Tx

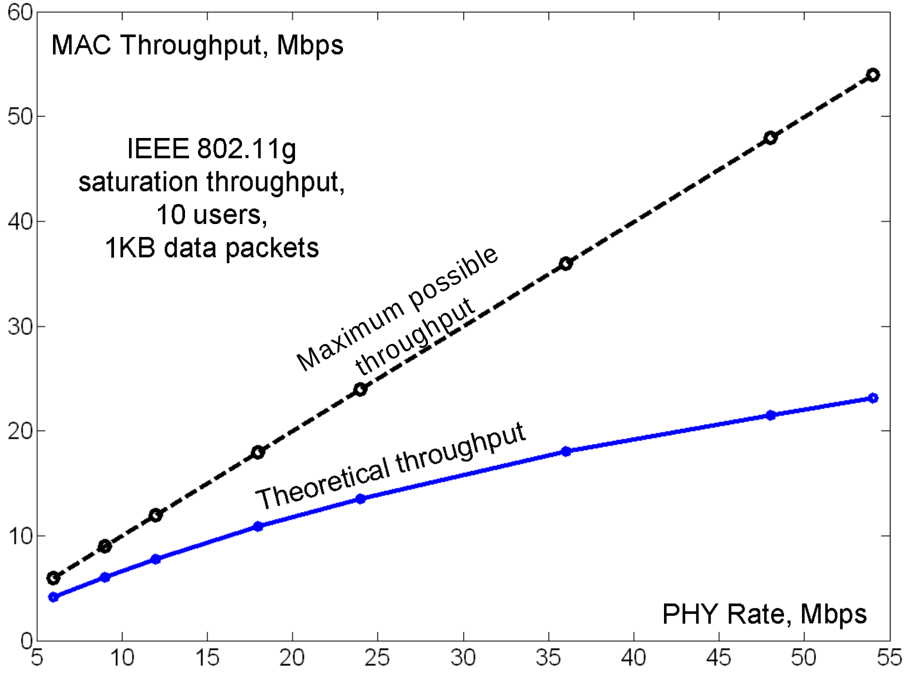


Problem Statement

- **Measure** IEEE 802.11g **MAC throughput** with high time resolution (required for real-time video transmission modeling)
- **Obtain** mean **packet error rate** without packet retransmission
- **Collect** realistic **packet error traces**
- **Build** appropriate **error source model** (required to calculate transport coding parameters)

Expected MAC Throughput

- Follow Bianchi (2000) approach to calculate **throughput in saturation conditions**
- **Gap** between PHY rate and MAC throughput **increases** as rate grows

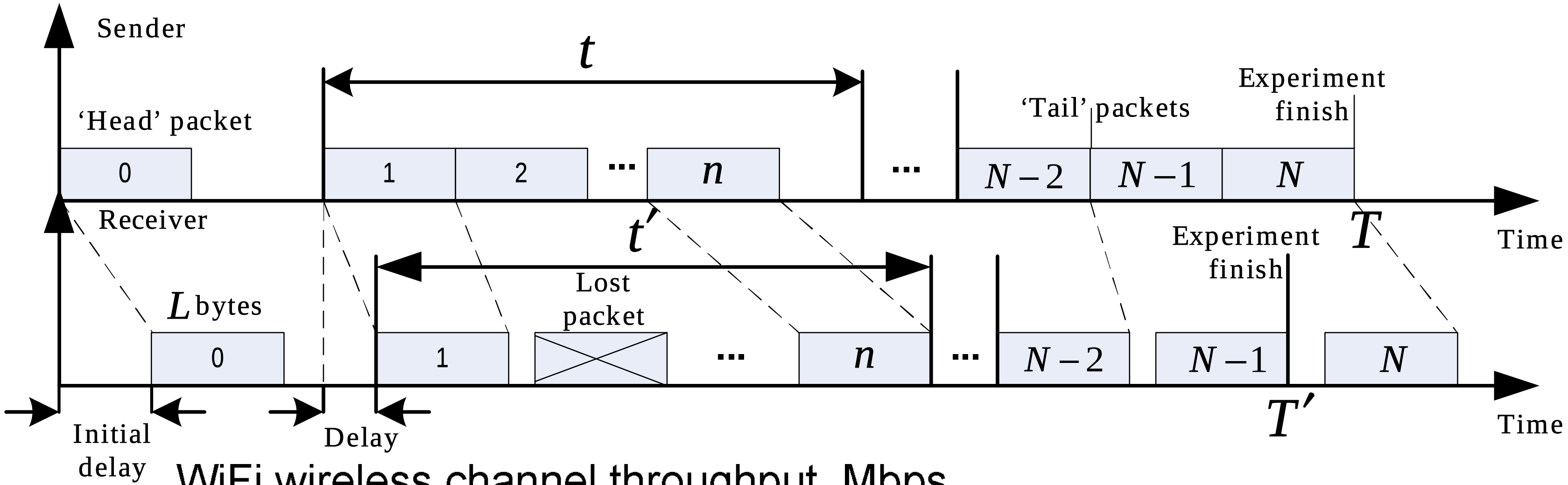


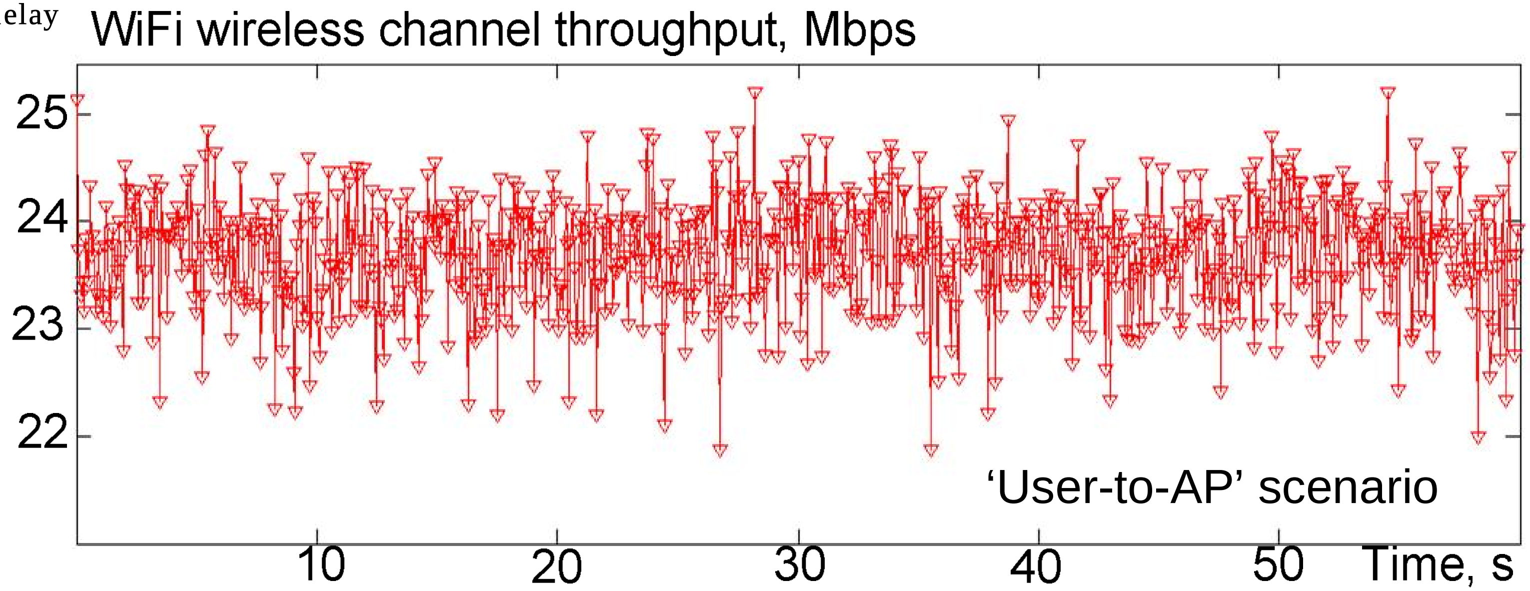
Main considerations

- To measure actual throughput adequately **retransmission should be disabled!**
- Existing tools are **incapable** of measuring throughput with **high time resolution***

* see discussion in S. Andreev, S. Semenov, A. Turlikov “Methods of estimation of radiochannel parameters”, 2007

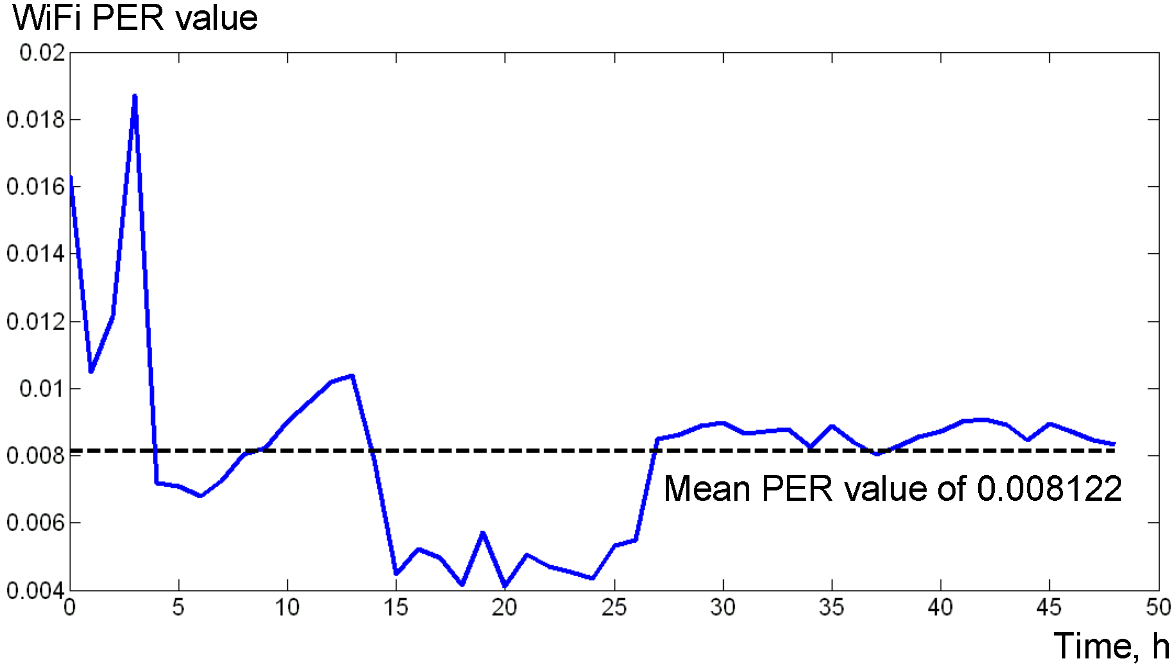
Proposed Measuring Methodology

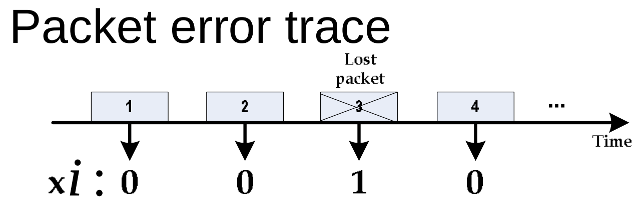




Measured throughput accords with Bianchi theoretical estimation!

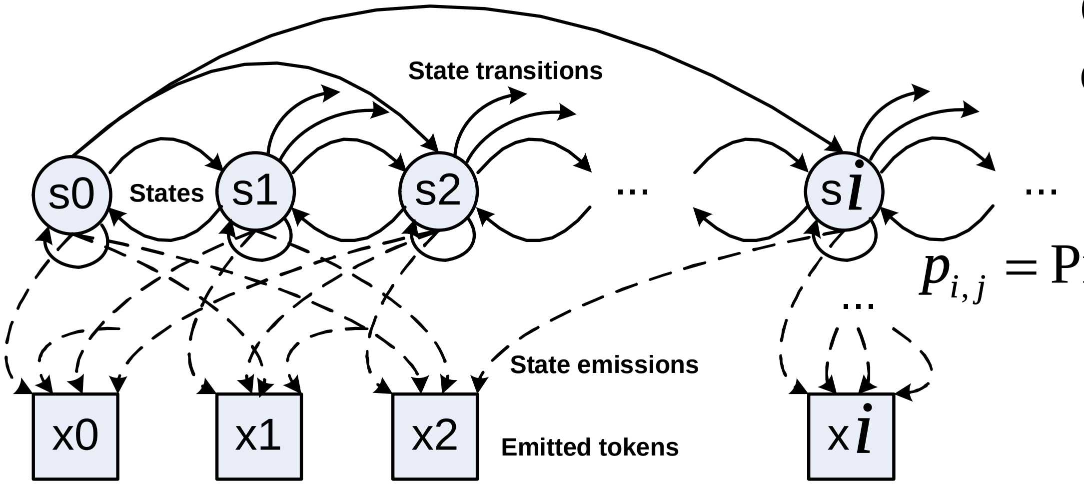
Packet Error Rate (PER) Measurement





- Average PER with disabled retransmission is **below 1%**
- A model is needed to **describe PER behavior** for realistic **packet error traces**
- Main target: maintain **simplicity – precision balance**
- Renown technique is to use Hidden Markov Models **(HMM)**

Hidden Markov Model (HMM) Summary



Given by **transition** and **emission** probability matrices

$$p_{i,j} = \Pr\{s_{t+1} = j \mid s_t = i\} = \begin{bmatrix} p_{1,1} & p_{1,2} & \dots \\ p_{2,1} & p_{2,2} & \dots \\ \dots & \dots & \dots \end{bmatrix}$$

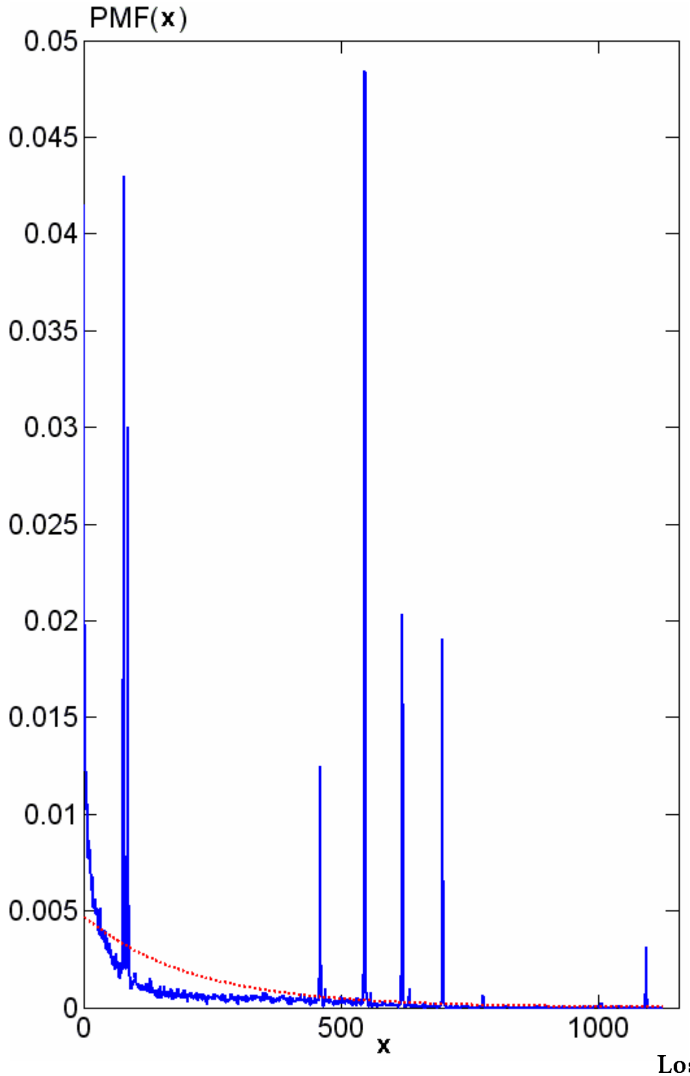
$$e_{i,j} = \Pr\{x_t = j \mid s_t = i\} = \begin{bmatrix} e_{1,1} & e_{1,2} & \dots \\ e_{2,1} & e_{2,2} & \dots \\ \dots & \dots & \dots \end{bmatrix}$$

Canonical problems

- Compute the probability of a particular output sequence for known parameters (forward-backward algorithm)
- Find the most likely sequence of hidden states for known parameters (Viterbi algorithm)
- **Find** the most likely set of **state transition and emission probabilities** given an output sequence of **x** i (Baum-Welch algorithm*)

* is **highly complex** and requires initial estimates of the transition and emission matrices

Binary Symmetric Channel (BSC) Assumption

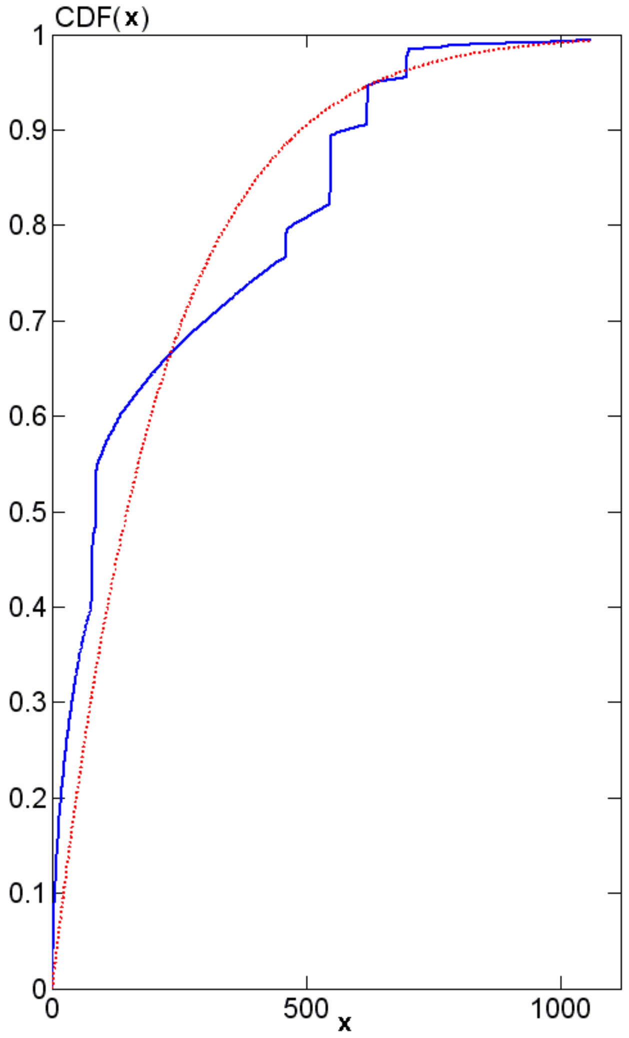


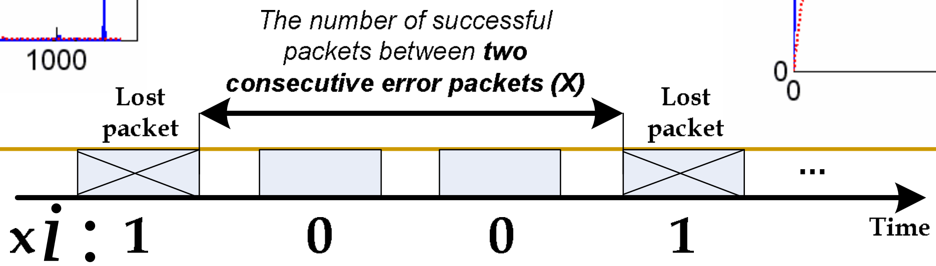
PMF for the number of successful packets between ***two consecutive error packets****: theory (dotted) and practice (solid)*

$$PMF(x) = \begin{cases} \Pr(X = x), x \in S \\ 0, x \in R \setminus S \end{cases}$$

CDF for the number of successful packets between ***two consecutive error packets****: theory (dotted) and practice (solid)*

$$CDF(x) = \Pr(X \leq x)$$





Previous Models

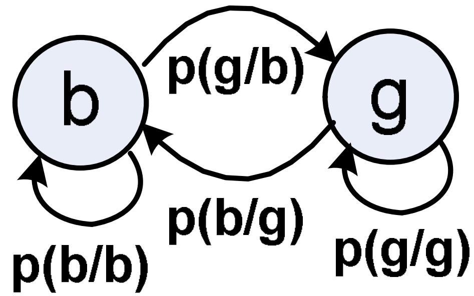
- Bit level models (PHY bit inversion probability)
  - Gilbert model, 1960
  - Gilbert-Elliott model, 1963
  - Wang et al., Zorzi et al., 1995-96
    (relevance of the 2-state model)
  - Lyakhov et al., 2004
    (2-state model for WiFi **with retransmissions**)

- Packet level models (Use with **packet error traces**)
  - Zorzi et al., 1997
    (2-state model is good at packet level)
  - Giao et al., Konrad et al., 1996-2001 (realistic data)
  - Wang et al., 1995 (larger Markov chain state space)

2-state HMM Definition

- Markov chain transition probabilities:

$$P = \begin{bmatrix} p(g/g) & p(b/g) \\ p(g/b) & p(b/b) \end{bmatrix}$$



- **Matrix 2-state model:**

$$A(0) = \begin{bmatrix} q_g p(g/g) & q_b p(b/g) \\ q_g p(g/b) & q_b p(b/b) \end{bmatrix} \qquad A(1) = \begin{bmatrix} p_g p(g/g) & p_b p(b/g) \\ p_g p(g/b) & p_b p(b/b) \end{bmatrix} \qquad \overline{a_0} = (p(g), p(b)) \quad \overline{b_0} = (1,1)^T$$

- Probability of a given error sequence:

$p(\bar{e}) = p(e_1, e_2, ..., e_n) = \overline{a_0} \prod_{i=1}^{n} A(e_i) \cdot \overline{b_0}$ instead of

$$p(\bar{e}) = \sum_{s_0} \sum_{s_1} \ldots \sum_{s_n} p(s_0) \cdot p(s_1 | s_0) \cdot p(e_1 | s_1) \cdot \ldots \cdot p(s_n | s_{n-1}) \cdot p(e_n | s_n)$$

- Easy way to calculate $P(m,n)$ characteristics

Model Parameters Derivation

- Denote 0^i and 1^j the sequences of i zeros and j ones:

$$a_{00} = \frac{p^2(0^2) - p(0)p(0^3)}{p(0^2) - p^2(0)} \quad a_{01} = \frac{p(0^3) - p(0)p(0^2)}{p(0^2) - p^2(0)} \quad A = 1 + \frac{a_{00} - a_{10}}{a_{11} + a_{01} - 1}$$

$$a_{10} = \frac{p^2(1^2) - p(1)p(1^3)}{p(1^2) - p^2(1)} \quad a_{11} = \frac{p(1^3) - p(1)p(1^2)}{p(1^2) - p^2(1)} \quad B = \frac{-a_{10}}{a_{11} + a_{01} - 1}$$

- The **resulting expressions*** for the 2-state model:

$$p_b = \frac{A + \sqrt{A^2 - 4B}}{2} \quad p_g = \frac{A - \sqrt{A^2 - 4B}}{2}$$

$$p(b/b) = \frac{(a_{11} + a_{01})p_g - a_{11}}{p_g - p_b} \quad p(g/g) = \frac{a_{11} - p_b(a_{11} + a_{01})}{p_g - p_b}$$

$$p(g/g) = 0.9999$$
$$p(b/b) = 0.9188$$
$$p_g = 0.0044$$
$$p_b = 0.5423$$

* see discussion in S. Andreev, A. Vinel "Gilbert-Elliott Model Parameters Derivation for the IEEE 802.11 Wireless Channel", 2007

Conclusion

- Achievements
  - A method to measure MAC throughput with high time resolution is introduced
  - Realistic packet error traces of IEEE 802.11g are obtained
  - Appropriate hidden Markov model selection is addressed
  - 2-state wireless experimental model is built
  - The results are published in 2 articles during 2007

- Open problems
  - Perform goodness-of-fit check of a introduced model
  - Account for ‘peaks’ in the experimental PMF
  - Compare the derived model with alternatives

    (e. g. D. Moltchanov “Cross-layer performance evaluation and control of wireless channels in NG All-IP networks”, Ph.D. thesis, 2006)

Discussion