Contention window optimization for IEEE 802.11 DCF access control

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Contention Window Optimization for IEEE 802.11 DCF Access Control

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IEEE Transaction on Wireless Communication

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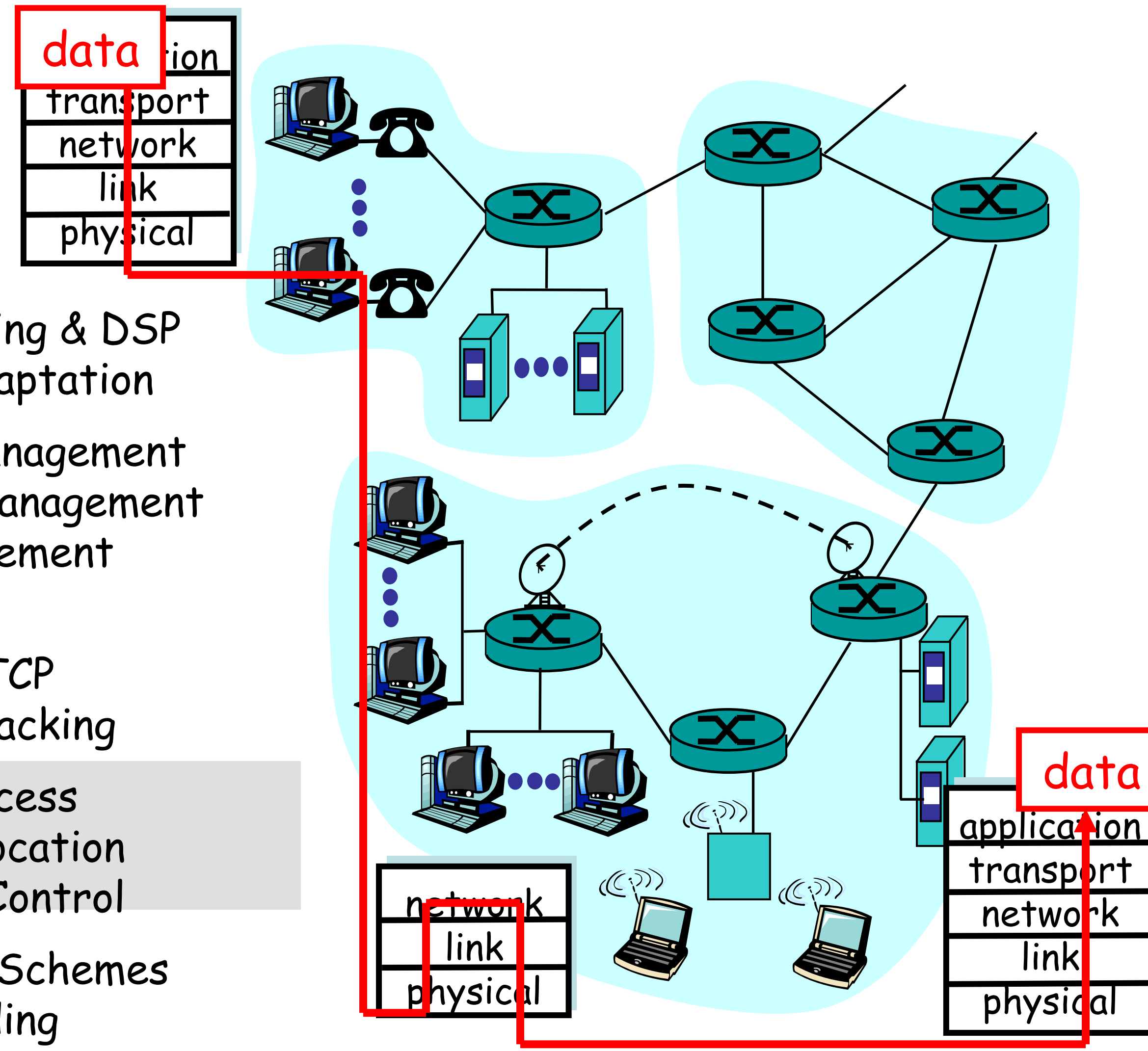
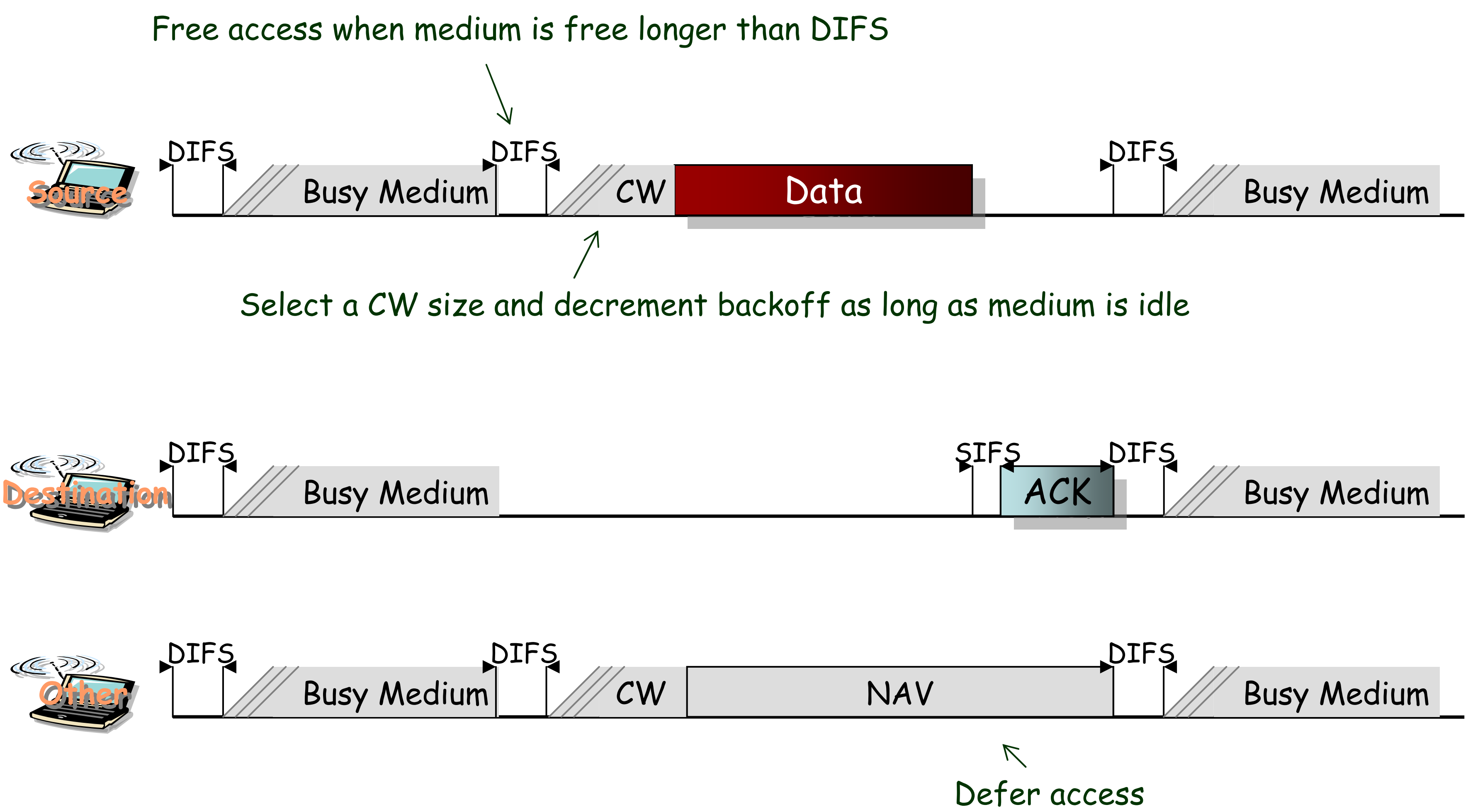
Generic Mobile computing System Arch.

This talk will cover:

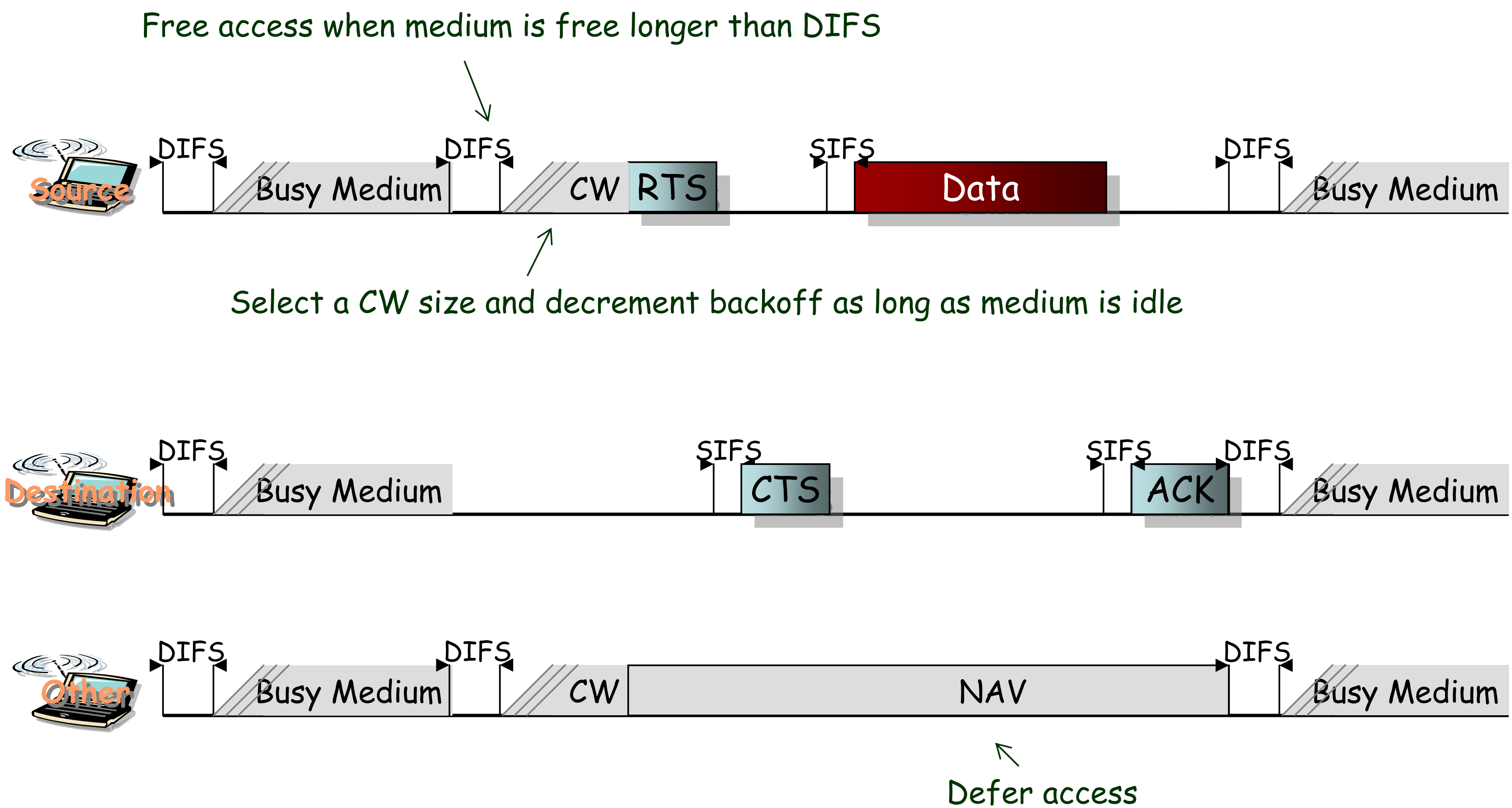
Application & Services	Partitioning Source Coding & DSP Context Adaptation
OS & Middleware	Mobility Management Resource Management QoS Management
Network	Rerouting Impact on TCP Location Tracking
Data Link	Multiple Access Channel Allocation Link Error Control
Radio	Modulation Schemes Channel Coding RF Circuit



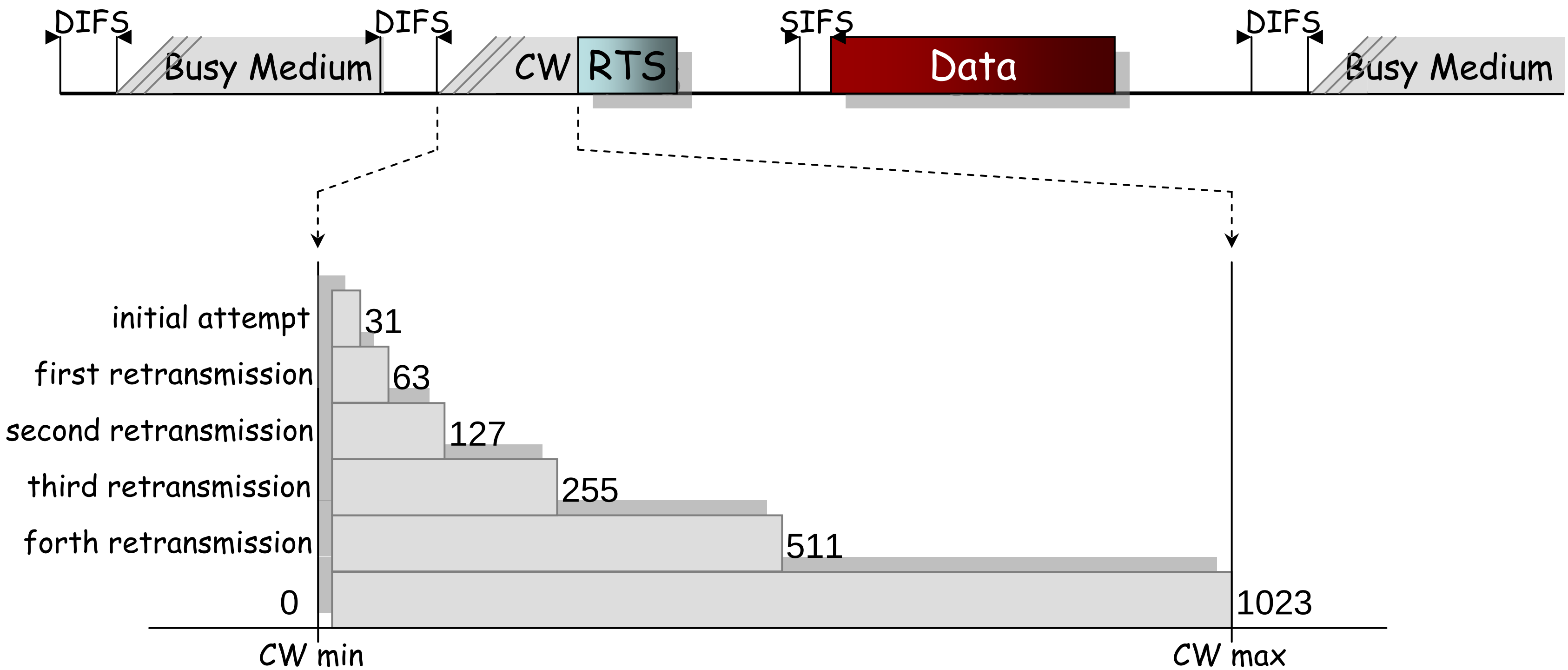
Basic Access Method (CSMA/CA)



RTS/CTS Mechanism

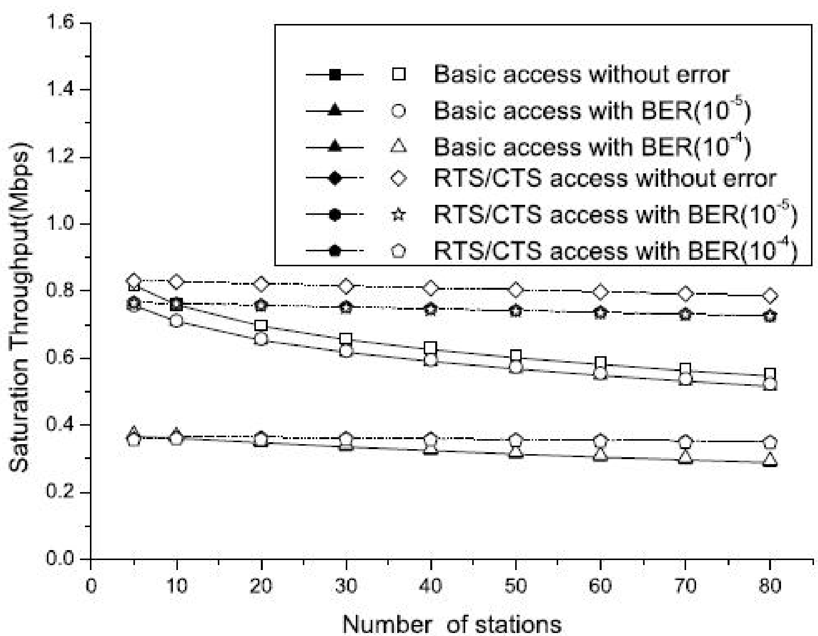


Exponential Backoff

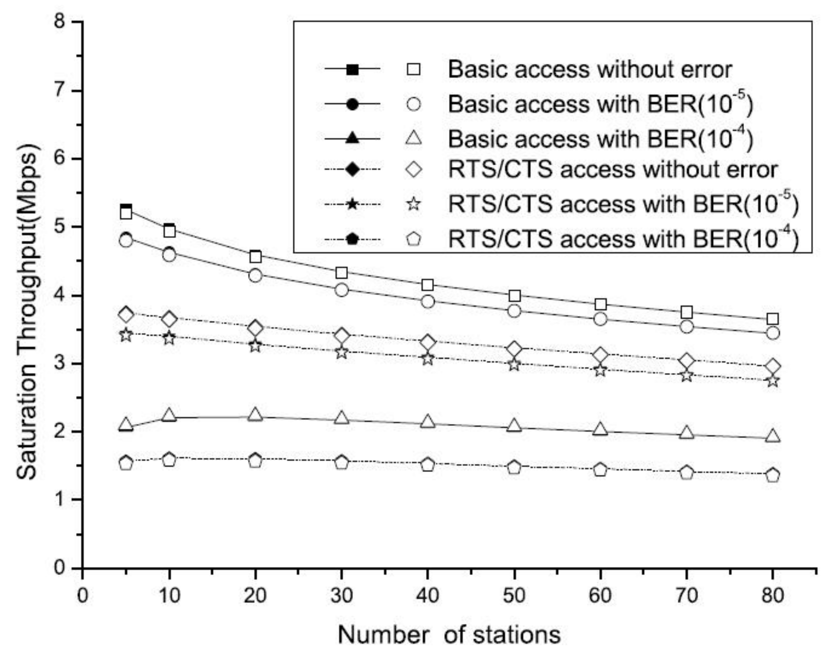


$$\left\lfloor random\_function() \times 2^{5+i} \right\rfloor \times \text{time slot}$$

Throughput Efficiency



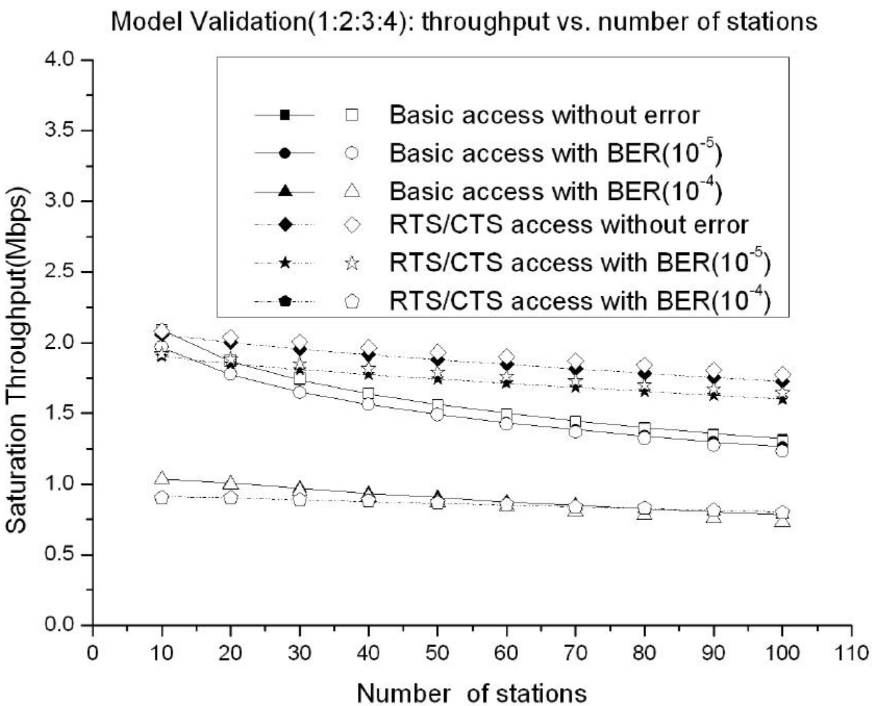
single-rate, 1 Mbps



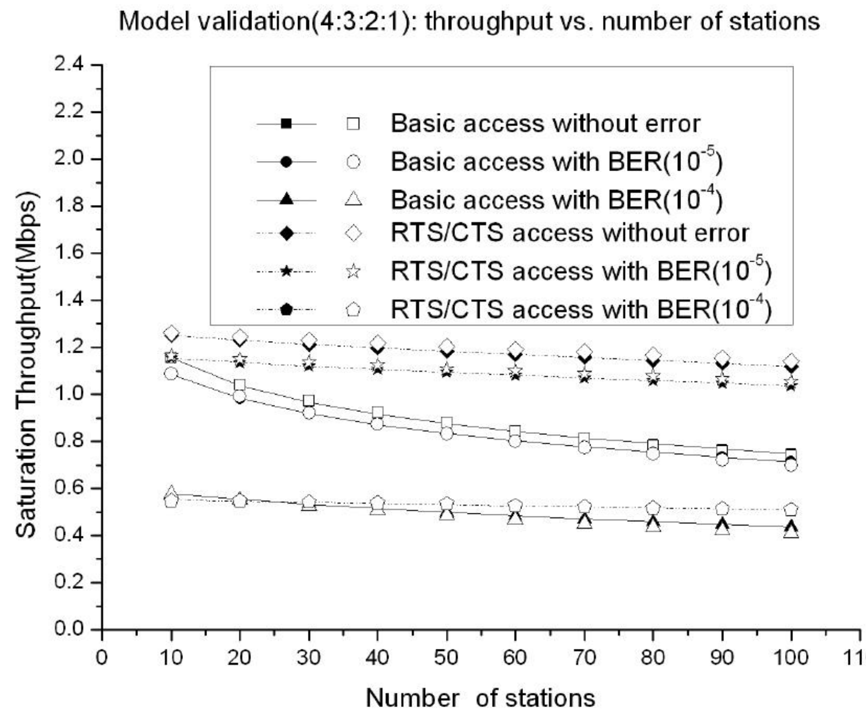
single-rate, 11 Mbps

D. J. Deng, L. Bin, L. F. Huang, C. H. Ke, and Y. M. Huang, "Saturation Throughput Analysis of Multi-rate IEEE 802.11 Wireless Networks," accept for publications in *Wireless Communications and Mobile Computing.*

Throughput Efficiency



multi-rate, 1, 2, 5.5, 11 Mbps



multi-rate, 1, 2, 5.5, 11 Mbps

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Congested Scenario

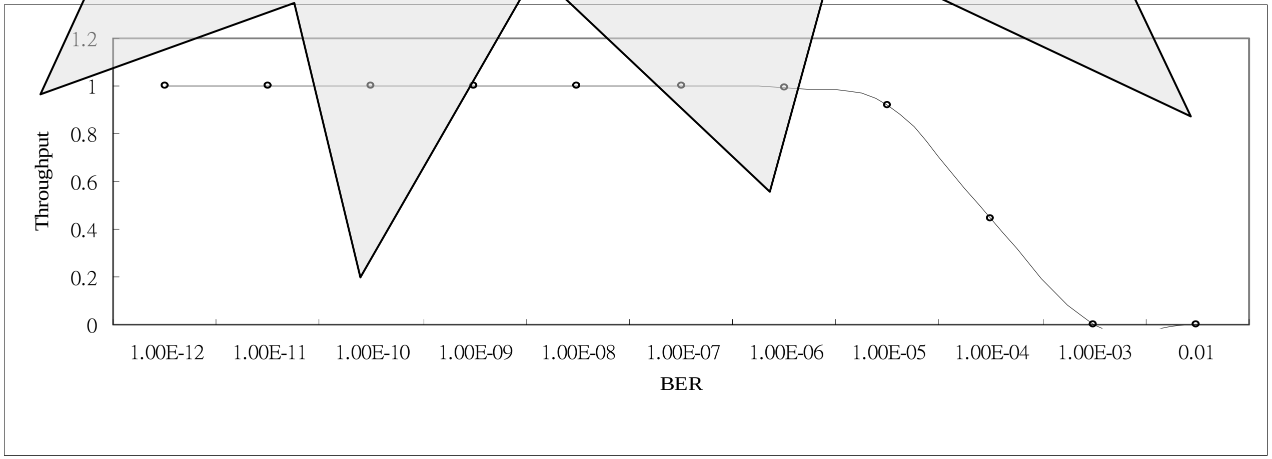
- The usage of backoff algorithm avoids long access delays when the load is light because it selects an initial (small) parameter value of contention window (CW) by assuming a low level of congestion in the system.
- This strategy might allocate initial size of CW, only to find out later that it is not enough when the load increased, but each increase of the CW parameter value is obtained paying the cost of a collision (bandwidth wastage)
- After a successful transmission, the size of CW is set again to the minimum value without maintaining any knowledge of the current channel status.

It incurs a high collision probability
and channel utilization is degraded
in bursty arrival or congested scenarios

Noisy Environment

- In DCF access method, immediate positive acknowledgement informs the sender of successful reception of each data frame
- In case an acknowledgement is not received, the sender will presume that the data frame is lost due to collision, not by frame loss.
- Unfortunately, wireless transmission links are noisy and highly unreliable, for example, for BER= 10^{-4}, the probability of receiving a full data frame correctly is less than 30%.

The proper approach to dealing with lost frames is to send them again, and as quickly as possible



Geometric Distribution

Consider a sequence of Bernoulli trails with the probability of success on being *P*. Let r.v. X denote the number of trials up to and including the first success

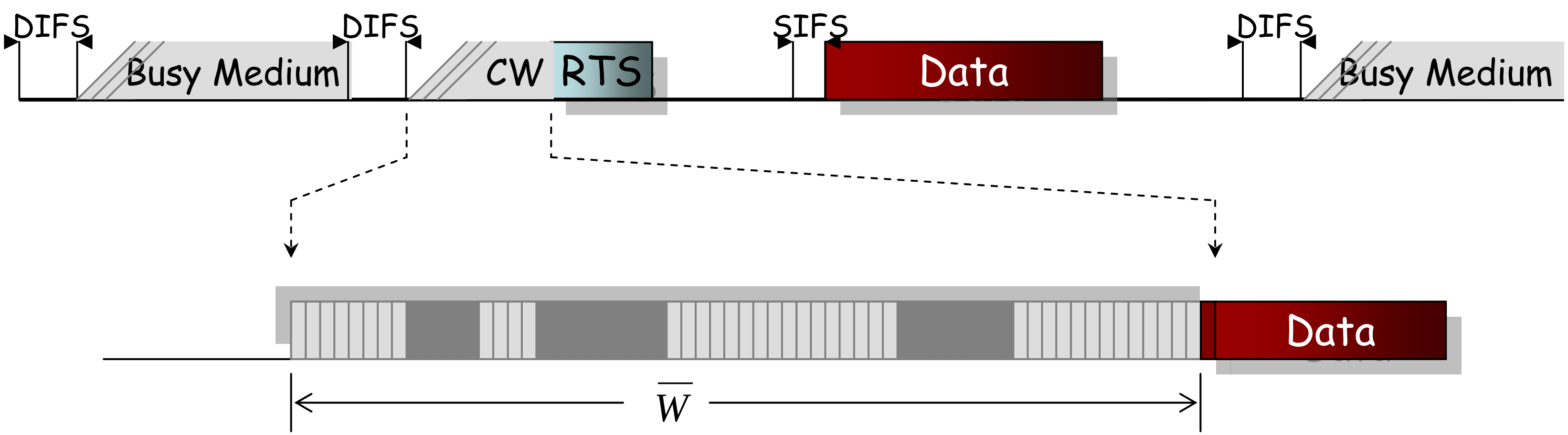
$$f(x) = (1-p)^{x-1} \cdot p, \quad 1 \le x \le \infty$$

$$E(X) = \sum x \cdot f(x) = \sum_{x=1}^{\infty} x \cdot p(1-p)^{x-1}$$

$$= \frac{p}{1-p} \sum_{x=1}^{\infty} x(1-p)^{x}$$

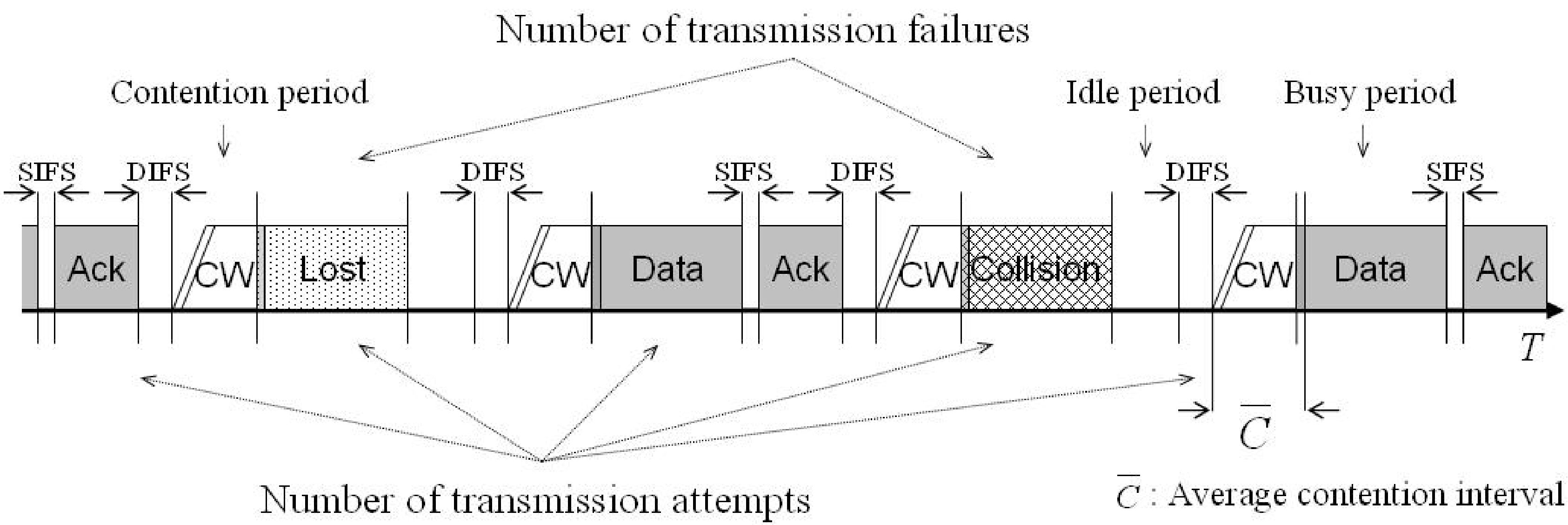
$$= \frac{p}{1-p} \cdot \frac{1-p}{(1-(1-p))^2} = \frac{1}{p}$$

P-Persistent CSMA/CA



$$\frac{\overline{W}+1}{2}=\frac{1}{p}\Rightarrow\overline{W}=\frac{2}{p}-1$$

Runtime Estimate Channel Status



$$p_f = \frac{\text{Number of transmission failures}}{\text{Number of transmission attempts}}$$

Average CW size

$$\overline{W} = \frac{(1-p_f)W + p_f(1-p_f)2W + p_f^2(1-p_f)2^2W + \ldots + p_f^m(1-p_f)2^mW}{1-p_f^{m+1}}$$

$$= \frac{W(1-p_f)[\frac{1-(2p_f)^{m+1}}{1-2p_f}]}{1-p_f^{m+1}} = \frac{W(1-p_f)[1-(2p_f)^{m+1}]}{(1-2p_f)(1-p_f^{m+1})}$$

$$p = \frac{2(1-2p_f)(1-p_f^{m+1})}{W(1-p_f)[1-(2p_f)^{m+1}]+(1-2p_f)(1-p_f^{m+1})}$$

No. of Active Stations Estimation

$$p_f = 1 - (1-p)^{M-1} \times (1 - BER)^{L_{DATA}}$$

$$M = 1 + \frac{\log\left[\dfrac{1-p_f}{(1-BER)^{L_{DATA}}}\right]}{\log(1-p)}$$

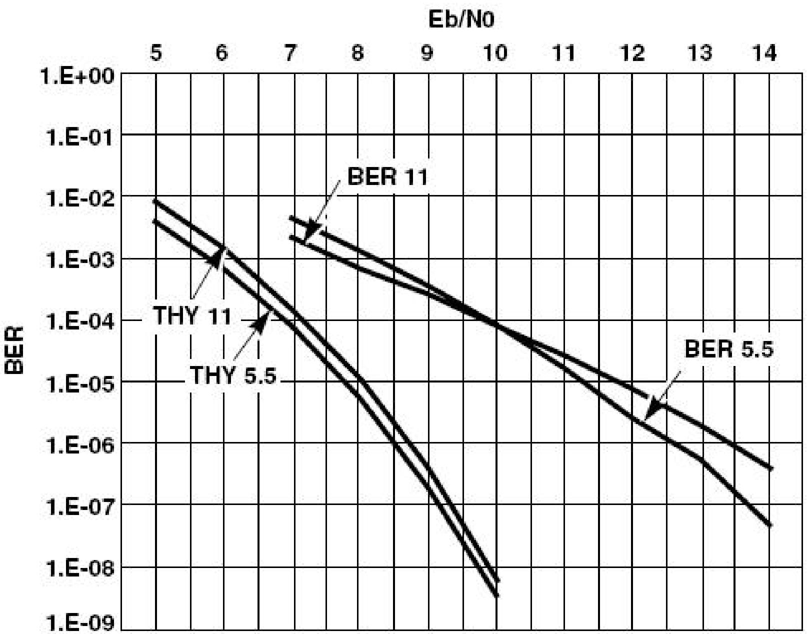
$$M = 1 + \frac{\log\left[\dfrac{1-p_f}{(1-BER)^{L_{DATA}}}\right]}{\log\left[1 - \dfrac{2(1-2p_f)(1-p_f^{m+1})}{W(1-p_f)[1-(2p_f)^{m+1}] + (1-2p_f)(1-p_f^{m+1})}\right]}$$

CW Optimization

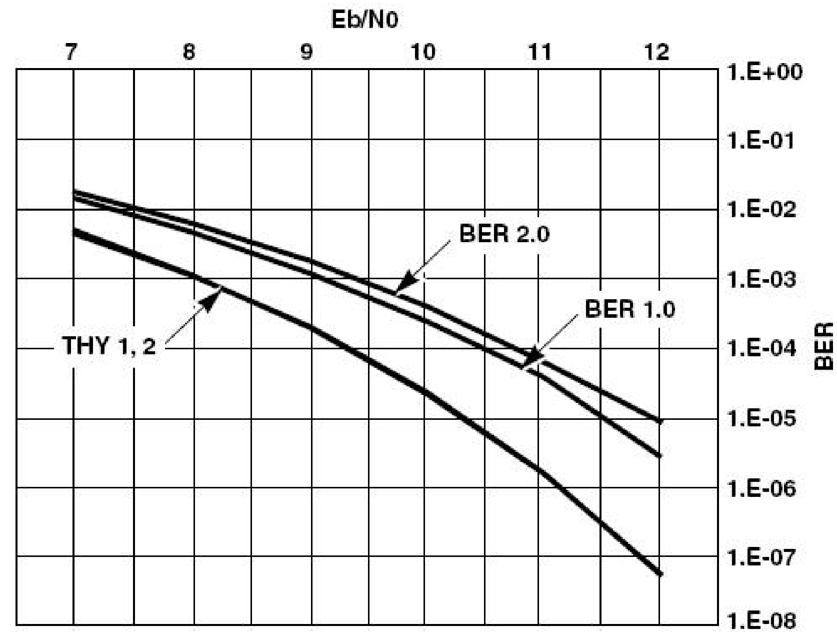
$$M \cdot p_{opt} = \sum_{i=1}^{M} i \cdot p\{M = i\} \geq \sum_{i=1}^{M} p\{M = i\} = 1 - p\{M = 0\} = \frac{1}{\overline{C}}$$

$$2\overline{C}\left\{1 + \frac{\log\left[\frac{1-p_f}{(1-BER)^{L_{DATA}}}\right]}{\log\left[1 - \frac{2(1-2p_f)(1-p_f^{m+1})}{W(1-p_f)[1-(2p_f)^{m+1}] + (1-2p_f)(1-p_f^{m+1})}\right]}\right\} - 1$$

BER Estimating



CCK Mode



PSK Mode

BER vs. SNR for Intersil HFA3861B chipset

Using Block-Code

$$2\overline{C}\left\{1+\frac{\log\left\{\dfrac{1-p_f}{\sum_{i=k}^{k+h}\binom{k+h}{i}\times(1-BER)^{i\times L_{DATA}}\times\left[1-(1-BER)^{L_{DATA}}\right]^{k+h-i}}\right\}}{\log\left\{1-\dfrac{2(1-2p_f)(1-p_f^{m+1})}{W(1-p_f)[1-(2p_f)^{m+1}]+(1-2p_f)(1-p_f^{m+1})}\right\}}\right\}-1$$

Priority Enforcement

$$\left\{2\overline{C}\left[1+\frac{\log\left[\dfrac{1-p_f}{(1-BER)^{L_{DATA}}}\right]}{\log\left[1-\dfrac{2(1-2p_f)(1-p_f^{m+1})}{W(1-p_f)[1-(2p_f)^{m+1}]+(1-2p_f)(1-p_f^{m+1})}\right]}\right]-1\right\}\times\frac{\sum_{j=1}^{i}M_j}{M}$$

Theoretical Limit (Basic Access Method)

$$\frac{L_{DATA}\cdot(1-BER)^{(L_{DATA}+L_{ACK})}}{2T_p+2T_H+2\tau+T_{DIFS}+\dfrac{L_{DATA}+L_{ACK}}{R_{DATA}}+T_{SIFS}+\dfrac{W}{2}\cdot T_{slot}}$$

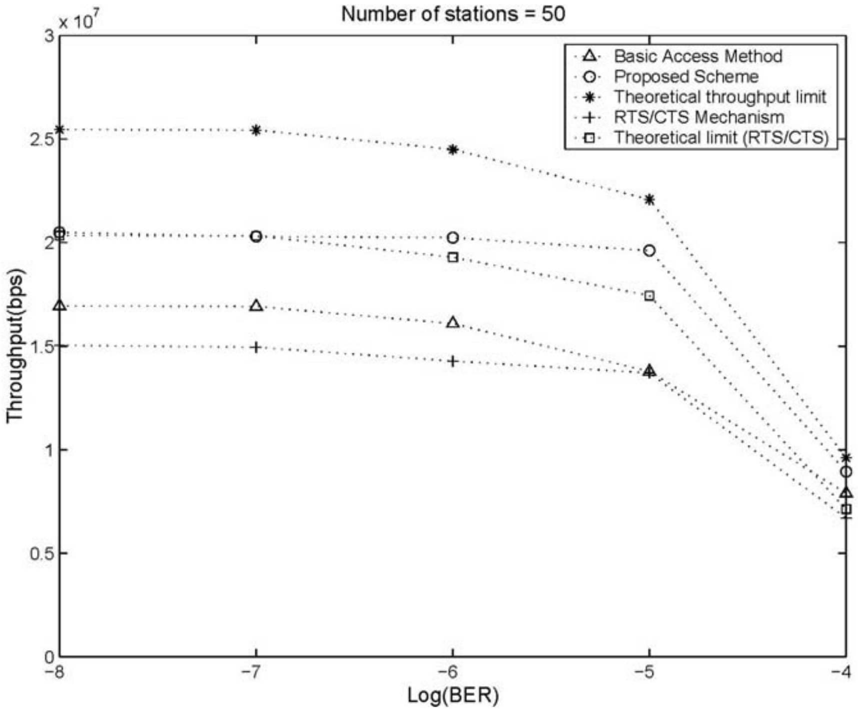
Theoretical Limit (RTS/CTS Mechanism)

$$\frac{L_{DATA}\cdot(1-BER)^{(L_{RTS}+L_{CTS}+L_{DATA}+L_{ACK})}}{4T_p+4T_H+4\tau+T_{DIFS}+\dfrac{L_{RTS}+L_{CTS}+L_{DATA}+L_{ACK}}{R_{DATA}}+3T_{SIFS}+\dfrac{W}{2}\cdot T_{slot}}$$

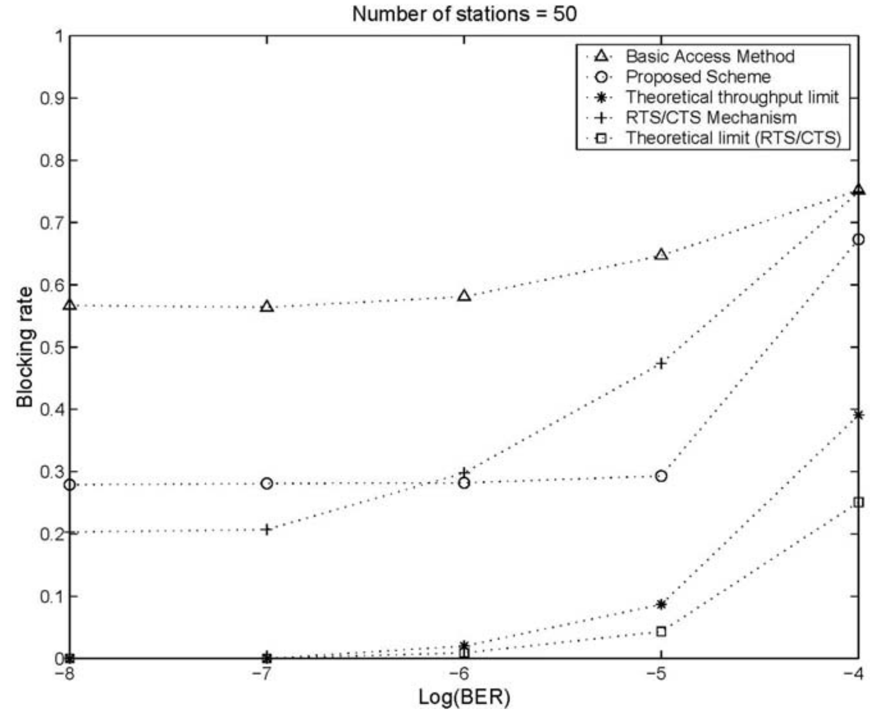
Simulation – Default Values

Attribute	Value	Meaning & Explanation
R_{DATA}	54 Mb/s	Maximum data rate (64 QAM modulation)
T_{slot}	9 μs	Time needed for each time slot
T_{SIFS}	16 μs	Duration of short interframe space (SIFS)
T_{DIFS}	34 μs	Duration of DCF interframe space (DIFS)
L_{DATA}	1000 bytes	Mean payload size
L_{ACK}	112 bits	Ack frame size
L_{RTS}	160 bits	Request-to-send frame size
L_{CTS}	112 bits	Clear-to-send frame size
L_{MAC}	224 bits	MAC overhead
T_p	16 μs	Duration of a PLCP preamble
T_H	4 μs	Duration of a PLCP header
T_S	4 μs	Interval of an OFDM symbol
τ	1 μs	Propagation Delay
W	16 slots	Minimum contention window size
m	6	Maximum backoff stages
d	250 meters	Simulation topology 250m$\times$250m

Simulation - Congested Scenario

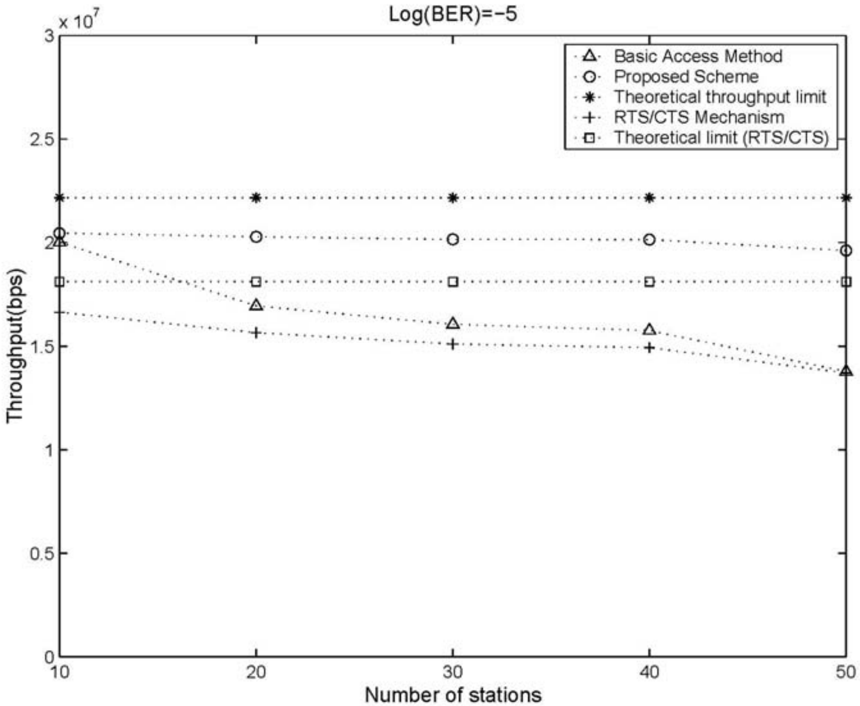


Achievable throughput versus channel BER with different network sizes

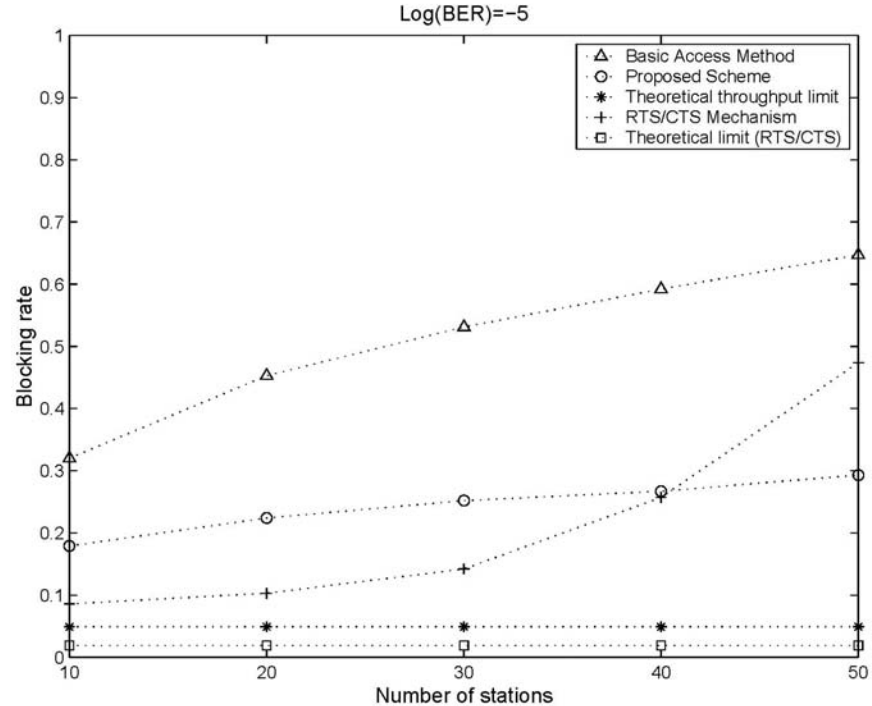


Blocking rate versus channel BER with different network sizes

Simulation - Noisy Environment

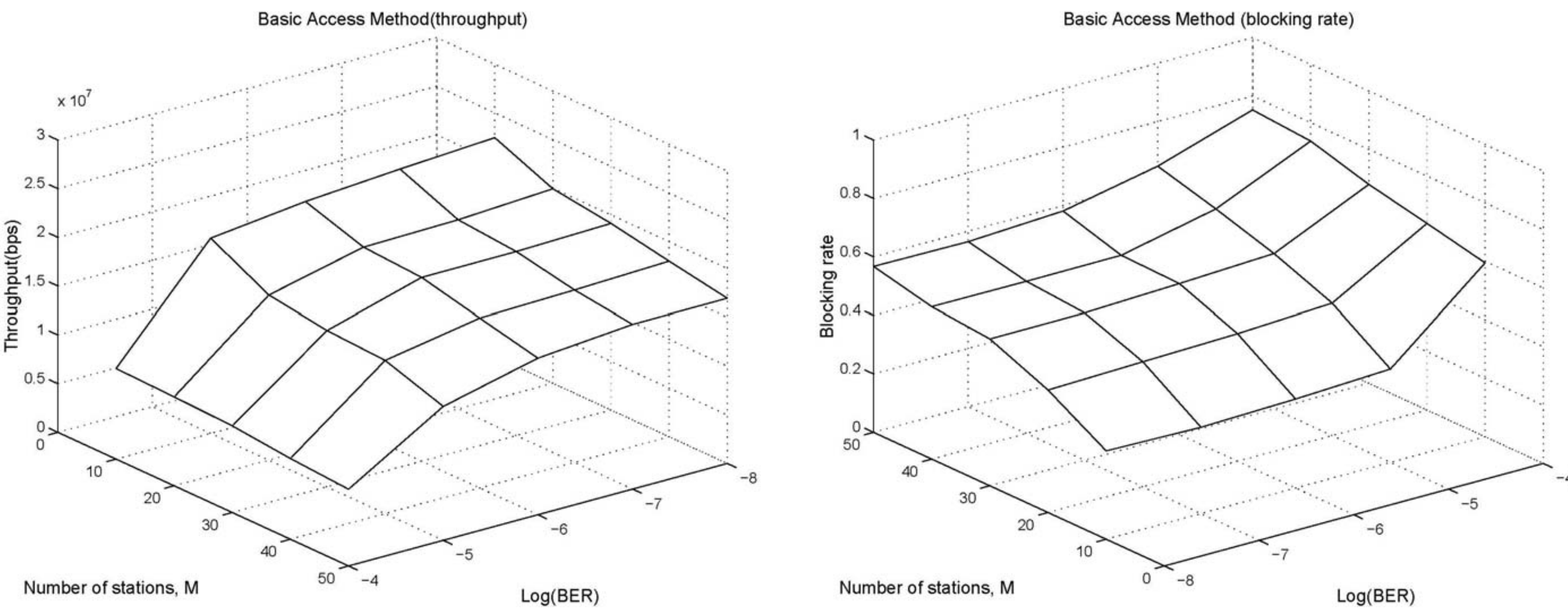


Achievable throughput versus number of stations under different channel BER



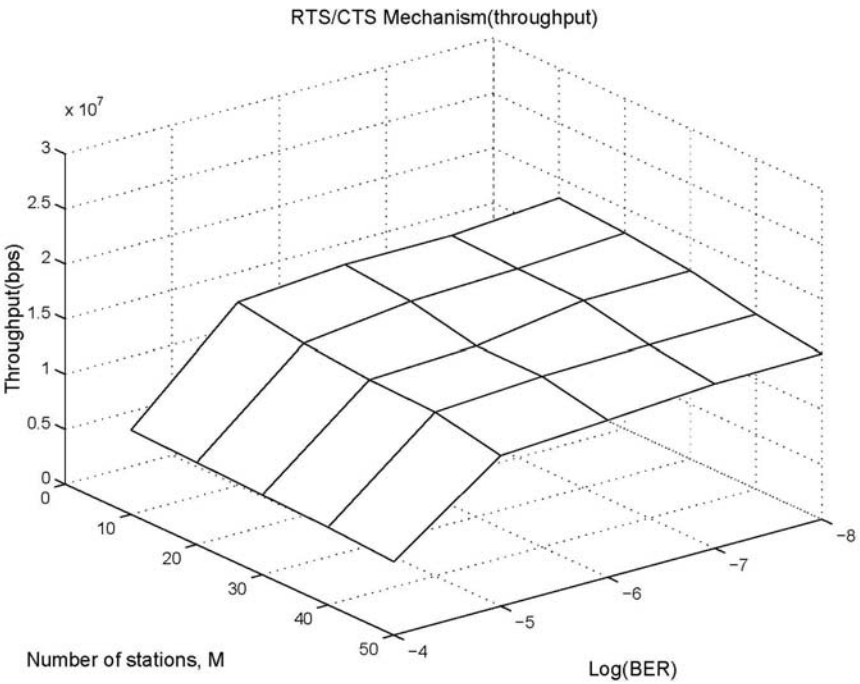
Blocking rate versus number of stations under different channel BER

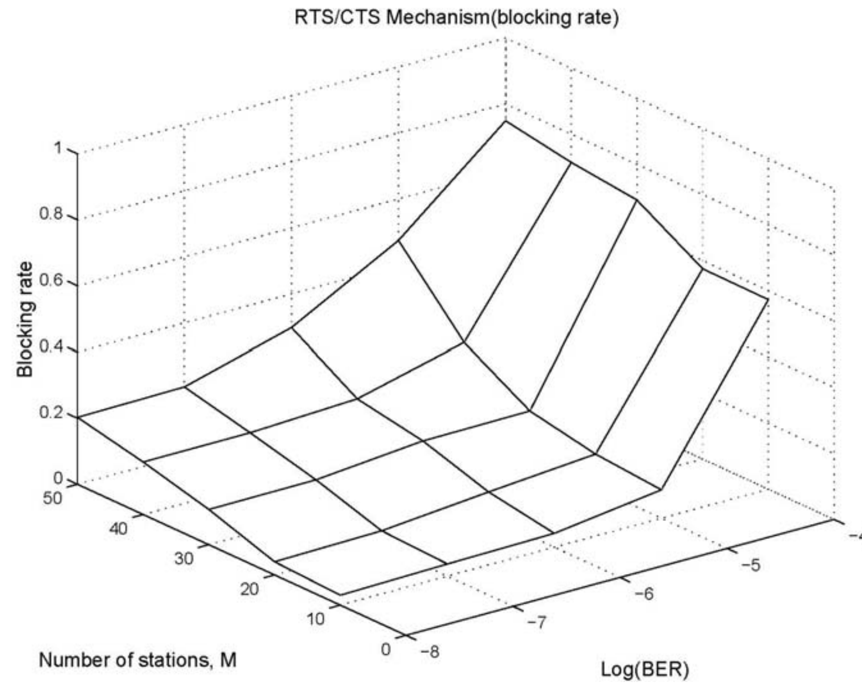
Simulation – Basic Access Method



The performance of basic access method

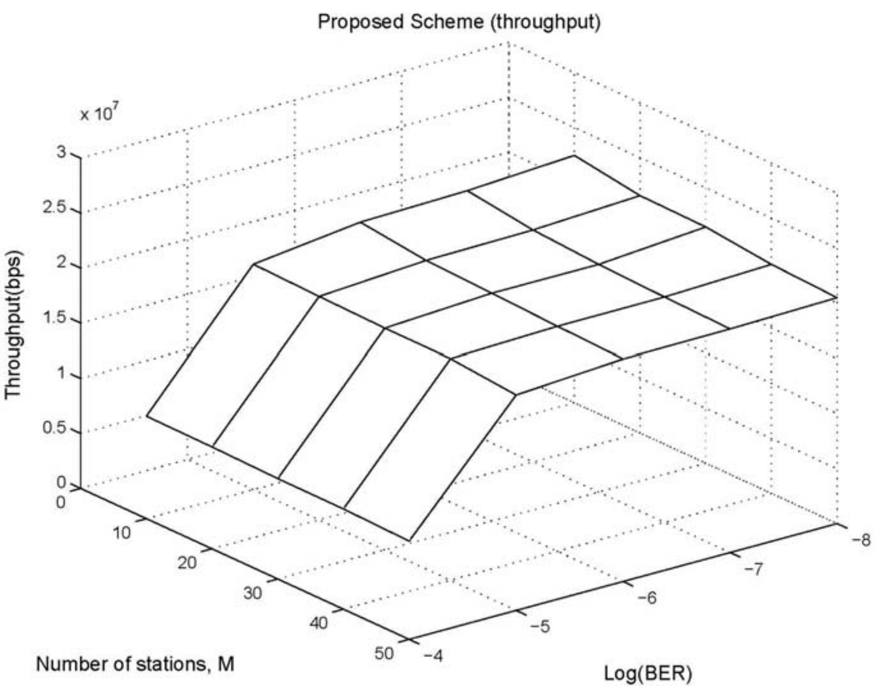
Simulation – RTS/CTS Mechanism

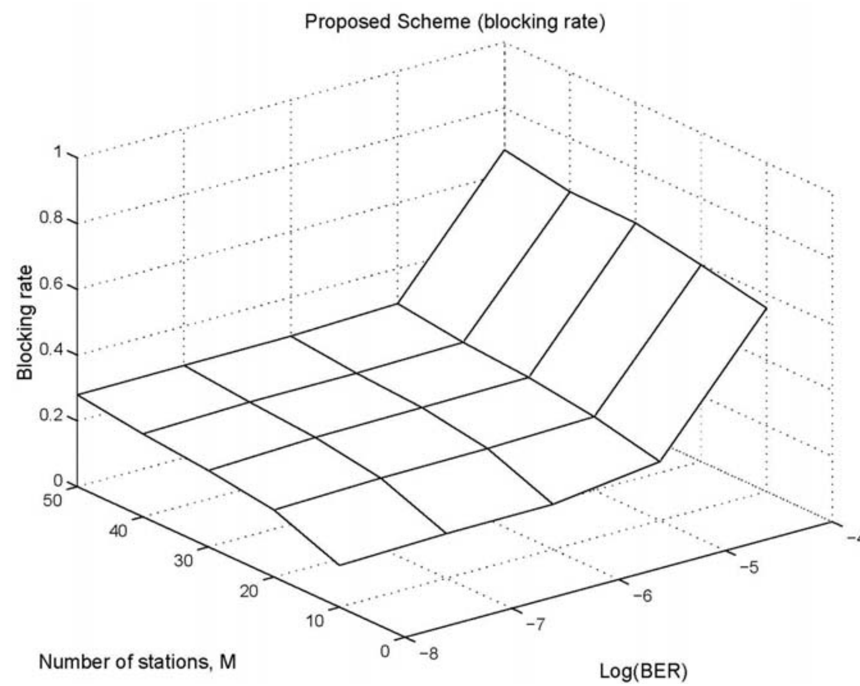




The performance of RTS/CTS mechanism

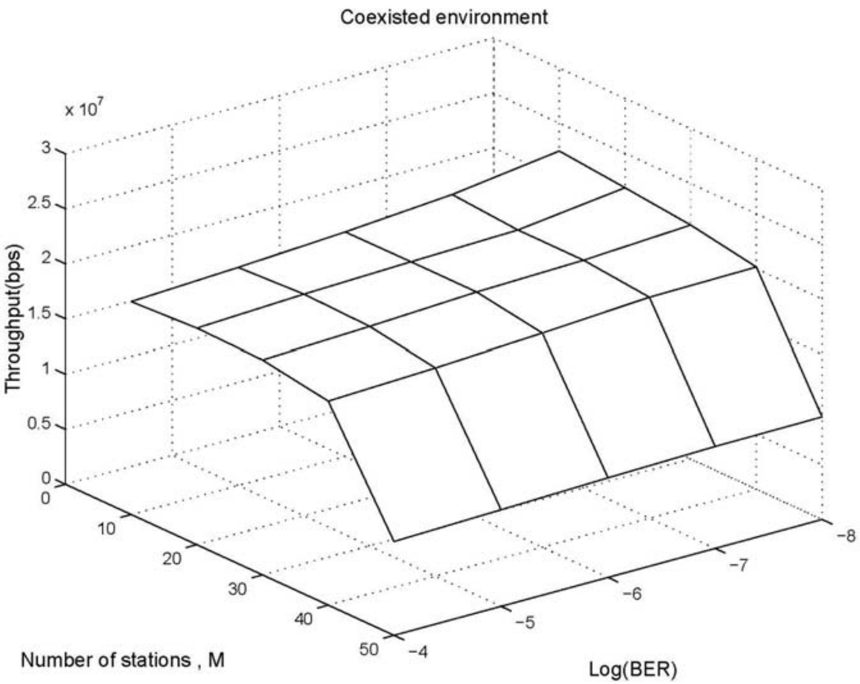
Simulation – Proposed Scheme

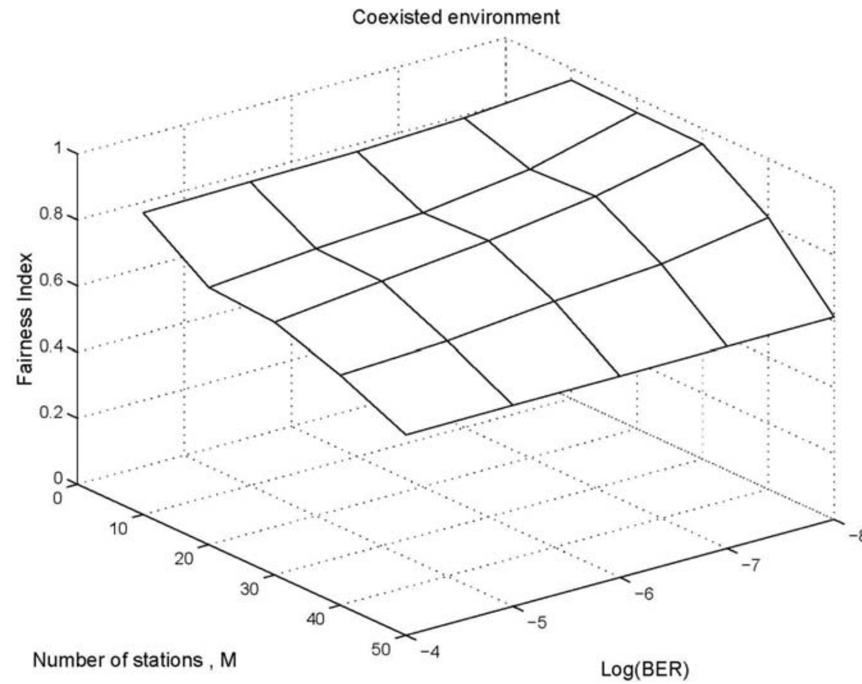




The performance of proposed scheme

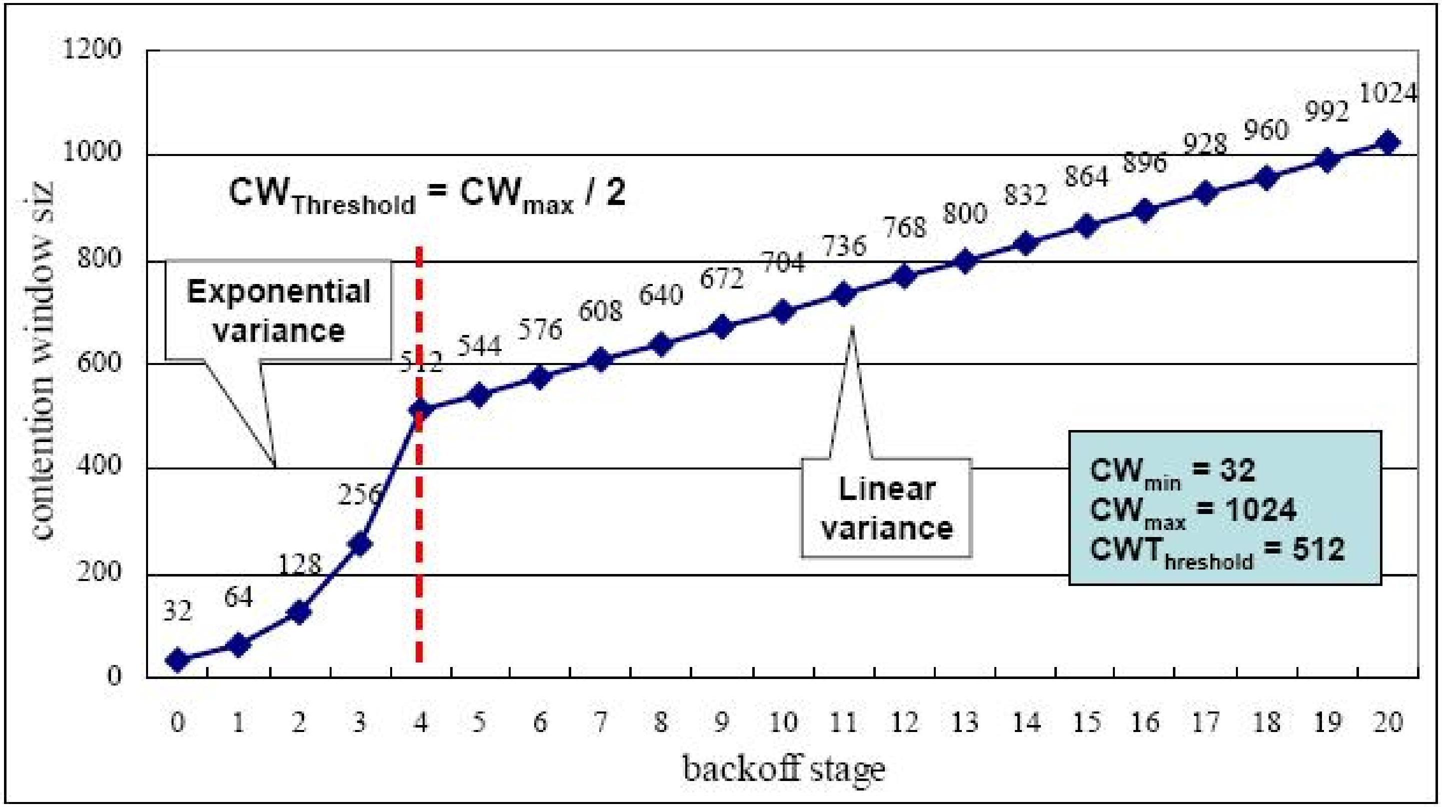
Simulation – Coexisted Environments



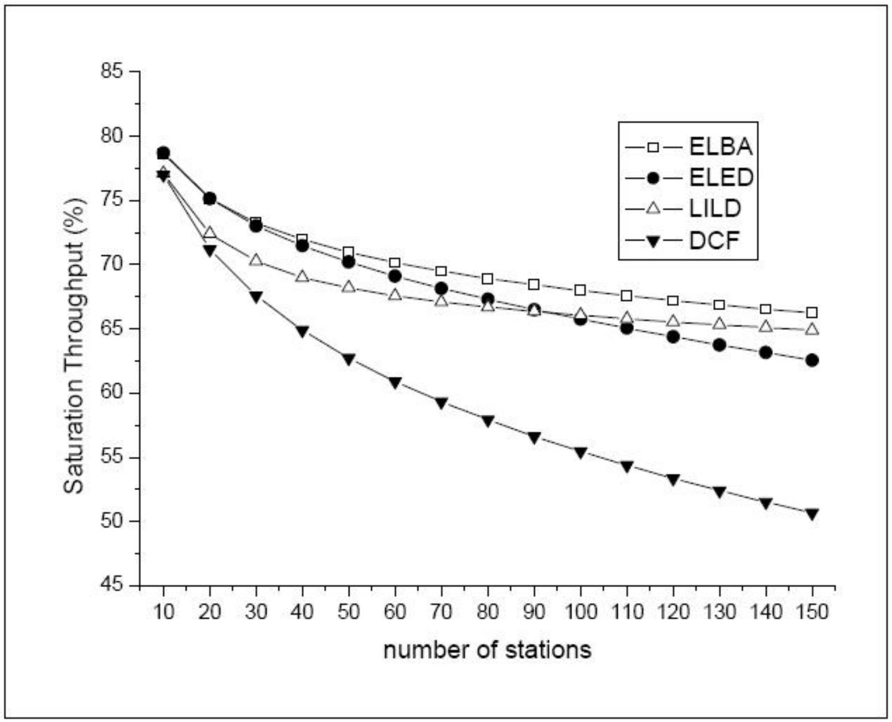


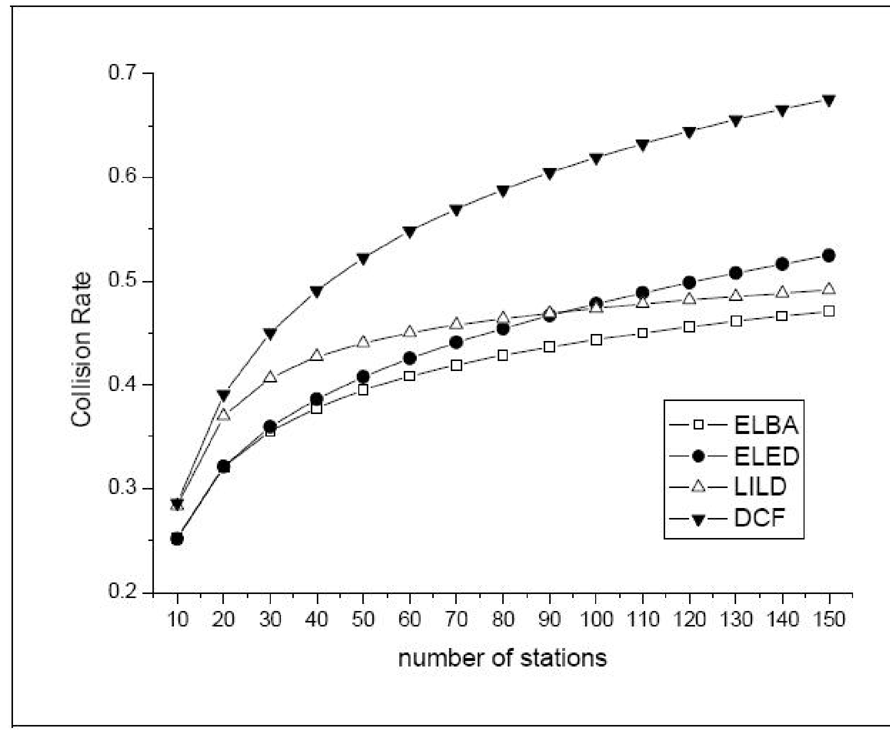
The proposed scheme and legacy DCF access method coexist in a same BSS

Simulation – Slow-Start Scheme

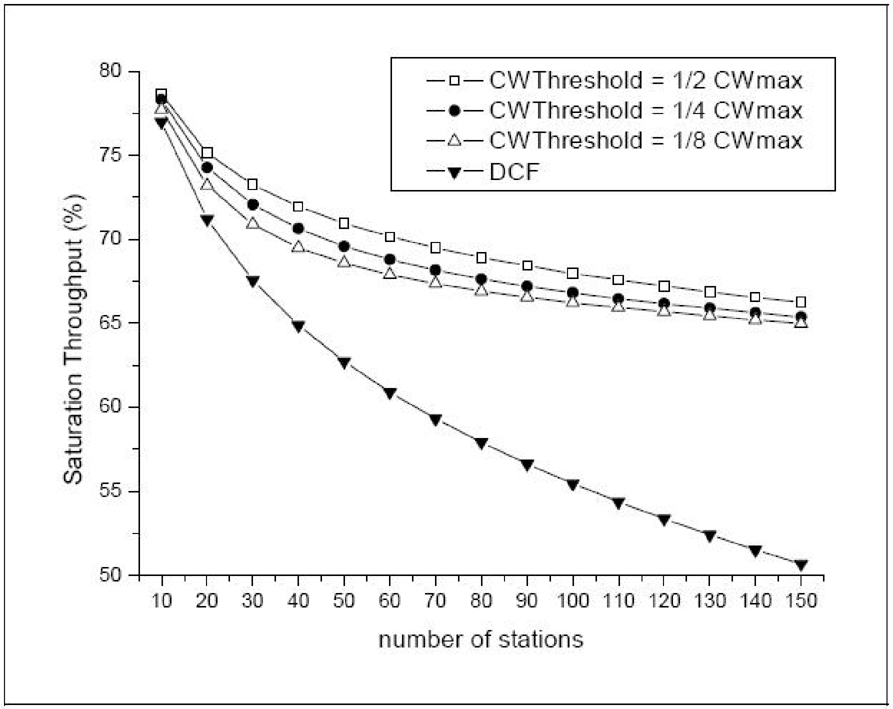


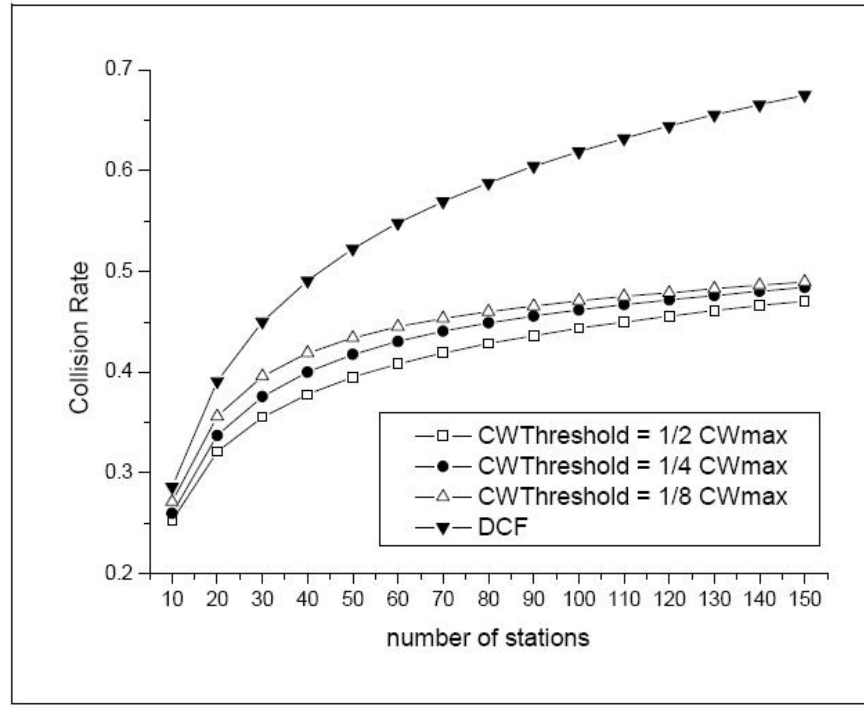
Simulation – Slow-Start Scheme





Simulation – Slow-Start Scheme





Conclusions

- The backoff parameters in IEEE 802.11 DCF access method are far from the optimal setting in heavy-load and error-prone WLANs environment
- In this paper, we attempt to identify the relationship between backoff parameters and channel BER and put forth a pragmatic problem-solving solution
- The proposed scheme is performed at each station in a distributed manner, and it can be implemented in the present IEEE 802.11 standard with relatively minor modifications
- There's no such thing as a free lunch
  We believe that it is almost impossible to increase the probability of success of transmitting a frame excepting frames fragmentation or FEC (Forward Error Control) in an extremely noisy wireless environment.