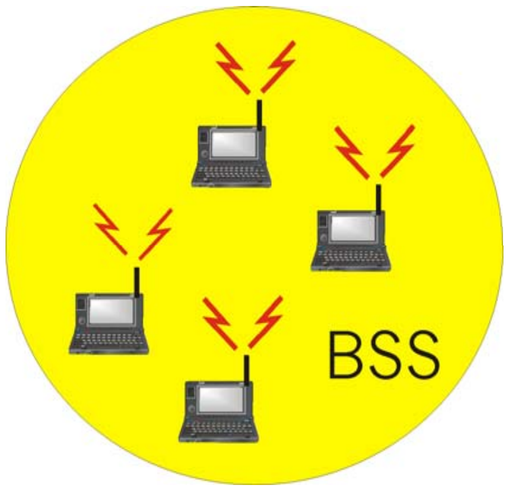
Saturation Throughput Analysis and Performance Optimization of BEB Algorithm

Speaker: Der-Jiunn Deng
Department of Computer Science and Information Engineering
National Changhua University of Education

Ad Hoc Networks

- Ad hoc network: mobile stations can dynamically form network *without* AP
- Applications:
  - "laptop" meeting in conference room, car
  - interconnection of "personal" devices
  - battlefield
- IETF MANET (Mobile Ad hoc Networks) working group



CSMA/CA

CSMA: sender

- if sense channel idle for **DISF** sec.

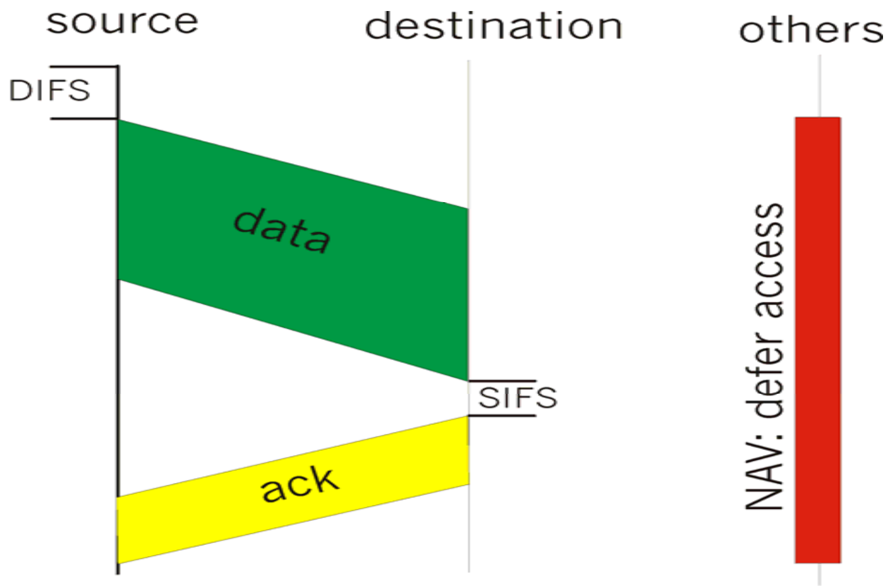
  then transmit entire frame (no collision detection)

- if sense channel busy then binary backoff

CSMA receiver:

if received OK

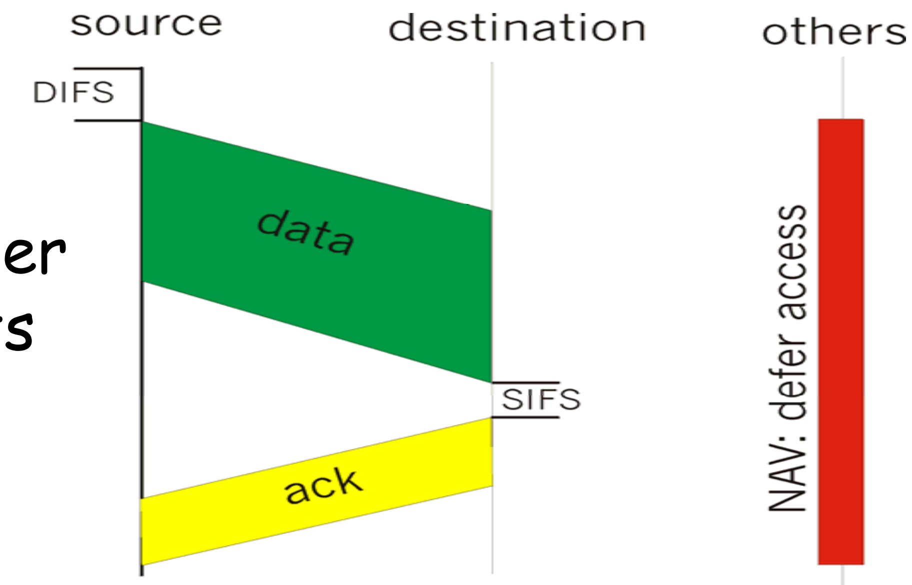
return ACK after **SIFS**



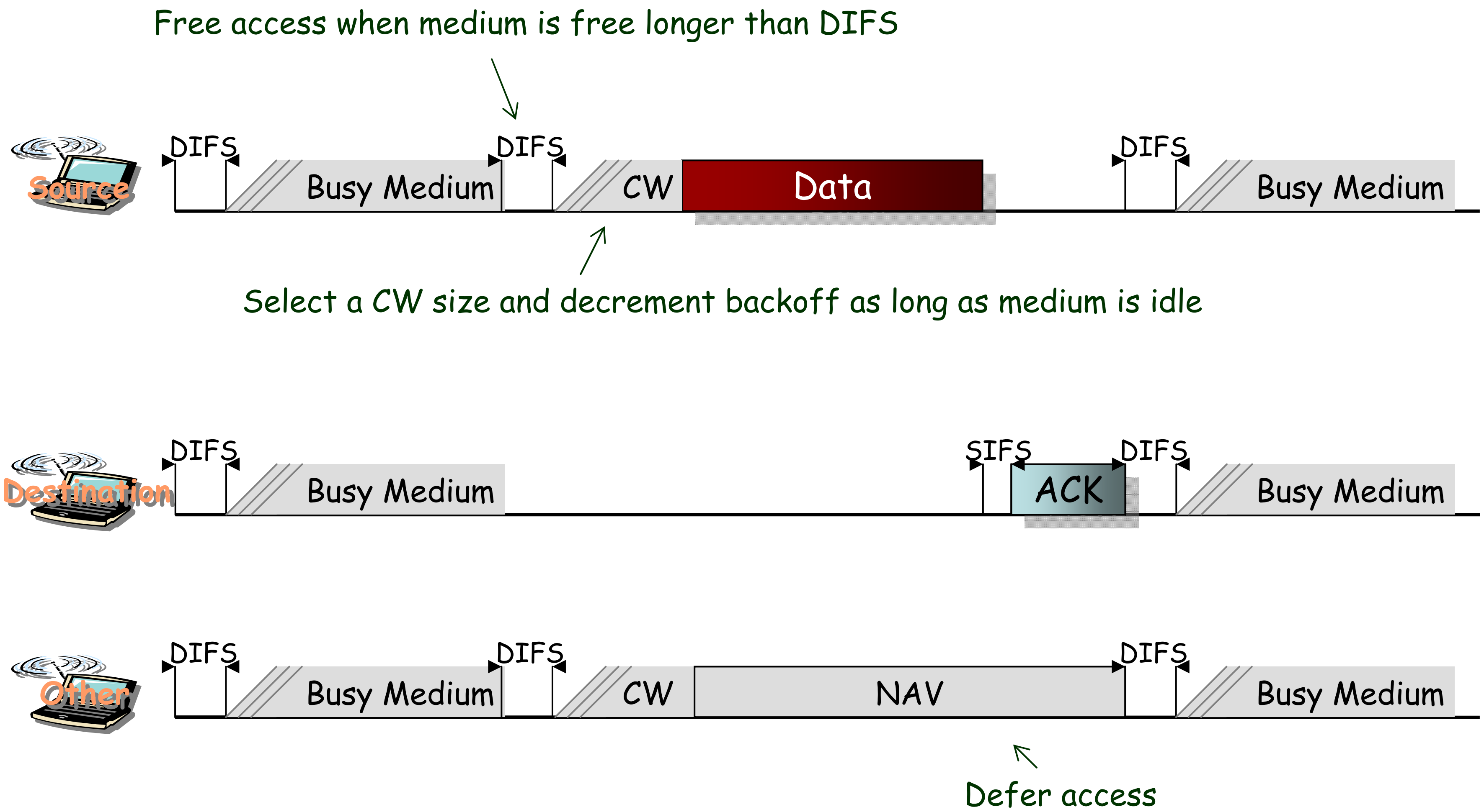
CSMA/CA

CSMA: others

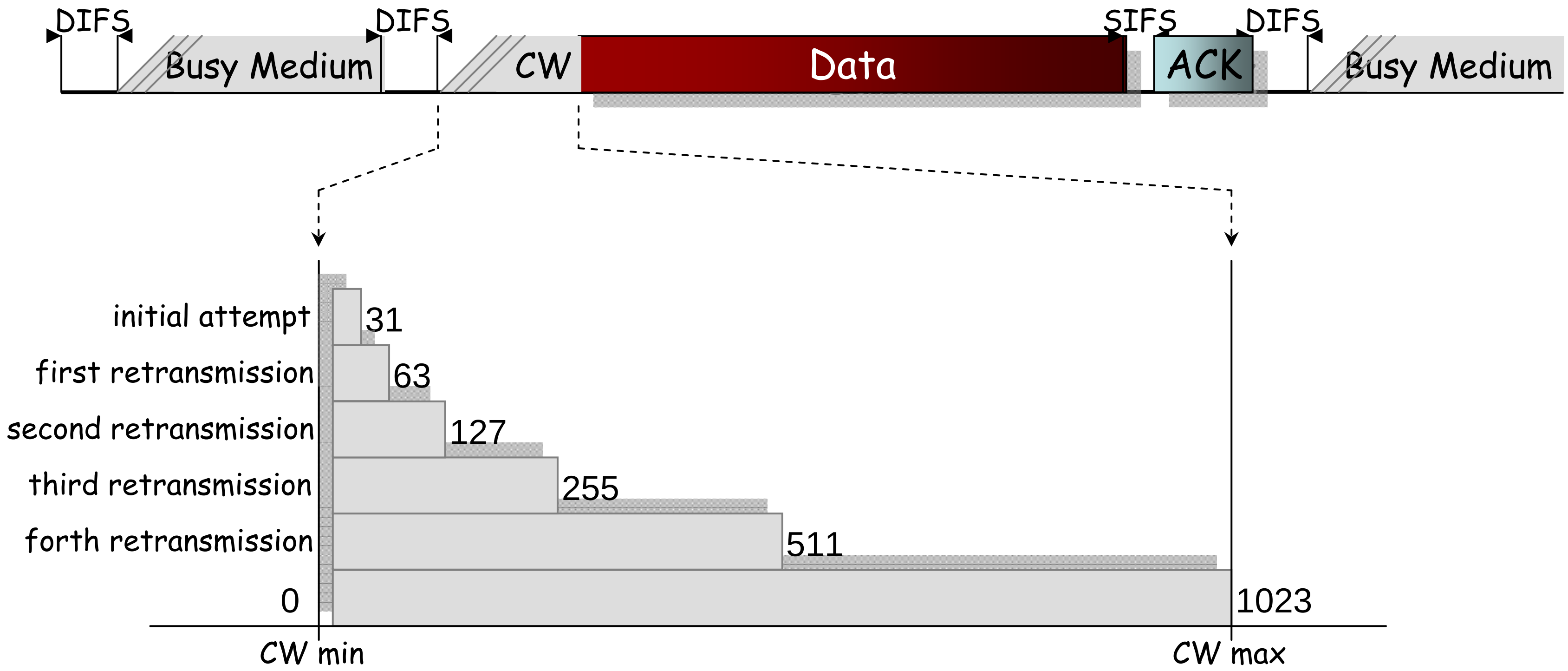
- **NAV**: Network Allocation Vector
- 802.11 frame has transmission time field
- others (hearing sata) defer access for NAV time units



Basic Access Method (CSMA/CA)



Binary Exponential Backoff



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

Congested Scenario

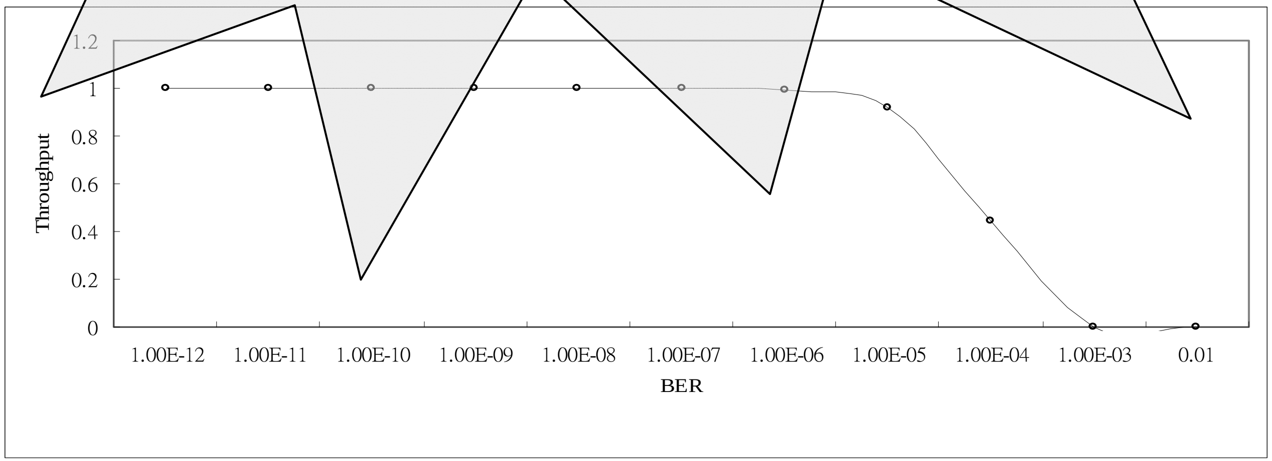
- The usage of backoff algorithm avoids long access delays when the load is light because it selects an initial (small) parameter value of contention window (CW) by assuming a low level of congestion in the system.
- This strategy might allocate initial size of CW, only to find out later that it is not 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

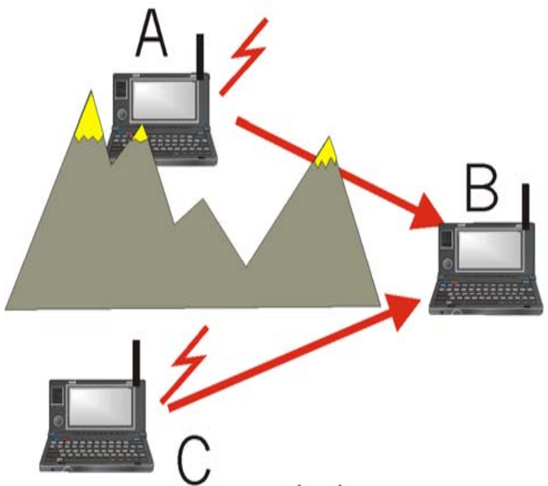
- In DCF access method, immediate positive acknowledgement informs the sender of successful reception of each data frame
- In case an acknowledgement is not received, the sender will presume that the data frame is lost due to collision, not by frame loss.
- Unfortunately, wireless transmission links 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

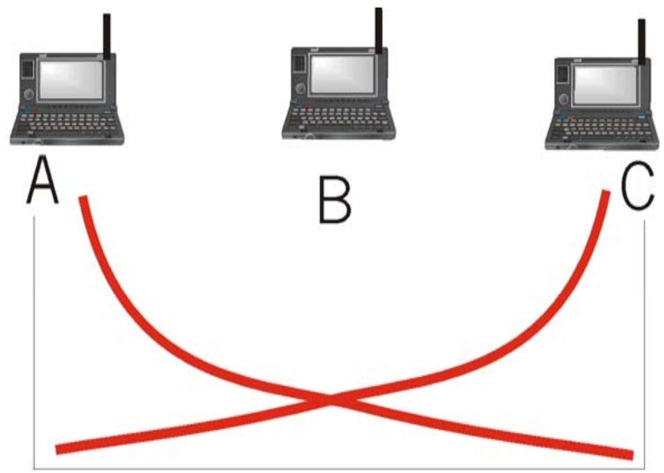


Hidden Terminal effect

- hidden terminals: A, C cannot hear each other
  - obstacles, signal attenuation
  - collisions at B
- goal: avoid collisions at B
- **CSMA/CA: CSMA with C**ollision Avoidance



(a)



(b)

Fairness Problem (hidden)

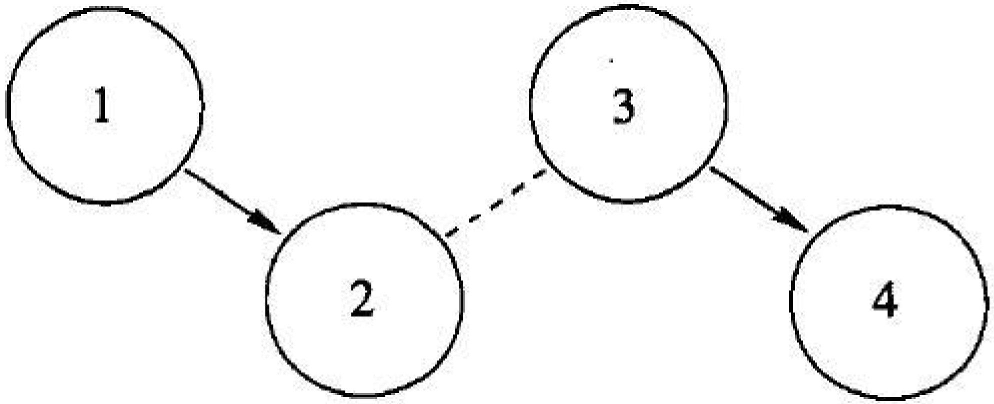
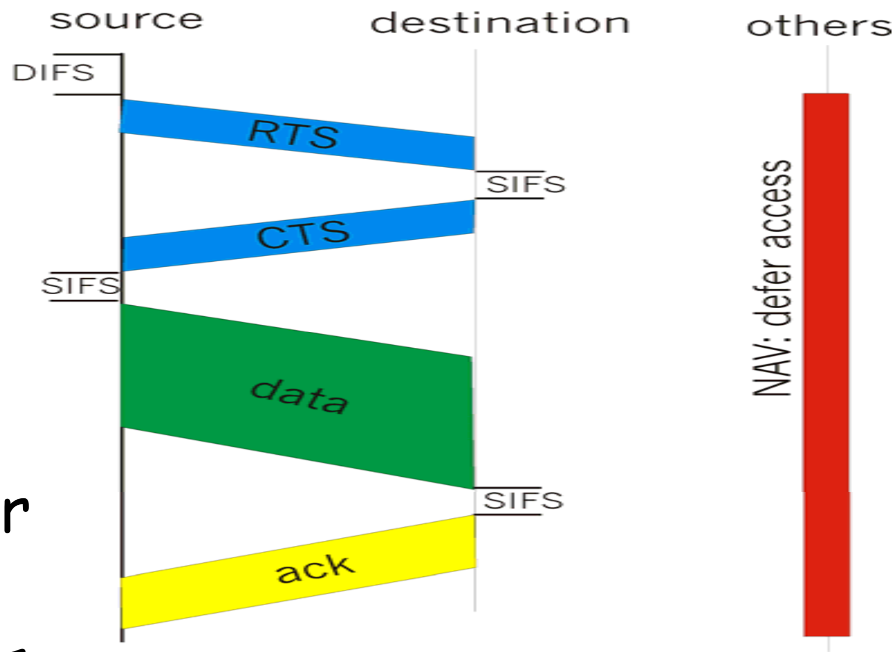


Fig. 1. Sample network

B. Bensaou , Y. Wang , and C. C. Ko, "Fair medium access in 802.11 based wireless ad-hoc networks," in *Proc. of the 1st ACM international symposium on Mobile ad hoc networking & computing*, November 20, 2000, Boston, Massachusetts.

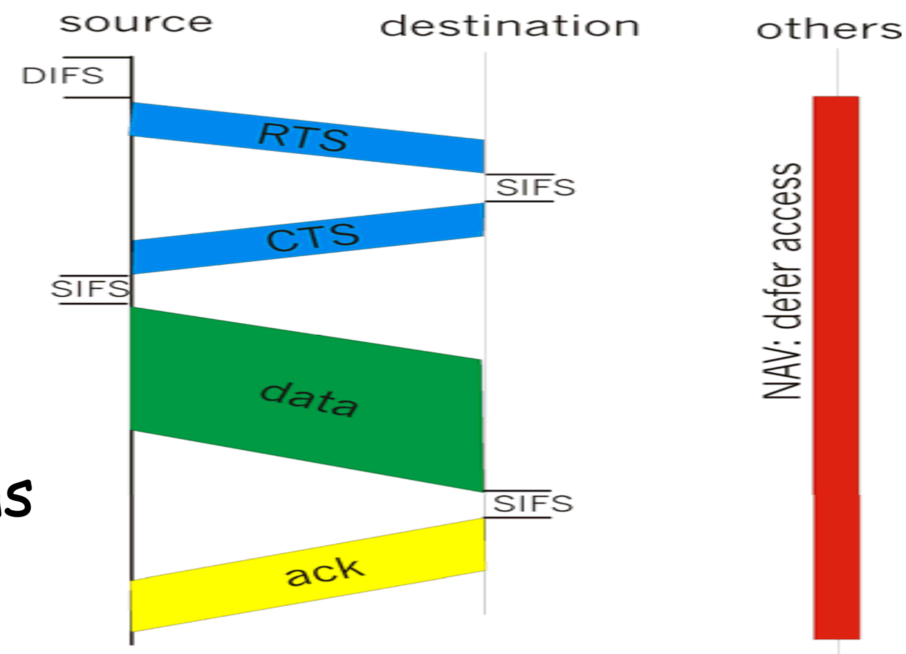
Collision Avoidance: RTS-CTS Mechanism

- CSMA/CA: explicit channel reservation
  - sender: send short RTS: request to send
  - receiver: reply with short CTS: clear to send
- CTS reserves channel for sender, notifying (possibly hidden) stations
- avoid hidden station collisions

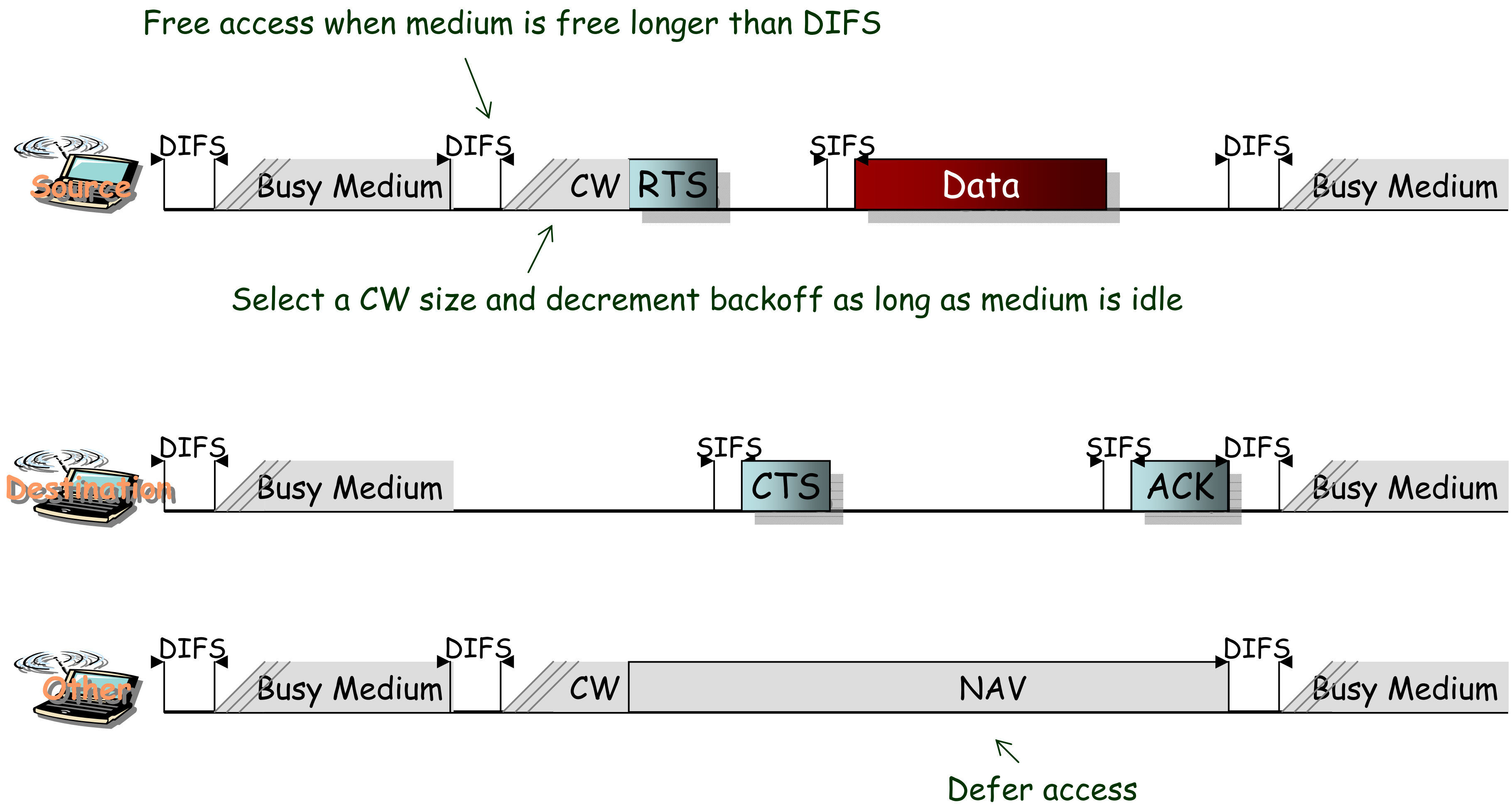


RTS-CTS Mechanism

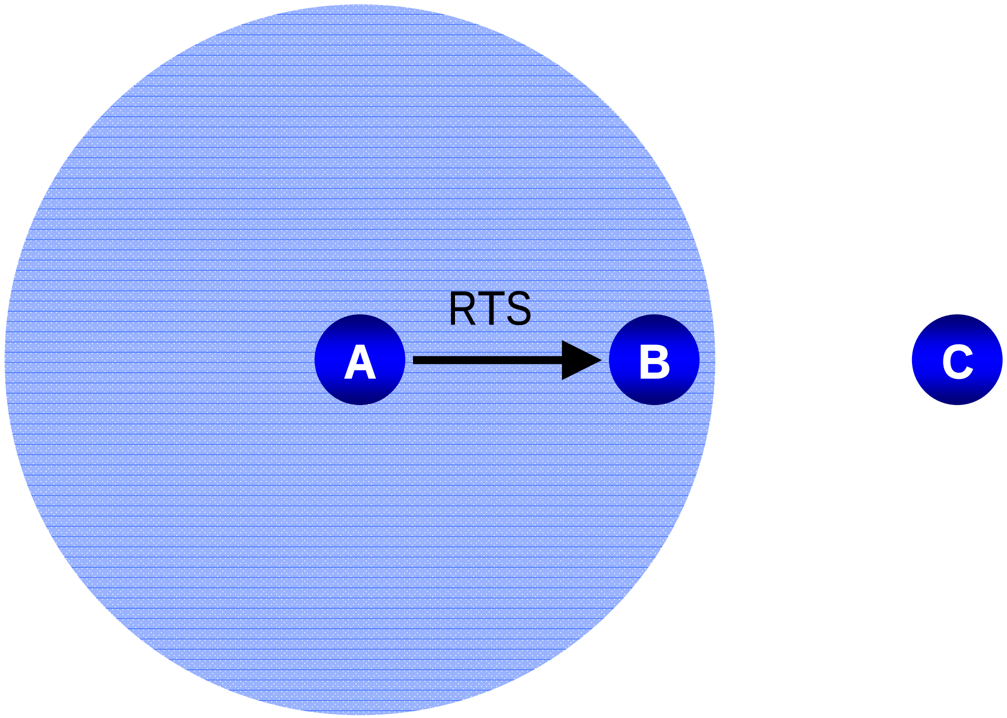
- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- IEEE 802.11 allows:
  - CSMA
  - CSMA/CA: reservations
  - polling from AP



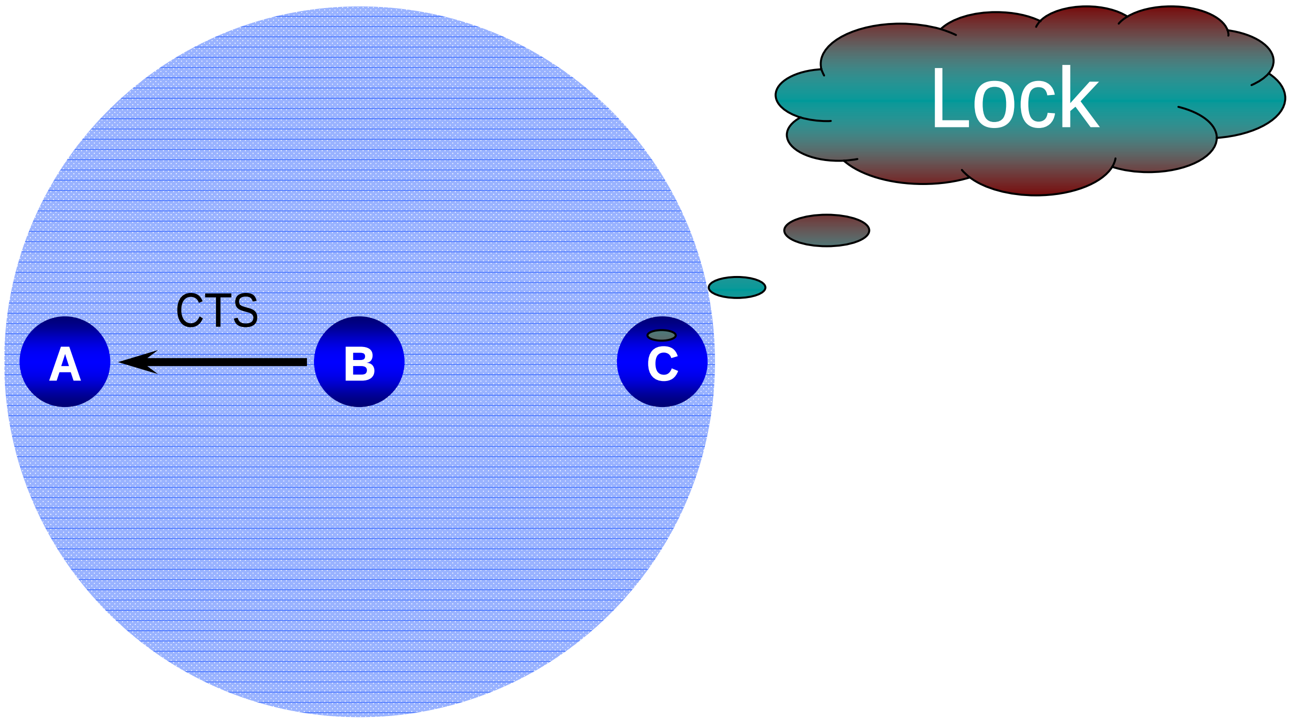
RTS/CTS Mechanism



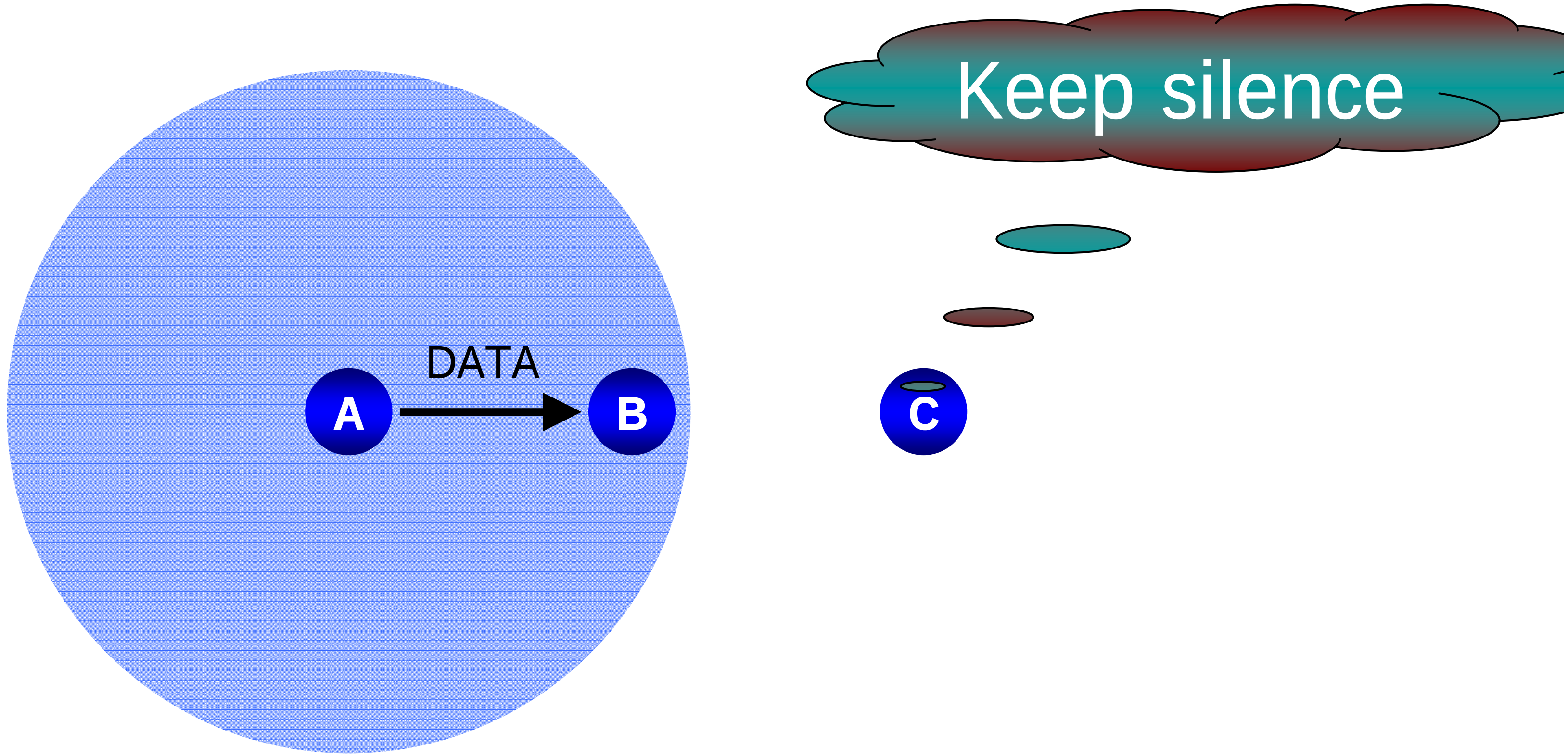
RTS/CTS (4-way handshaking)



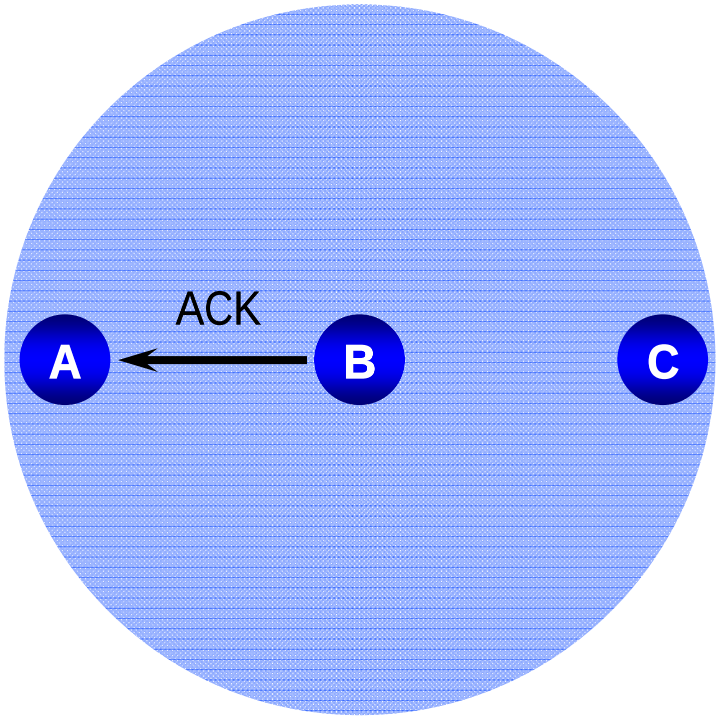
RTS/CTS (4-way handshaking)



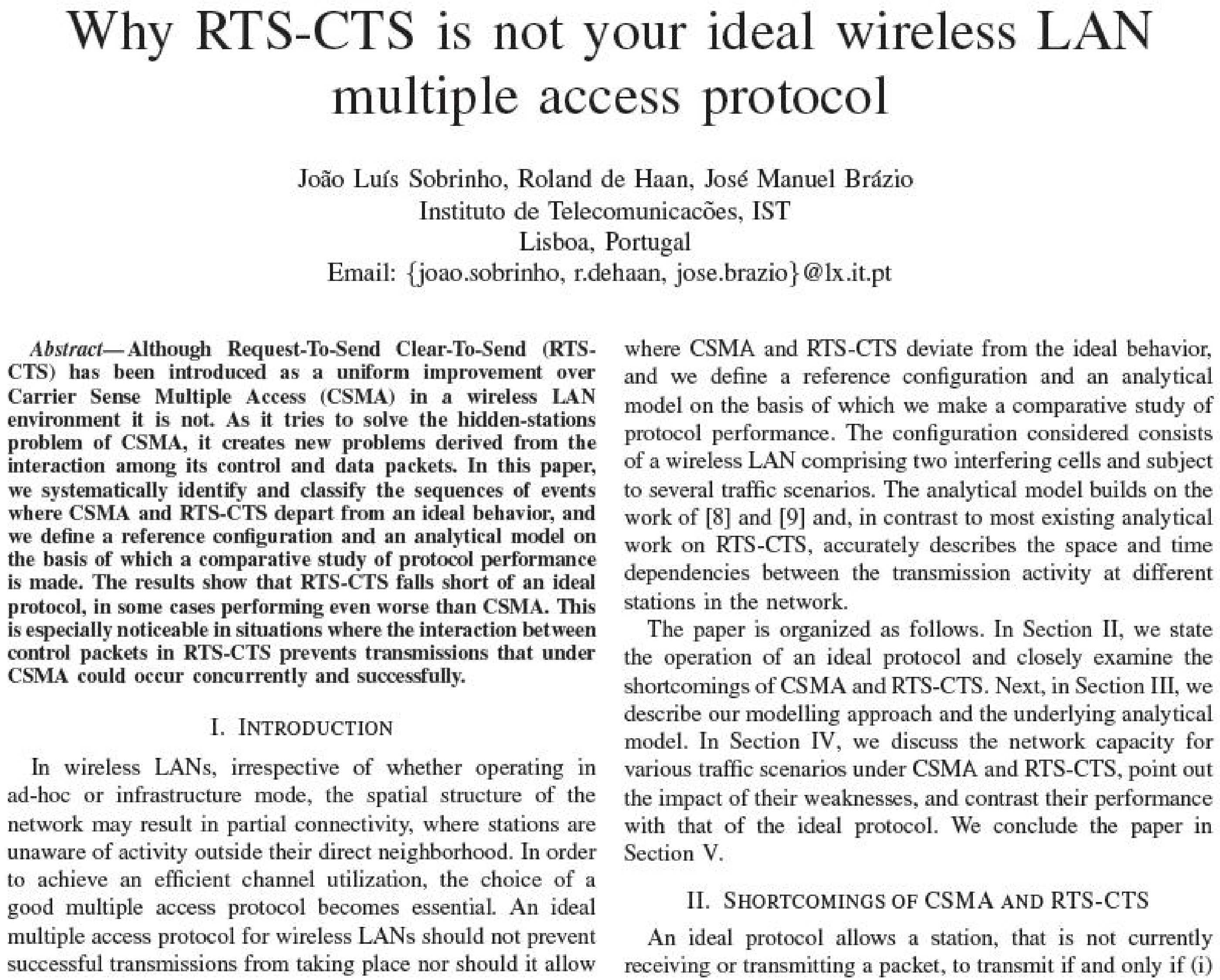
RTS/CTS (4-way handshaking)



RTS/CTS (4-way handshaking)



WCNC 2005



Why RTS-CTS is not your ideal wireless LAN multiple access protocol

João Luís Sobrinho, Roland de Haan, José Manuel Brázio
Instituto de Telecomunicacões, IST
Lisboa, Portugal
Email: {joao.sobrinho, r.dehaan, jose.brazio}@lx.it.pt

***Abstract*— Although Request-To-Send Clear-To-Send (RTS-CTS) has been introduced as a uniform improvement over Carrier Sense Multiple Access (CSMA) in a wireless LAN environment it is not. As it tries to solve the hidden-stations problem of CSMA, it creates new problems derived from the interaction among its control and data packets. In this paper, we systematically identify and classify the sequences of events where CSMA and RTS-CTS depart from an ideal behavior, and we define a reference configuration and an analytical model on the basis of which a comparative study of protocol performance is made. The results show that RTS-CTS falls short of an ideal protocol, in some cases performing even worse than CSMA. This is especially noticeable in situations where the interaction between control packets in RTS-CTS prevents transmissions that under CSMA could occur concurrently and successfully.**

I. Introduction

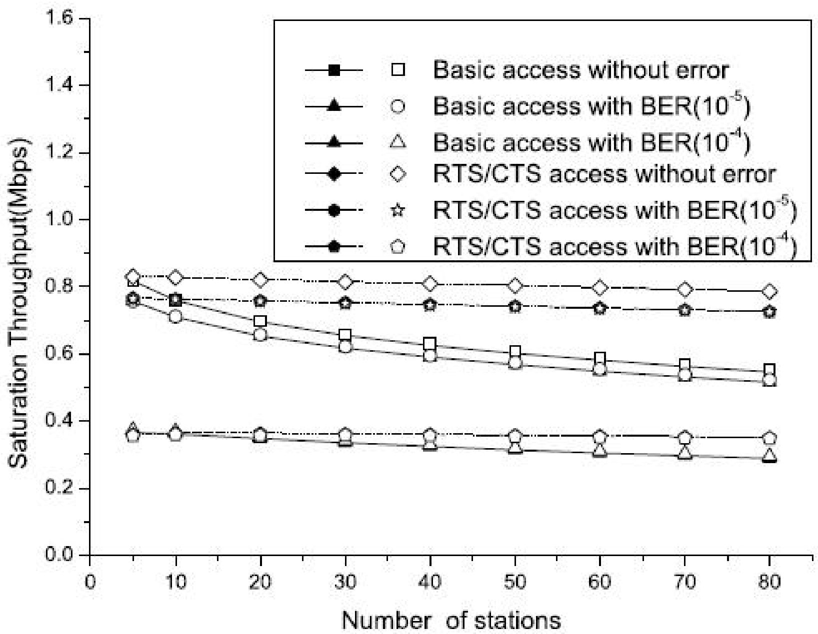
In wireless LANs, irrespective of whether operating in ad-hoc or infrastructure mode, the spatial structure of the network may result in partial connectivity, where stations are unaware of activity outside their direct neighborhood. In order to achieve an efficient channel utilization, the choice of a good multiple access protocol becomes essential. An ideal multiple access protocol for wireless LANs should not prevent successful transmissions from taking place nor should it allow where CSMA and RTS-CTS deviate from the ideal behavior, and we define a reference configuration and an analytical model on the basis of which we make a comparative study of protocol performance. The configuration considered consists of a wireless LAN comprising two interfering cells and subject to several traffic scenarios. The analytical model builds on the work of [8] and [9] and, in contrast to most existing analytical work on RTS-CTS, accurately describes the space and time dependencies between the transmission activity at different stations in the network.

The paper is organized as follows. In Section II, we state the operation of an ideal protocol and closely examine the shortcomings of CSMA and RTS-CTS. Next, in Section III, we describe our modelling approach and the underlying analytical model. In Section IV, we discuss the network capacity for various traffic scenarios under CSMA and RTS-CTS, point out the impact of their weaknesses, and contrast their performance with that of the ideal protocol. We conclude the paper in Section V.

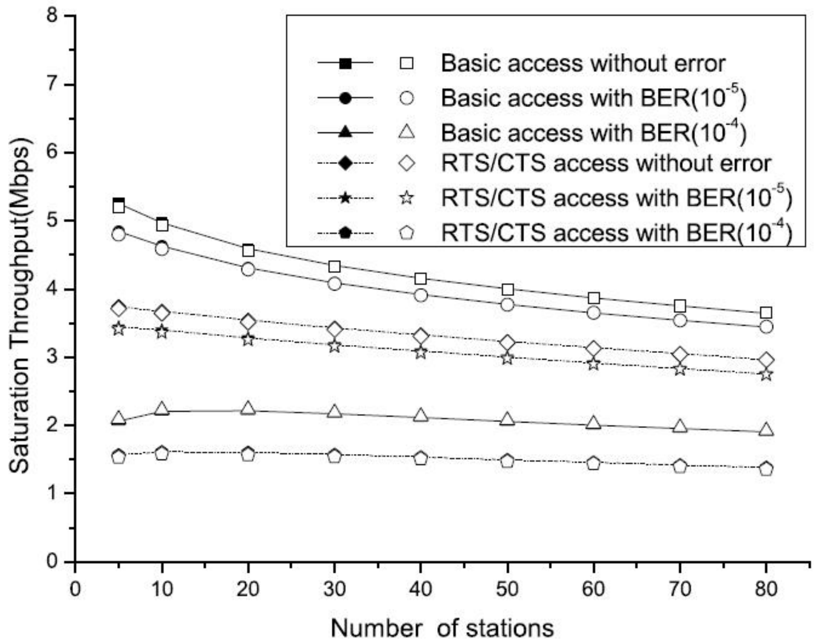
II. Shortcomings of CSMA and RTS-CTS

An ideal protocol allows a station, that is not currently receiving or transmitting a packet, to transmit if and only if (i)

Throughput Efficiency (multi-rate)



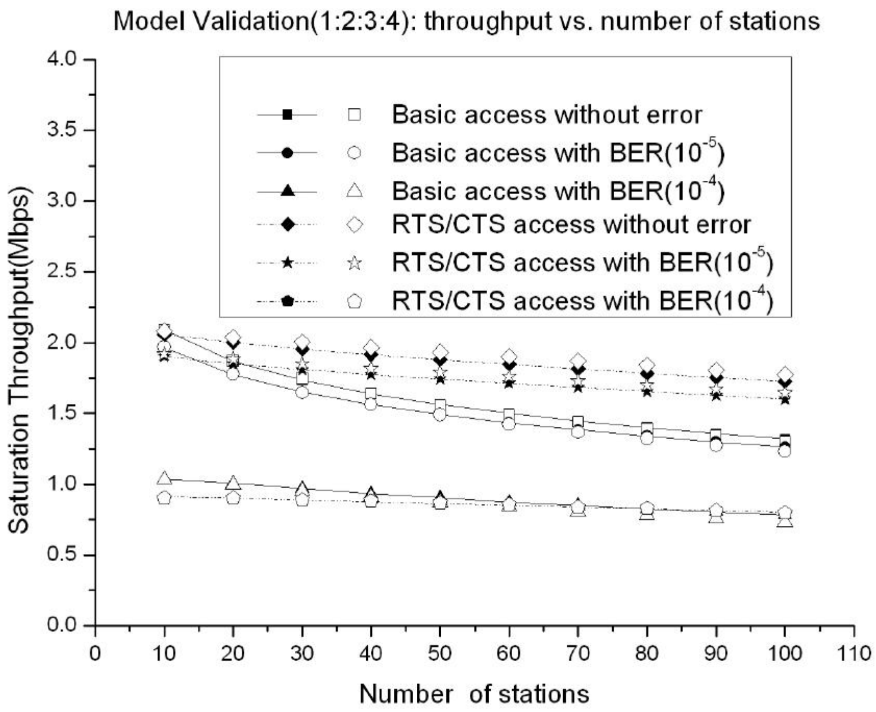
single-rate, 1 Mbps



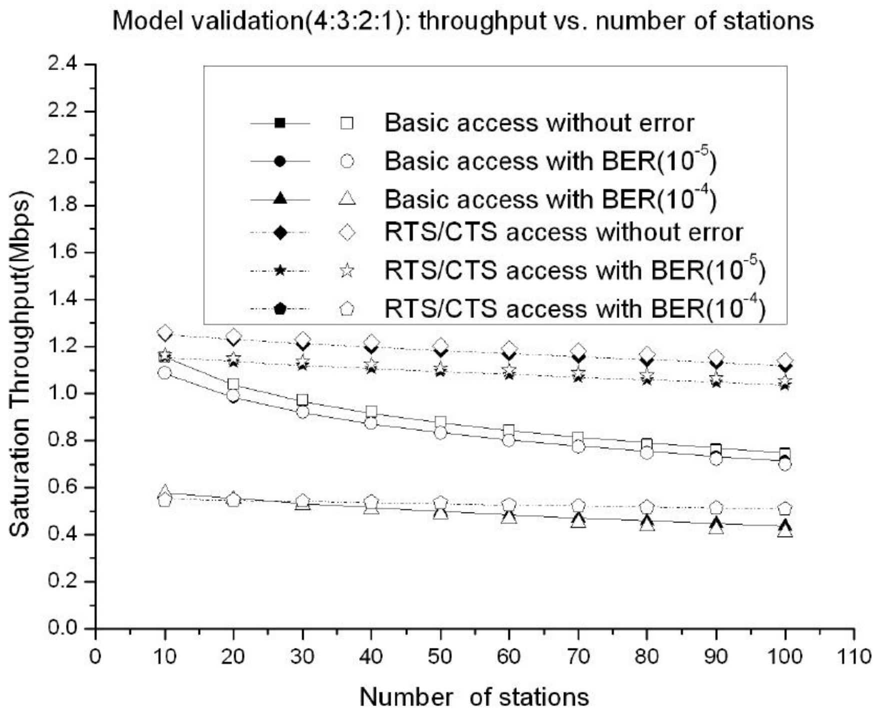
single-rate, 11 Mbps

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," *Wireless Communications and Mobile Computing*, Vol. 9, Issue 8, Aug. 2009, pp. 1102-1112.

Throughput Efficiency



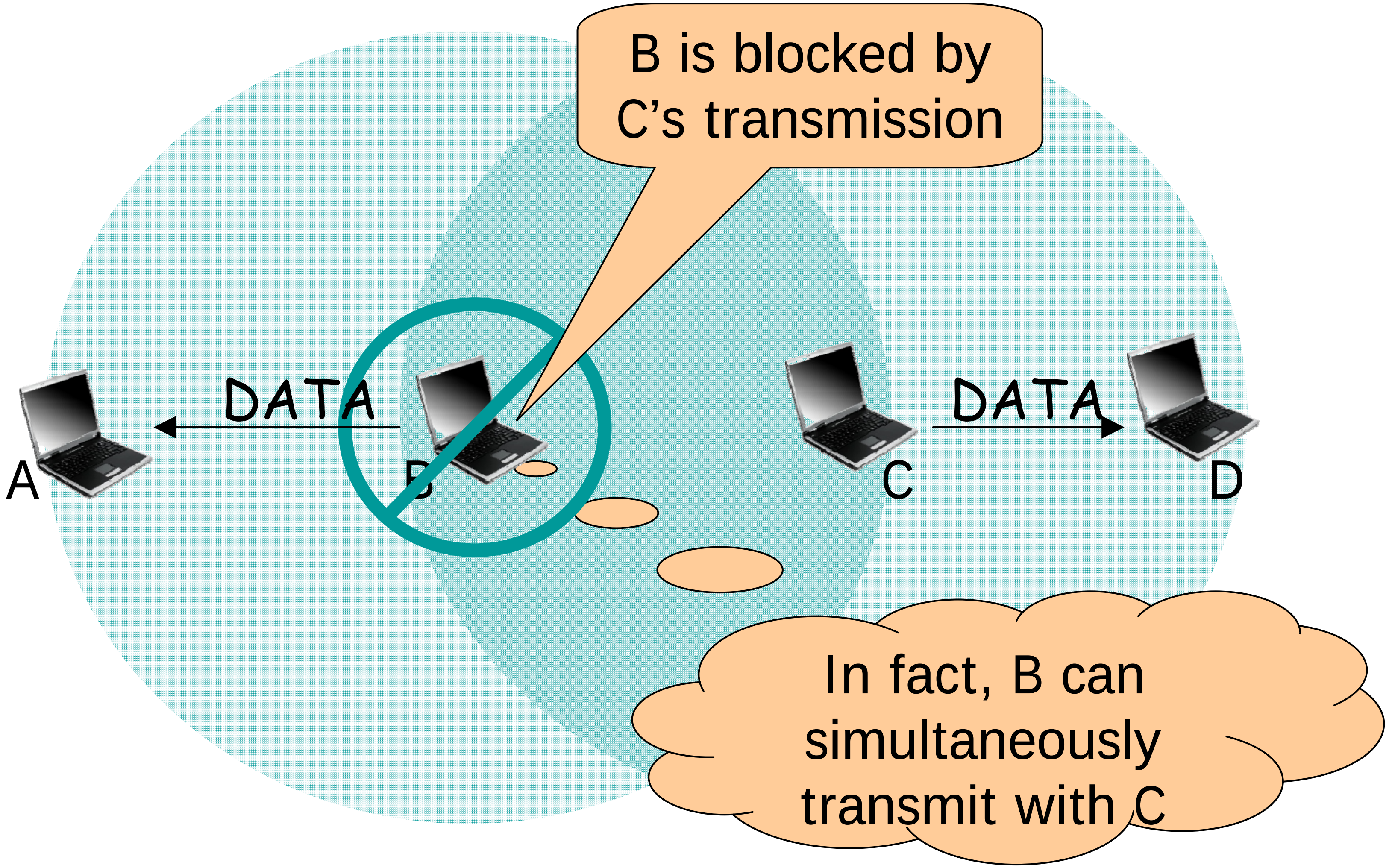
multi-rate, 1, 2, 5.5, 11 Mbps



multi-rate, 1, 2, 5.5, 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," *Wireless Communications and Mobile Computing*, Vol. 9, Issue 8, Aug. 2009, pp. 1102-1112.

Exposed Terminal Problem



Fairness Problem (exposed)

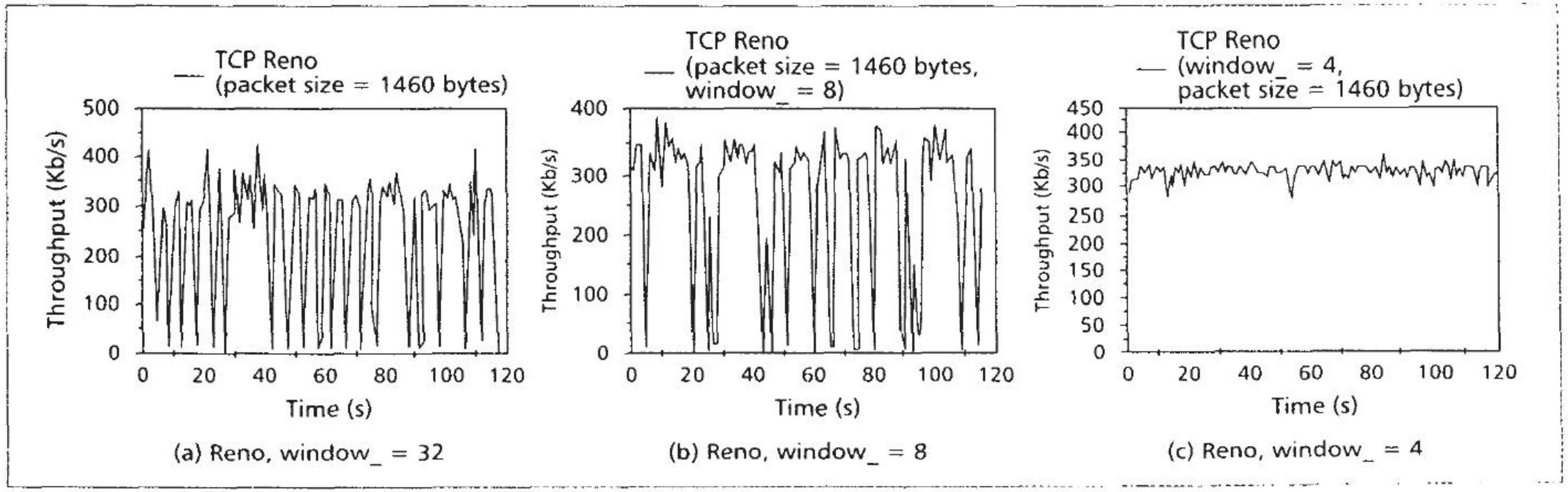
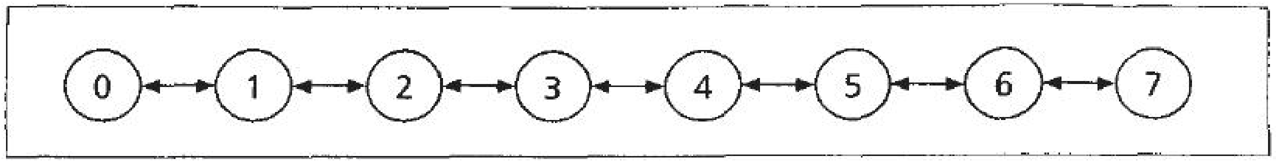


Figure 2. *The instability problem in the four-hop TCP connection (from node 1 to node 5). TCP packet size = 1460 bytes.*



S. Xu and T. Saadawi, "Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks?" IEEE Communications Magazine, vol. 39, issue 6, pp. 130-137, Jun. 2001.

Fairness Problem (exposed)

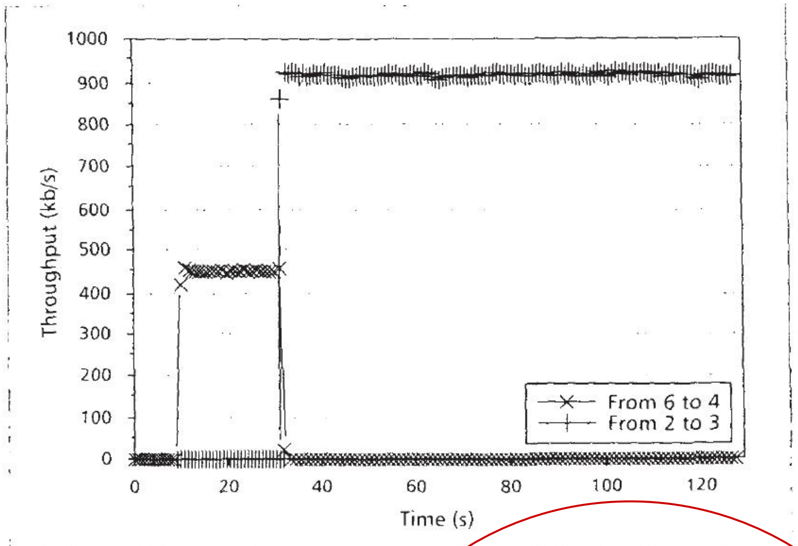


Figure 4. *Throughput of two TCP connections with different sender and receiver, window_=4.*

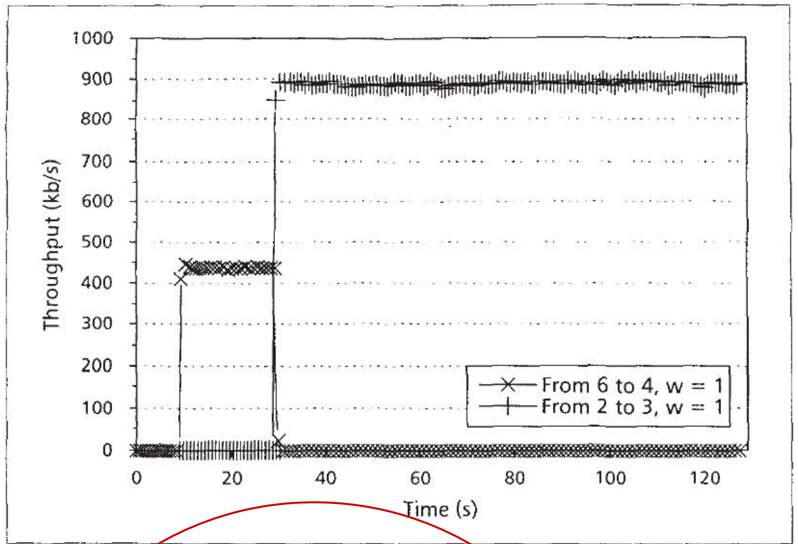
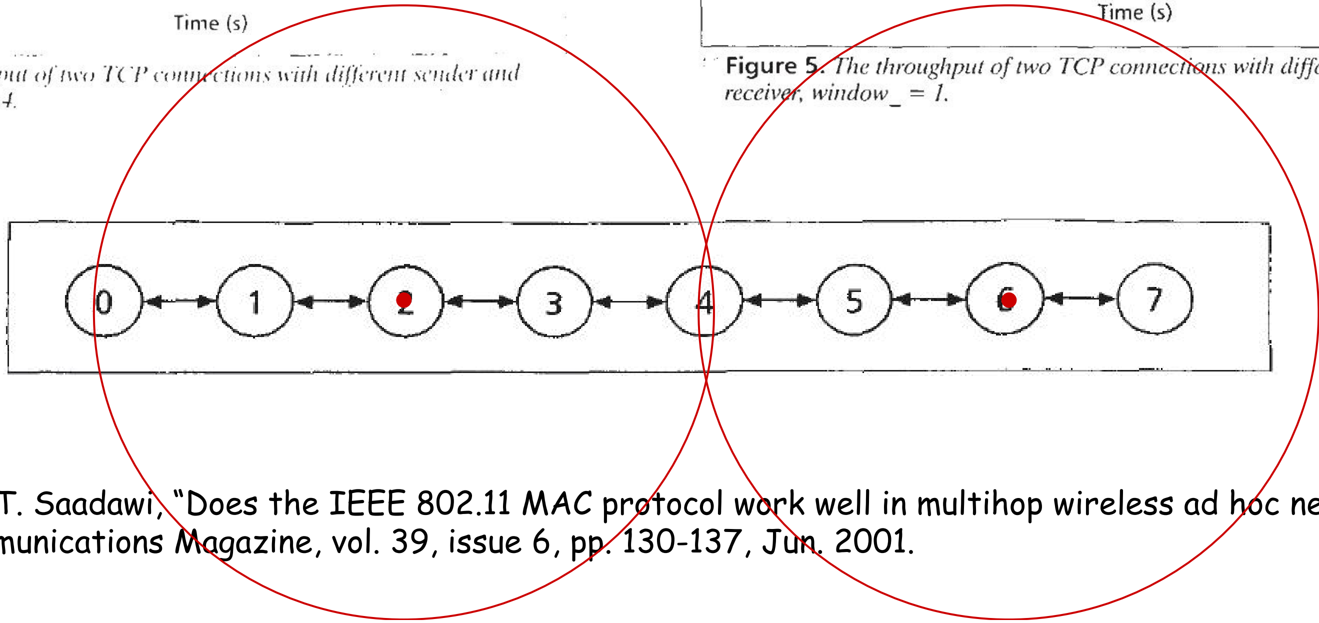


Figure 5. *The throughput of two TCP connections with different sender and receiver, window_ = 1.*



S. Xu and T. Saadawi, "Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks?" IEEE Communications Magazine, vol. 39, issue 6, pp. 130-137, Jun. 2001.

Fairness Problem (Feb. 2010)

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 9, NO. 2, FEBRUARY 2010

Adaptive Contention Control for Improving End-to-End Throughput Performance of Multihop Wireless Networks

Daewon Jung, Jaeseon Hwang, Hyuk Lim, *Member, IEEE,* Kyung-Joon Park, *Member, IEEE,* and Jennifer C. Hou, *Fellow, IEEE*

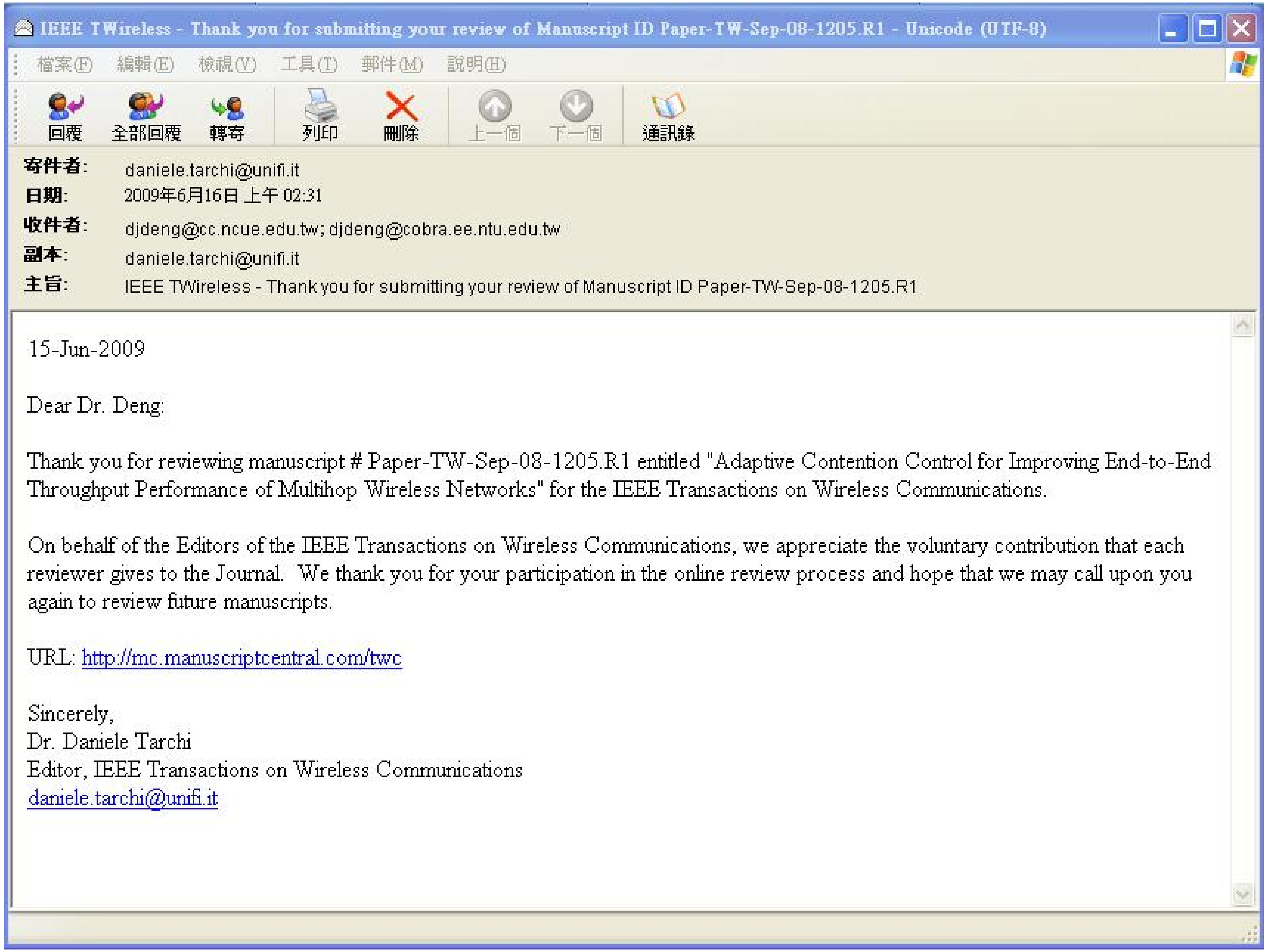
***Abstract*—In multihop wireless networks, packets of a flow originating from a source node are relayed by intermediate nodes (relay nodes) and travel towards their destination along a multihop wireless path. Since the traffic forwarding capability of each node varies according to its level of contention, ideally, a node should not transmit more packets to its relay node than the corresponding relay node can forward. Instead, each node should yield its channel access opportunity to its neighbor nodes so that all the nodes can evenly share the channel and have similar forwarding capabilities. In this manner, nodes can utilize the wireless channel effectively, and further increase the end-to-end throughput of a multihop path. We propose a fully distributed contention window adaptation (CWA) mechanism, which adjusts the channel access probability depending on the difference between the incoming and outgoing traffic at each node, in order to equate the traffic forwarding capabilities among all the nodes in the path. We implement the proposed adaptive contention algorithm on Madwifi Linux kernel driver for Wi-Fi**

in multihop wireless networks, packets of a flow originating from a source node are relayed by intermediate nodes (relay nodes) and travel towards the destination along a multihop wireless path.

One of the critical performance metrics in multihop wireless networks is the network throughput, which heavily depends on the achievable channel capacity at each individual wireless link and the level of spatial reuse. Several PHY/MAC attributes in multihop wireless networks can be used in order to control channel access, reduce interference, and improve network throughput, among which the transmit power, the carrier sense threshold, and the channel access probability have been the main research topics.

In this paper, we consider the issue of improving the end-to-end throughput performance of IEEE 802.11 DCF-

Fairness Problem (exposed)



IEEE TWireless - Thank you for submitting your review of Manuscript ID Paper-TW-Sep-08-1205.R1 - Unicode (UTF-8)

檔案(F) 編輯(E) 檢視(V) 工具(T) 郵件(M) 說明(H)

回覆 全部回覆 轉寄 列印 刪除 上一個 下一個 通訊錄

寄件者: daniele.tarchi@unifi.it
日期: 2009年6月16日 上午 02:31
收件者: djdeng@cc.ncue.edu.tw; djdeng@cobra.ee.ntu.edu.tw
副本: daniele.tarchi@unifi.it
主旨: IEEE TWireless - Thank you for submitting your review of Manuscript ID Paper-TW-Sep-08-1205.R1

15-Jun-2009

Dear Dr. Deng:

Thank you for reviewing manuscript # Paper-TW-Sep-08-1205.R1 entitled "Adaptive Contention Control for Improving End-to-End Throughput Performance of Multihop Wireless Networks" for the IEEE Transactions on Wireless Communications.

On behalf of the Editors of the IEEE Transactions on Wireless Communications, we appreciate the voluntary contribution that each reviewer gives to the Journal. We thank you for your participation in the online review process and hope that we may call upon you again to review future manuscripts.

URL: http://mc.manuscriptcentral.com/twc

Sincerely,
Dr. Daniele Tarchi
Editor, IEEE Transactions on Wireless Communications
daniele.tarchi@unifi.it

Fairness Problem (exposed)

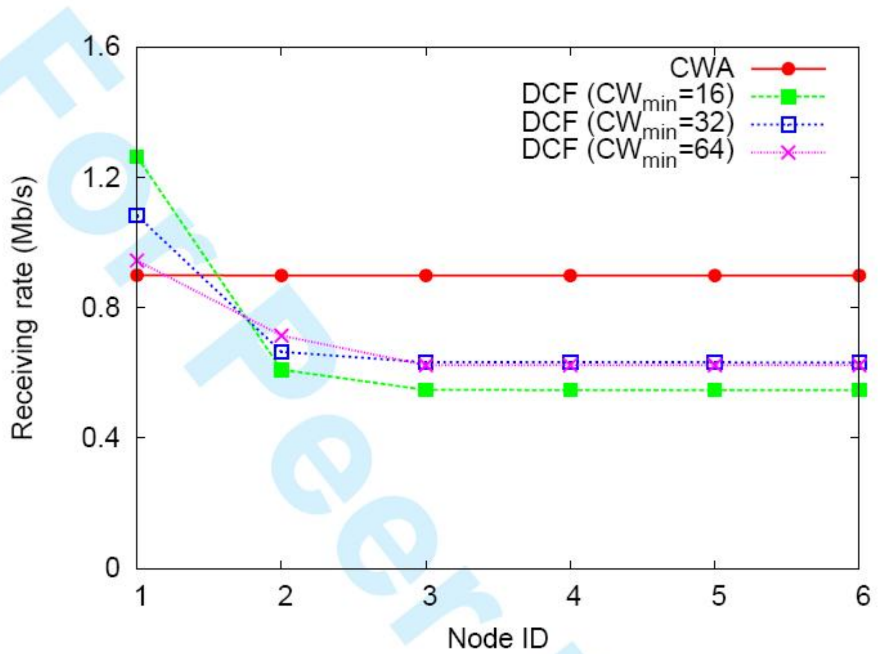


Fig. 2. Receiving traffic rate at each relay node on a 6-hop wireless path for a fixed, single CW_{min} and an adaptively selected CW_{min}. (The reiving rate at the last node is the end-to-end throughput of the multihop wireless path.)

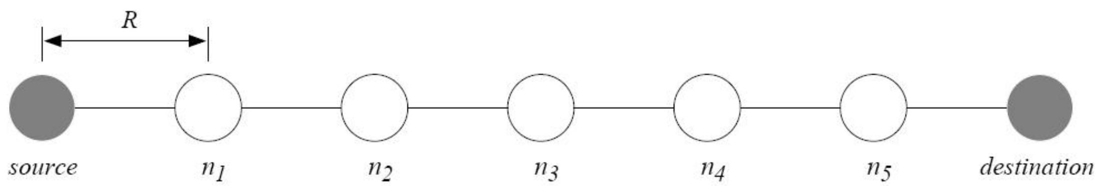
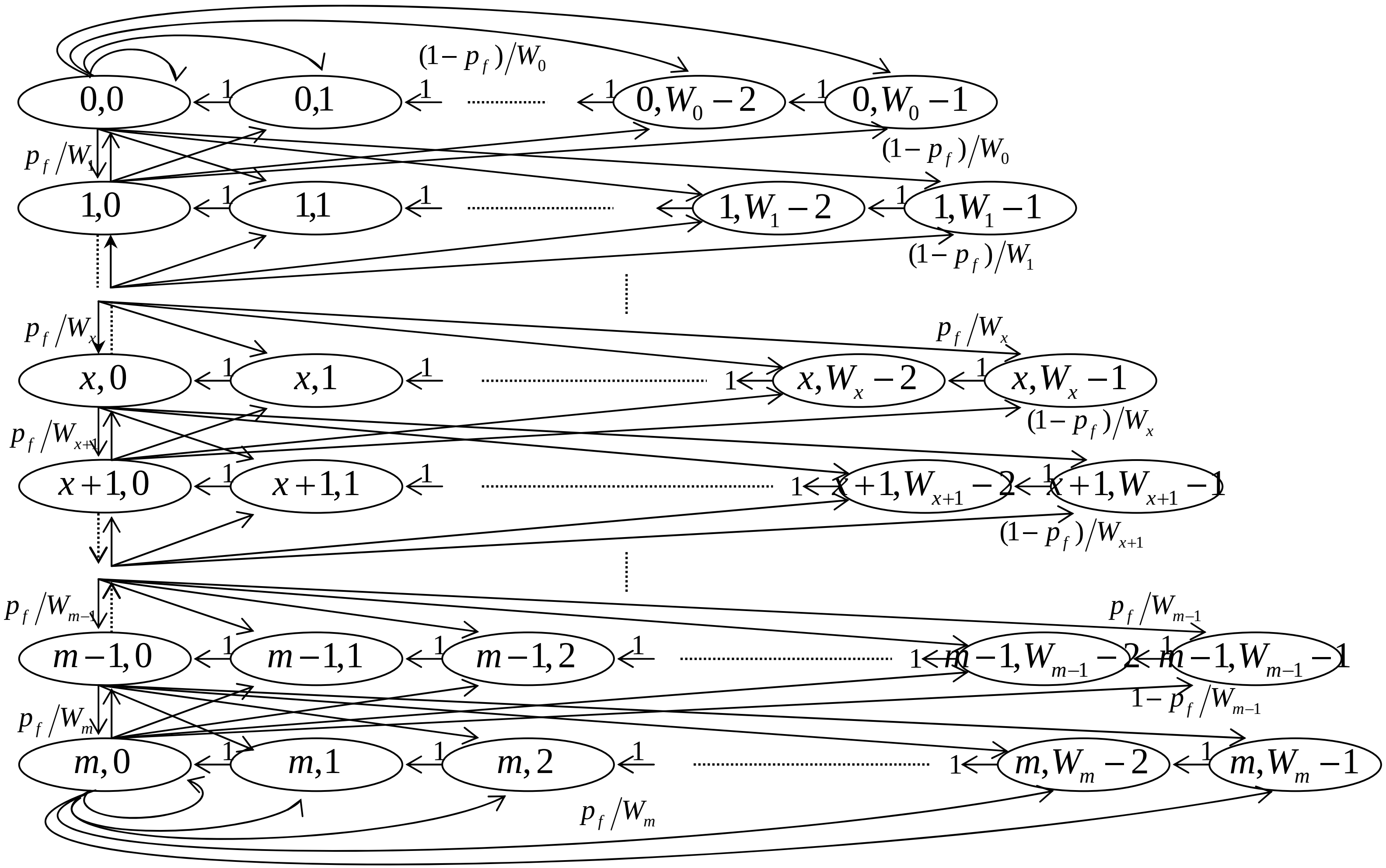


Fig. 1. A multihop wireless path consisting of a source node, a destination node, and five relay nodes.

Slow Start Backoff Alg.

```
Function Slow-Start Backoff
repeat
    if ACK frame received then successful transmission
     if current backoff window size ≤ W_m then
      if current backoff window size=W_0 then
       backoff window size=W_0
     else
     backoff window size=current backoff window size ÷ 2
    else
    backoff window size=current backoff window size-W_0
   else
     if current backoff window size < W_m then
     backoff window size=current backoff window size × 2
      else frame lost due to collision or interference
      if backoff window size= W_n then
      backoff window size=W_n
      else
    backoff window size=current backoff window size +W_0
   until no more frame to transmit
end
```

Slow-Start Backoff Alg.



Saturation Throughput Analysis

$$\bar{W} = P_0 W_0 \zeta^X \left\{ \frac{1-2^X \zeta^X}{\zeta^X (1-2\zeta)} + \frac{(2^X - X)(1-\zeta^{m-X+1})}{1-\zeta} + \frac{\zeta(1-\zeta^{m-X})}{(1-\zeta)^2} \right\}$$

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

$$f(x) = (1-p)^{x-1} \cdot p \qquad x = 1,2\ldots\infty$$

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

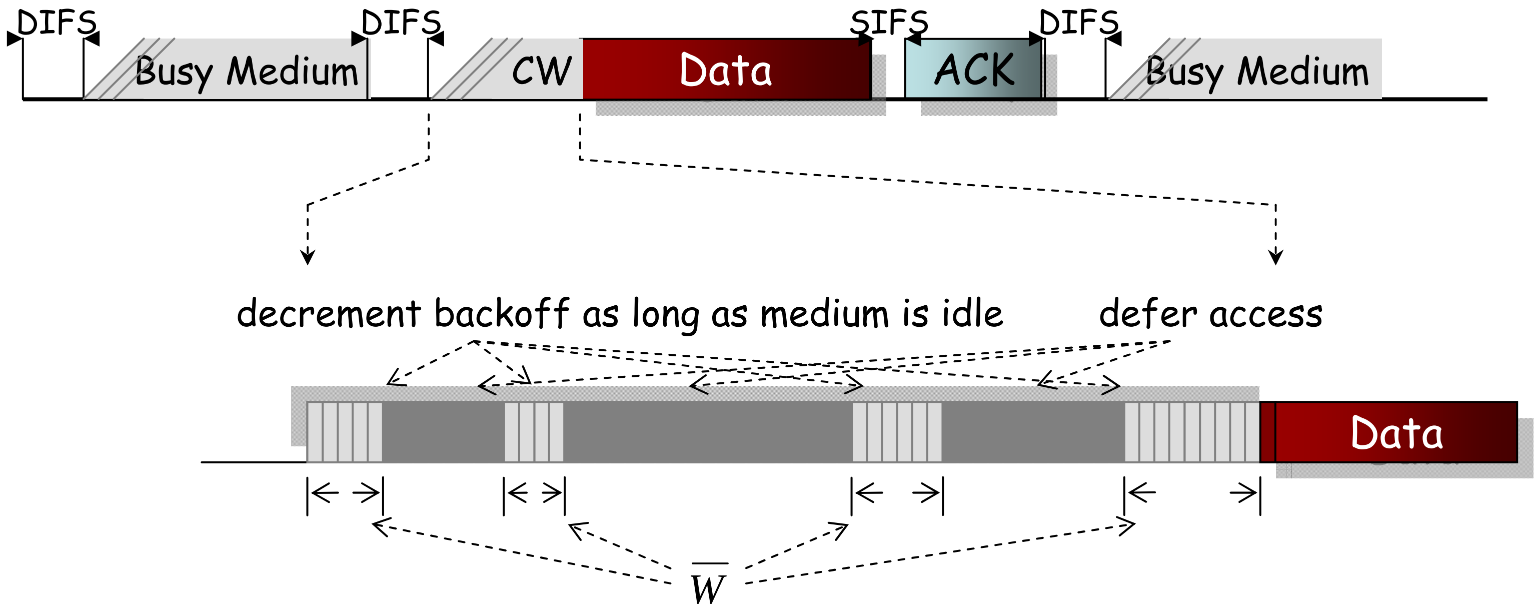
$$f(x) = (1-p)^{x-1} \cdot p, \quad 1 \le x \le \infty$$

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

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

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

P-Persistent CSMA/CA



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

Saturation Throughput Analysis

$$p := 2 \Bigg/ \left(W \cdot \left(\frac{(2\,\zeta)^{x+1} - 1}{2\,\zeta - 1} + \frac{\zeta^{m+1} \cdot \left((2x - x + m) \cdot (\zeta - 1) - 1 \right) - \zeta^{x+1} \cdot \left(2x\zeta - 2x - 1 \right)}{(\zeta - 1)^2} \right) + 1 \right)$$

Saturation Throughput Analysis

$$S = \frac{p_s E[p]}{(1-P^n)\sigma + p_s T_{sucess} + (1-(1-p)^n - p_s)T_{fail}}, P_s = np(1-p)^{n-1}$$

Optimal CW size

$$p = \frac{\sqrt{-n^2 + 2n + 2T^*_{fail} - 2nT^*_{fail}} - n}{n(-n + nT^*_{fail} + 1 - T^*_{fail})}$$

IEEE TWC (Dec. 2008)

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 7, NO. 12, DECEMBER 2008 5129

Contention Window Optimization for IEEE 802.11 DCF Access Control

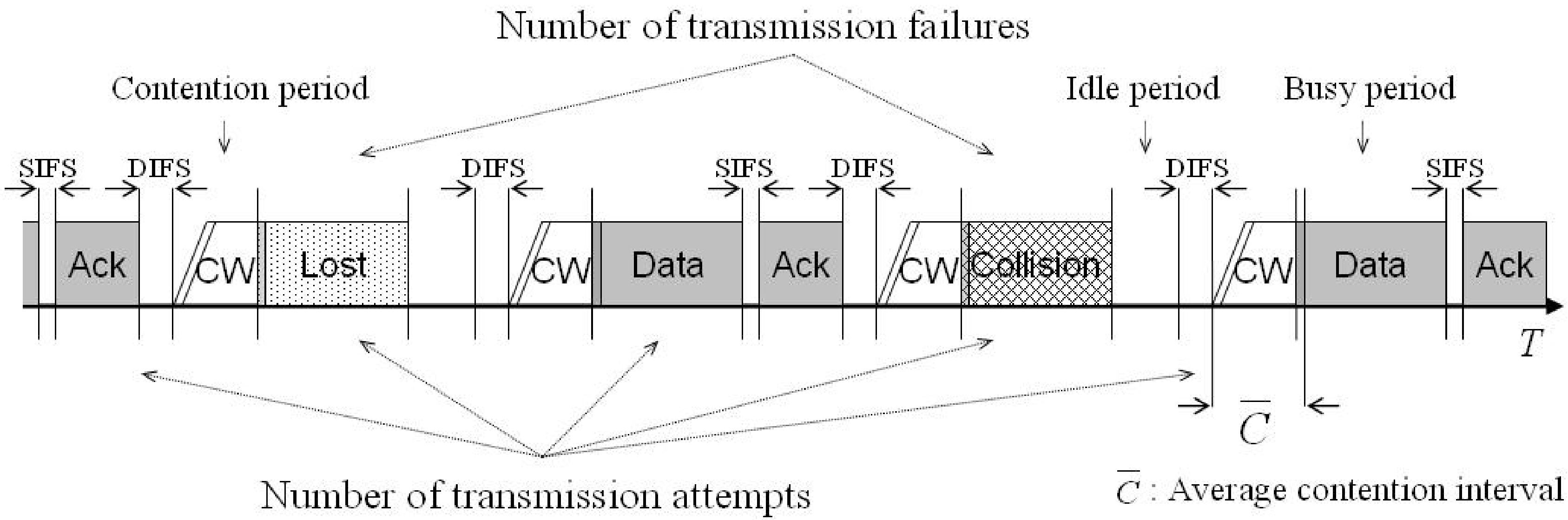
Der-Jiunn Deng, Chih-Heng Ke, Hsiao-Hwa Chen, and Yueh-Min Huang

***Abstract*—According to the latest version of the IEEE 802.11 standard, the backoff parameters of its collision avoidance mechanism are far from optimal, especially in a heavy load or error-prone WLAN environment. This strategy has a high collision probability and channel utilization is degraded in bursty arrivals or congested scenarios. Besides, the standard backoff mechanism may treat noise corruption as packet collisions. In this paper, we identify the relationship between backoff parameters, contention level, and channel BER in order to propose a simple, but yet well-performing distributed algorithm that allows a station to dynamically adjust its contention window size based on turn-around-time measurement of channel status. In addition to theoretical analysis, simulations are conducted to evaluate its performance. The proposed scheme works very well in providing a substantial performance improvement in heavy loaded and error-prone WLAN environments.**

***Index Terms*—IEEE 802.11, wireless network, distributed coordination function, backoff, bit error rate.**

scenarios but also in a situation where bit error rate (BER) increases in the wireless channel. The fundamental problem again comes from the backoff algorithm. In the CSMA/CA access scheme, immediate positive acknowledgement informs the sender of successful reception of each data frame. This is accomplished by a receiver initiating the transmission of an acknowledgement frame after a small time interval, SIFS, immediately following the reception of the data frame. In case that an acknowledgement is not received, as we mentioned earlier, the sender should automatically presume the data frame that was lost due to collision. Consequently, when a timer goes off, it exponentially increases backoff parameter value and retransmits the data frame less intensively. The idea behind this approach is to alleviate the probability of collisions. Unfortunately, wireless transmission links are noisy and highly unreliable. Path loss, channel noise, fading, and

Runtime Estimate Channel Status



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

Average CW size

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

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

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

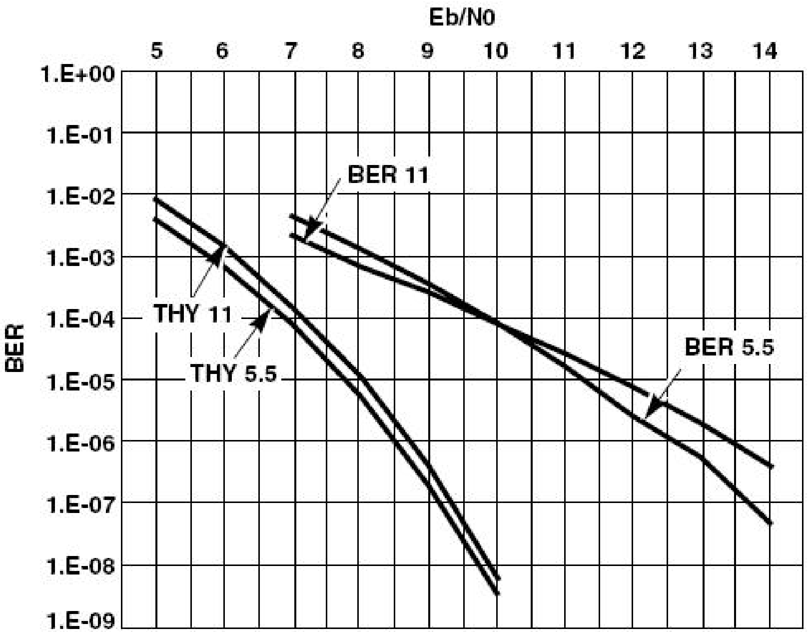
No. of Active Stations Estimation

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

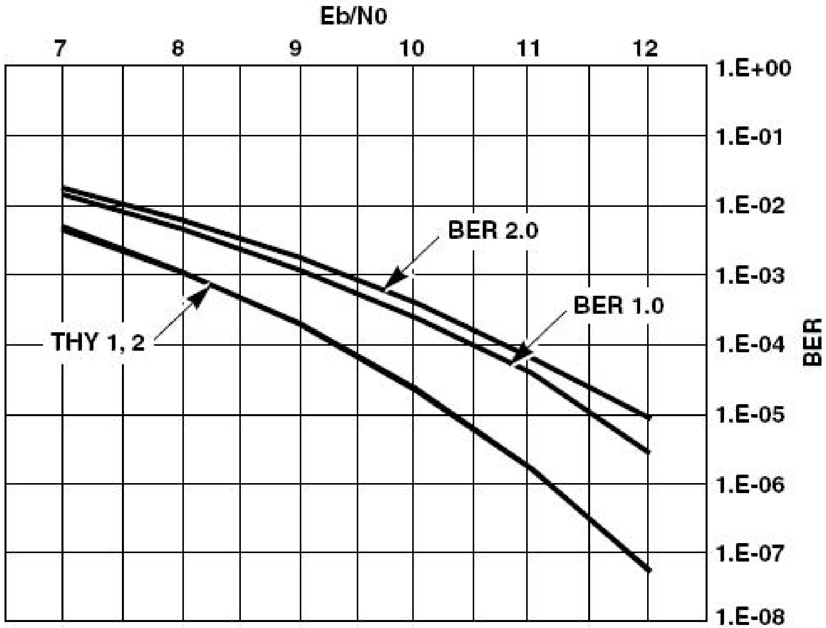
$$M = 1 + \frac{\log\left[\frac{1-p_f}{(1-BER)^{L_{DATA}}}\right]}{\log(1-p)}$$

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

BER Estimating



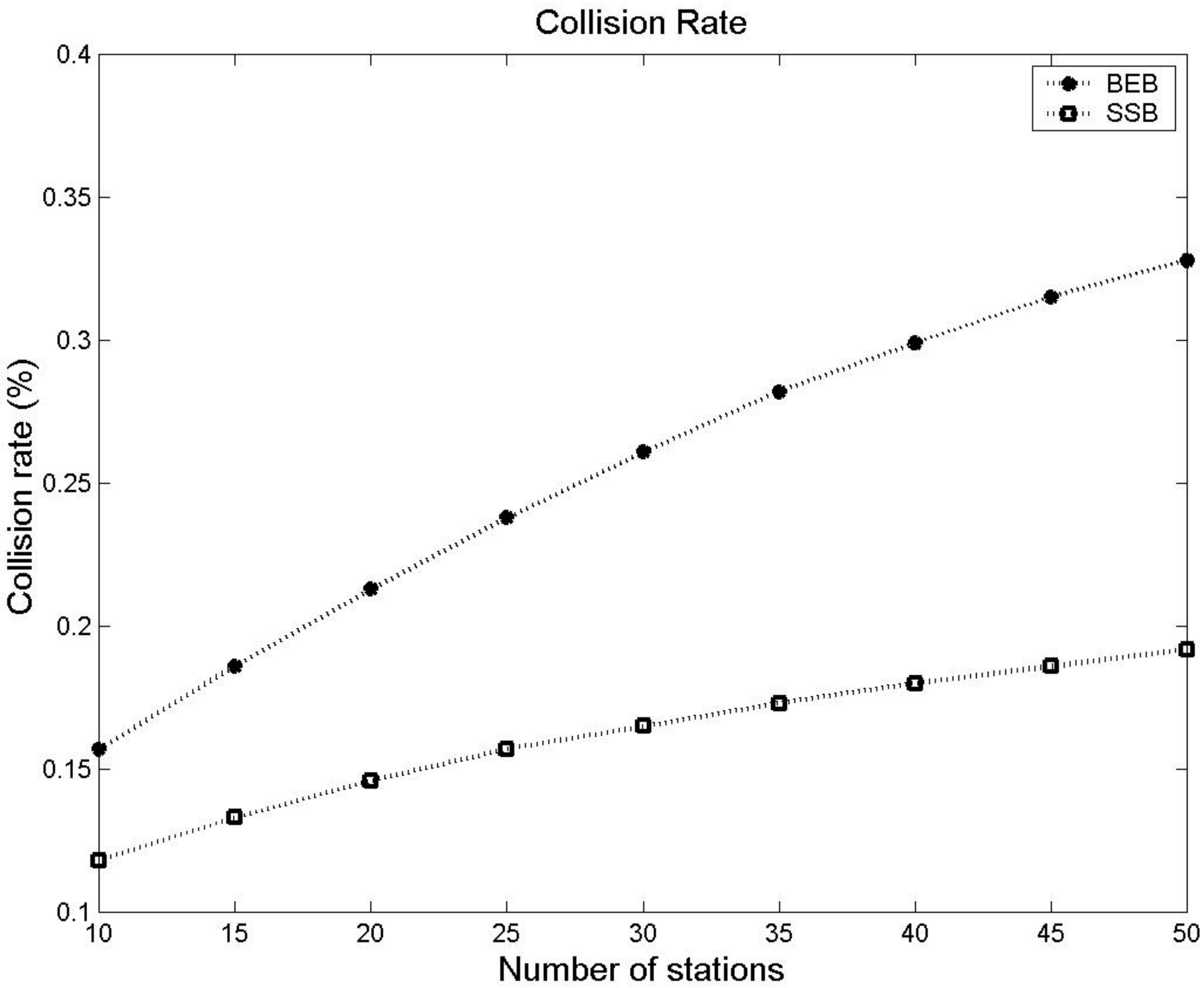
CCK Mode



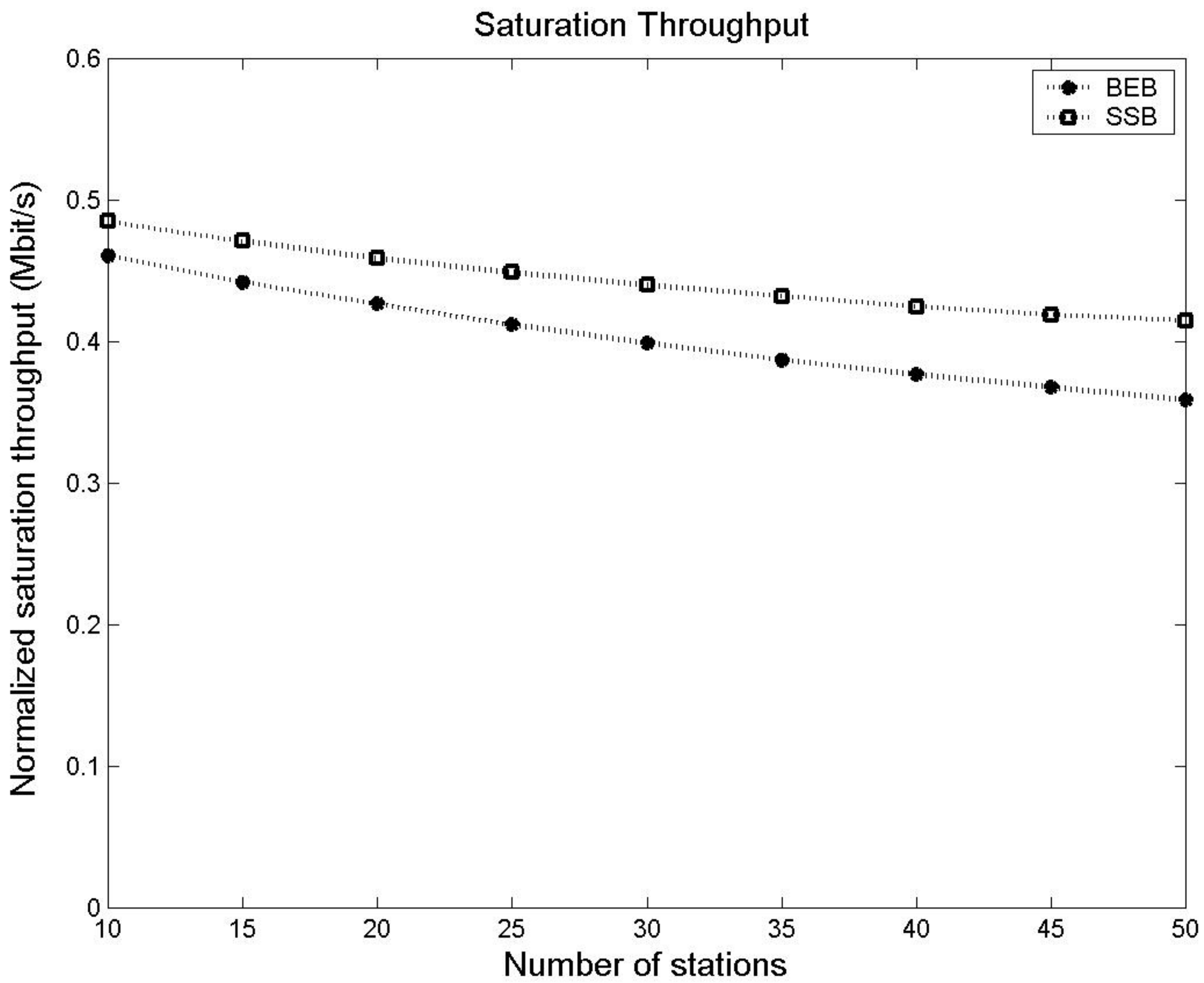
PSK Mode

BER vs. SNR for Intersil HFA3861B chipset

Simulation Results



Simulation Results



Simulation Results