CARA: Collision-Aware Rate Adaptation for IEEE 802.11 WLANs

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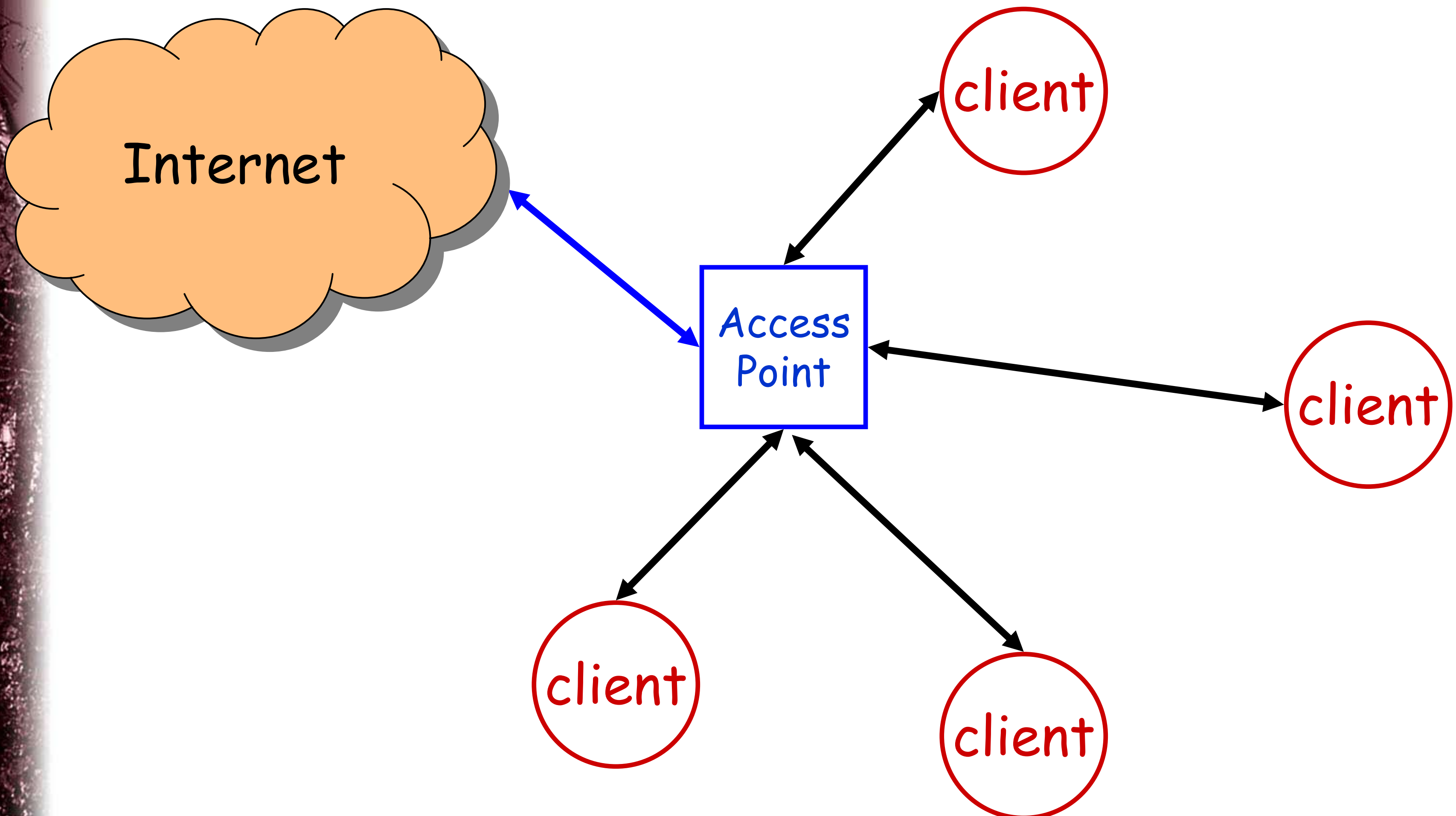
Outline

- Background
- Related Work
  - ARF
  - RBAR
- *CARA* (Collision Aware Rate Adaptation)
  - RTS Probing
  - CCA Detection
- Simulated Performance Results
- Conclusions and Comments

Infrastructure WLAN



Basic CSMA/CA

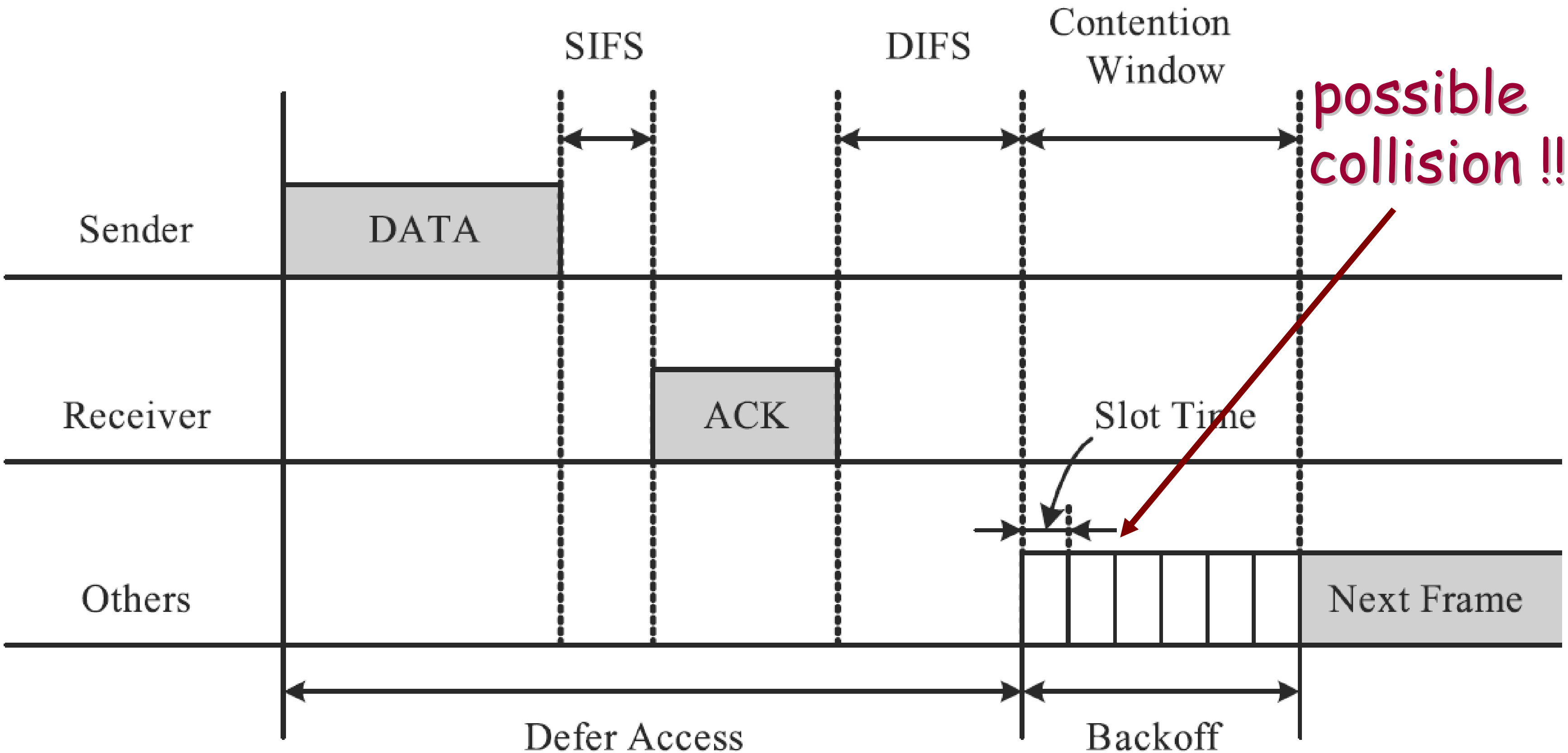


Fig. 1 CSMA/CA protocol of IEEE 802.11 MAC DCF.

[N. Kim]

Physical Layer Overhead

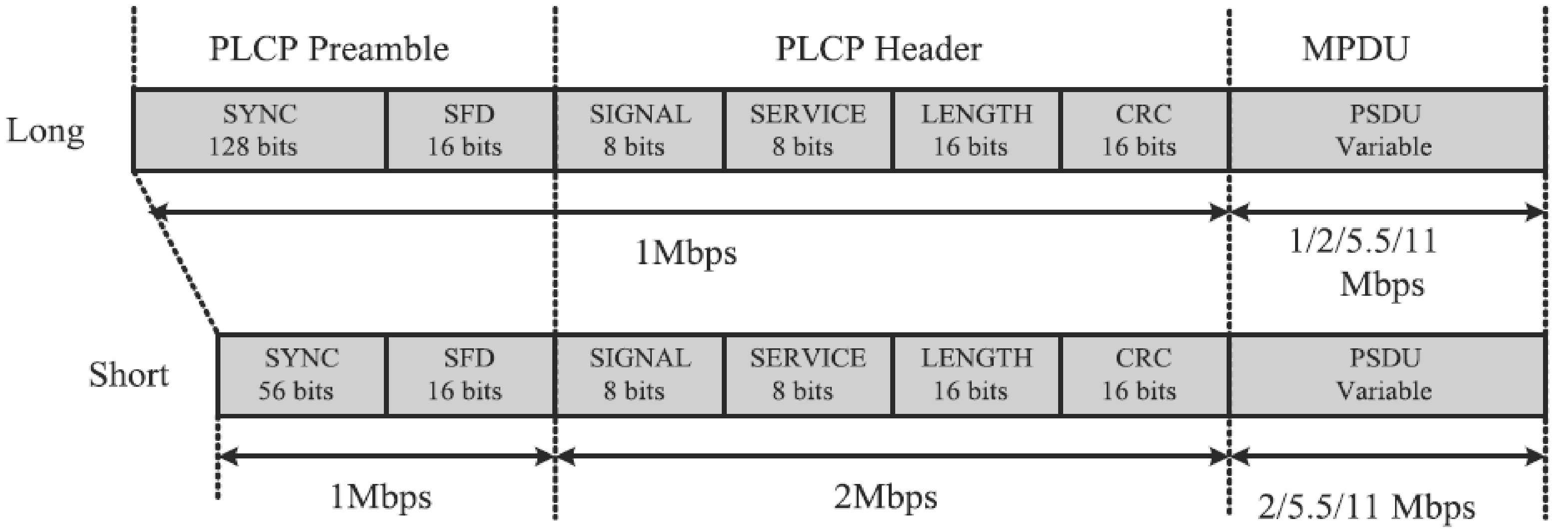


Fig. 2 IEEE 802.11b HR/DSSS PHY framing structure.

[N. Kim]

Node Contention

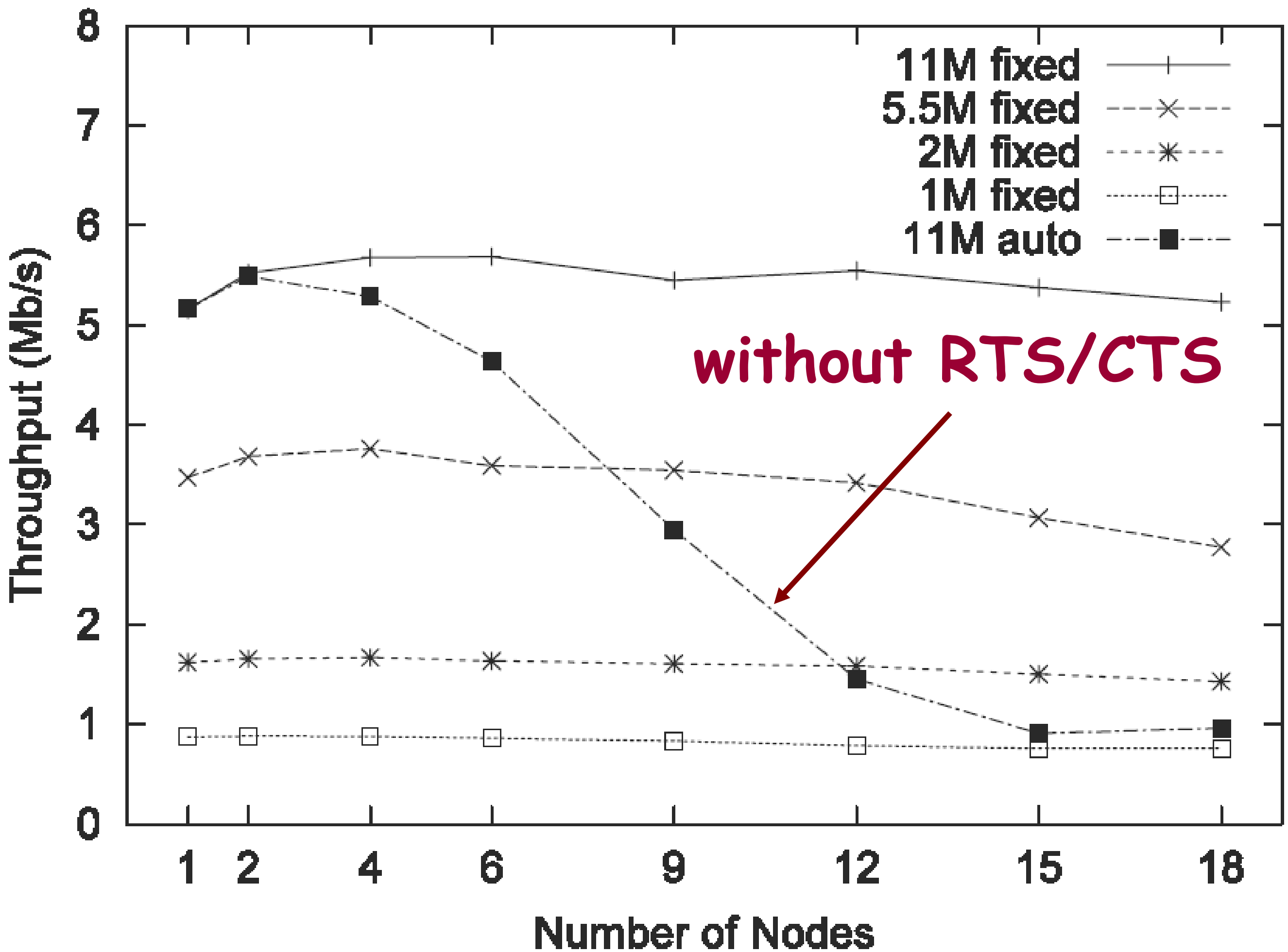


Fig. 7 Throughputs with node contentions.

[N. Kim]

Rate Adaptation versus Distance

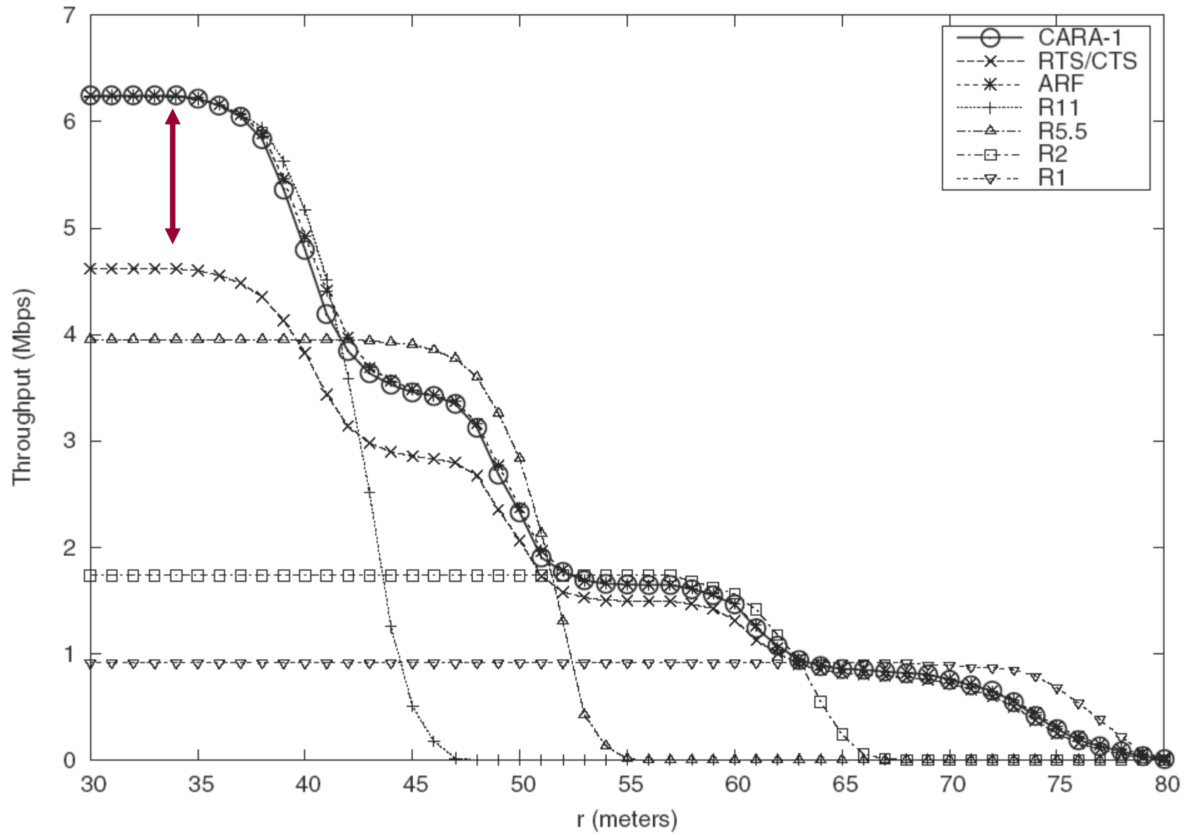


Fig. 6. Throughput comparison of our proposed rate adaptation scheme (CARA-1) against RTS/CTS, ARF, and single-rate schemes for one-to-one topology networks with various distance (r)

Unfairness

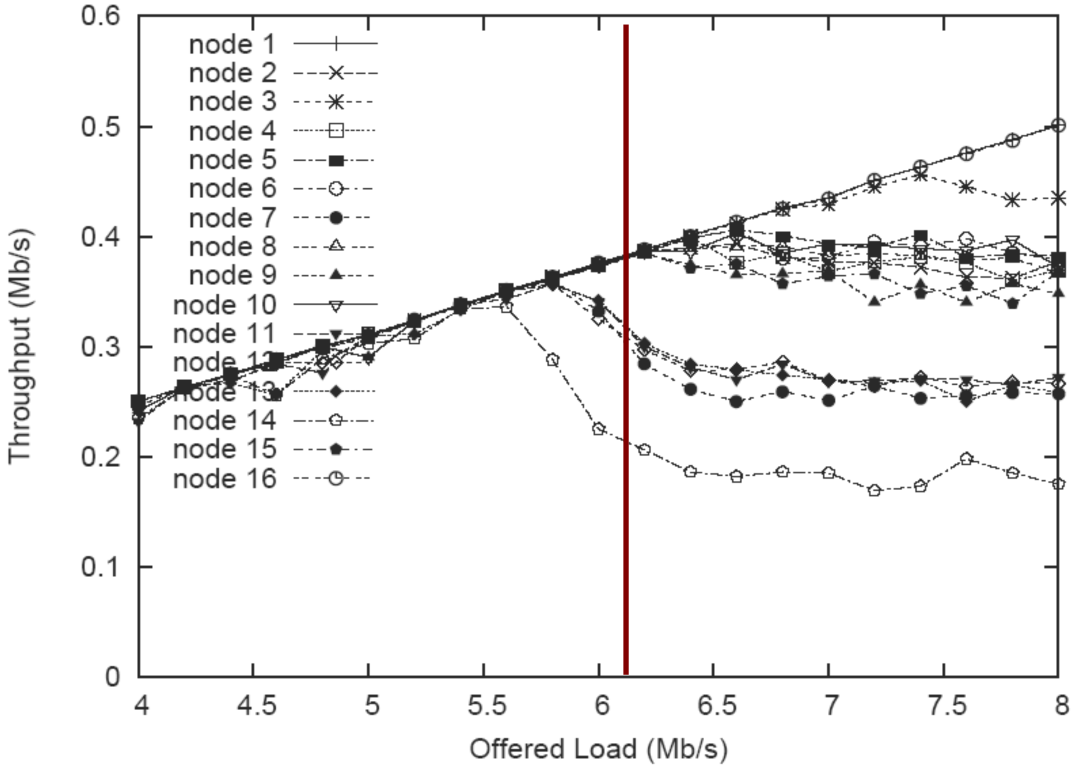
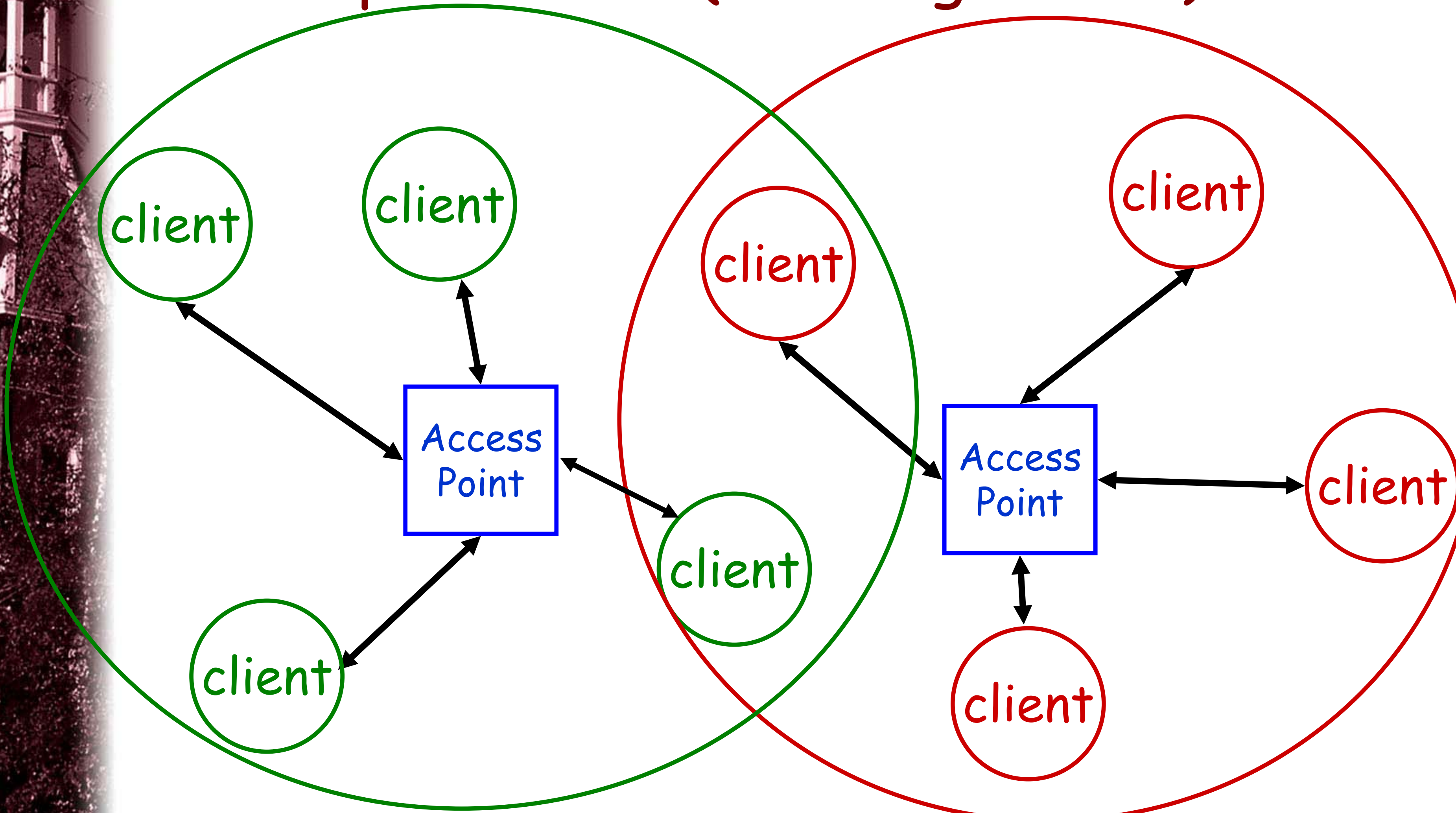


Figure 14: Empirical DCF fairness with respect to individual throughput share as a function of offered load for 16 iPAQs in indoor office environment.

[Choi]

Multiple APs
multiple clients (heterogeneous)



Hidden Terminals

Without a hidden terminal, loss ratio ~5.5%.
One hidden AP with mild sending rate (0.379 Mbps) yields:

	ARF	AARF	SampleRate	FixedRate
Goodput (Mbps)	0.65	0.56	0.58	1.46
Loss Ratio	61%	60%	59%	60%

Table 1: Performance of different rate adaptation algorithms in the presence of hidden stations. [Wong]

RTS/CTS Summary

- **RTS/CTS can reduce collisions.**
- **RTS/CTS can guard against and reduce hidden terminals.**
- **RTS/CTS adds overhead that reduces throughput.**
- **Normally, RTS/CTS is turned off!**

Rate Adaptation Algorithms

AARF	ARF	AMRR
CARA	CROAR	DOFRA
Fast-LA	HRC	LA
LD-ARF	MiSer	MultiRateRetry
MPDU	OAR	ONOE
PER	RBAR	RFT
RRAA	SampleRate	SwissRA

Rate Adaptation Algorithms

1997	ARF			
1998				
1999				
2000				
2001	RBAR			
2002	MPDU	OAR	PER	
2003	LA	MiSer	SwissRA	
2004	AARF	AMRR	HRC	MultiRateRetry
2005	Fast-LA	LD-ARF	RFT	SampleRate
2006	CARA	CROAR	DOFRA	RRAA
2007				

Rate Adaptation Algorithms

- Uses recent history and probes: ARF, AARF, SampleRate
- Long interval smoothing: ONOE, SampleRate
- Multiple rates: MultiRateRetry, AMRR, RRAA
- Uses RTS/CTS: RBAR, OAR, CROAR, CARA
- Uses RSSI to approximate SNR, each node maintains 12 dynamic RSS thresholds: LA
- Puts checksum on header and use NACK to signal link loss error: LD-ARF
- Table lookup with thresholds: HRC,MPDU(len,rSNR,count)
- Fragmentation: DOFRA, RFT
- Miscellaneous: PER, MiSer, SwissRA, Fast-LA

ARF Algorithm

- If two consecutive ACK frames are not received correctly, the second retry and subsequent transmissions are done at a lower rate and a timer is started.
- When the number of successfully received ACKs reaches 10 or the timer goes off, a probe frame is sent at the next higher rate. However, if an ACK is NOT received for this frame, the rate is lowered back and the timer is restarted.

ARF and AARF

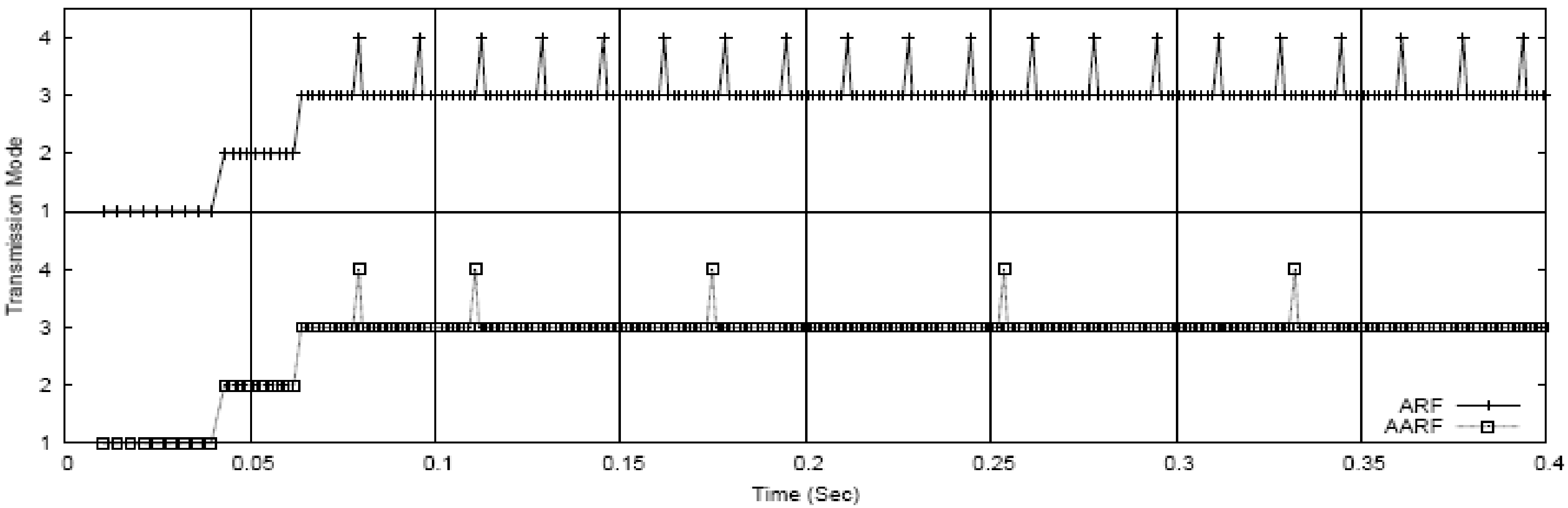


Figure 1: Mode selection comparison between ARF and AARF.

RBAR Algorithm

- {not 802.11 compatible}
- Receivers control sender's transmission rate.
- RTS and CTS are modified to contain info on size and rate.
- Uses analysis of RTS reception (RSSI?) to estimate SNR and send choice back to sender in CTS.
- Receiver picks rate based on apriori SNR thresholds.

Collision Aware Rate Adaptation (CARA)

- Employs two methods for identifying collisions:
  1. RTS Probing
  2. Clear Channel Assessment (CCA)
- Focuses on when to **decrease** the transmission rate.
  - →Set M_{th} , the consecutive increase threshold, to the same value as ARF:
    $M_{th} = 10.$

CARA RTS Probing

- Assumes all RTS transmission failures are due to collisions.
- Transmission failure after RTS/CTS must be due to channel errors.
- RTS probing that enables an RTS/CTS exchange ONLY when a data frame transmission fails.

RTS Probing State Diagram

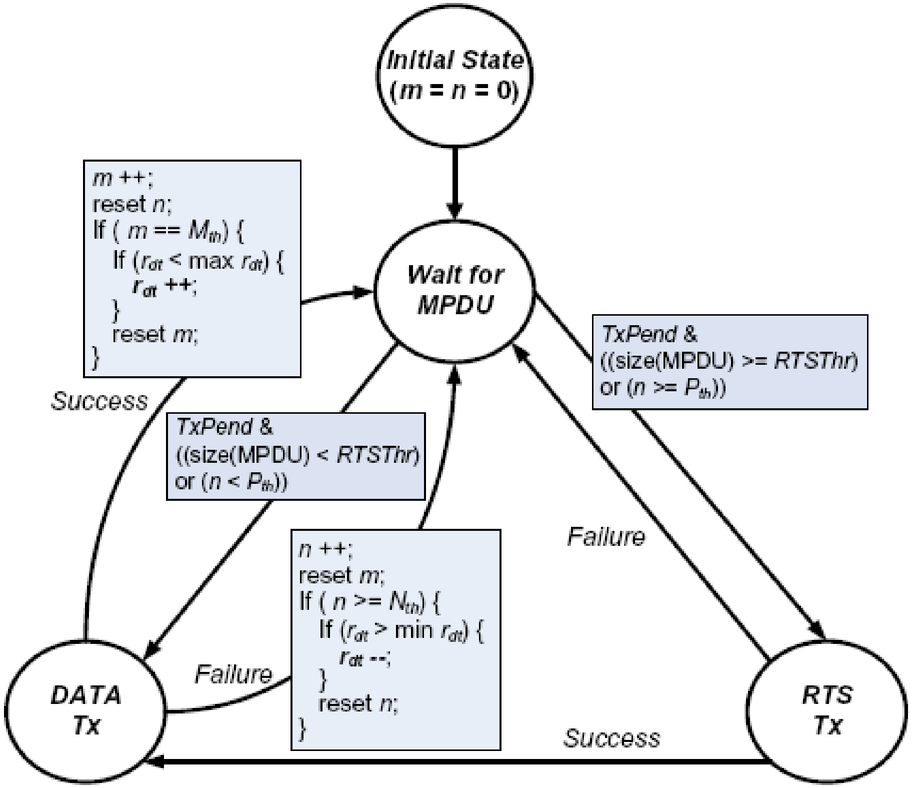


Fig. 3. State transition diagram of RTS Probing

RTS Probing

TABLE I

LIST OF NOTATIONS USED IN THE RTS PROBING PROCEDURE

Notations	Comments
m	consecutive success count
n	consecutive failure count
M_{th}	consecutive success threshold
N_{th}	consecutive failure threshold
TxPend	status: a data frame is pending
R_{dt}	array of transmission rates 802.11a = {6, 12, 18, 24, 36, 48, 54 Mbps}* 802.11b = {1, 2, 5.5, 11 Mbps}
r_{dt}	transmission rate: an element of R_{dt}
$++$	increase transmission rate to the next higher one
$--$	decrease transmission rate to the next lower one
P_{th}	probe activation threshold
RTSThr	frame size-based RTS Threshold as defined in the standard

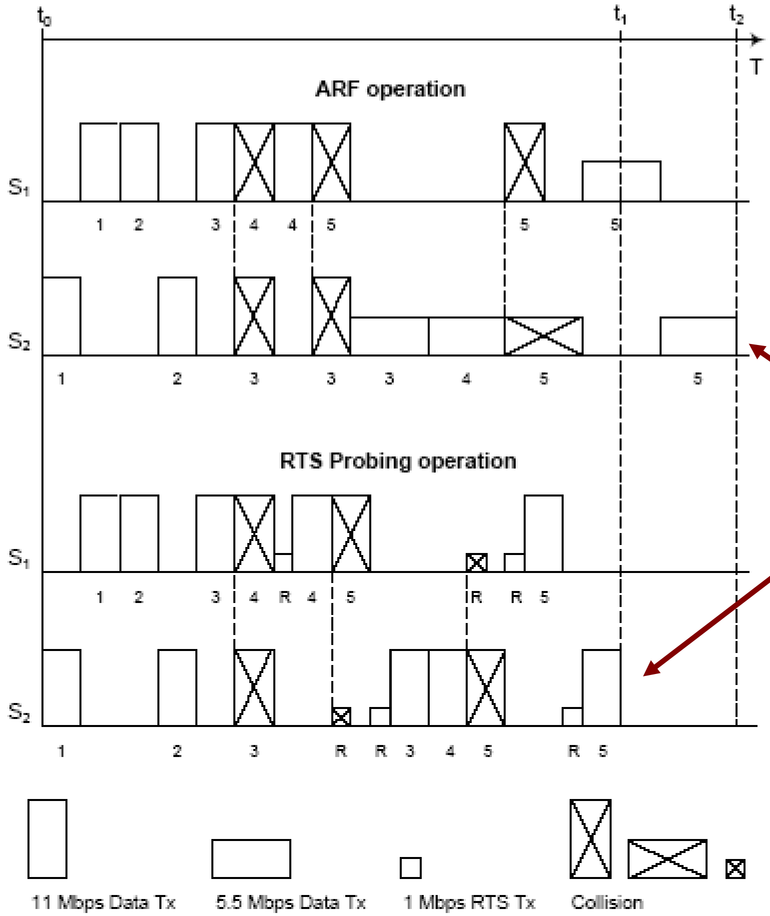
* The 9 Mbps rate is excluded as it is shown useless in [19].

RTS Probing

CARA default: [$P_{th} = 1, N_{th} = 2$]

- Data frame transmitted without RTS/CTS.
- If the transmission fails, RTS/CTS exchange is activated for the next retransmission. If this retransmission fails, then the rate is lowered.
- If retransmission is successful, stay at same rate and send next frame without RTS/CTS.

ARF vs RTS Probing



$t_1 < t_2$

Fig. 4. Illustration of ARF and RTS-Probing timelines for a two-station network, when channel status is good enough to accommodate the highest transmission rate of the 802.11b PHY, i.e., 11 Mbps

Clear Channel Assessment (CCA)

- At SIFS time after wireless transmission finishes, assess channel with *CCA*.
- Since *ACK* expected to start at SIFS, if channel assessed as busy (i.e. not an *ACK*) then assume it is a collision.
- In this case [Case 2], retransmit without increasing the failure count and ***without lowering the transmission rate***.
- *CCA* does not help for Case 1 or Case 3. Hence RTS Probing is launched.

CCA Detection

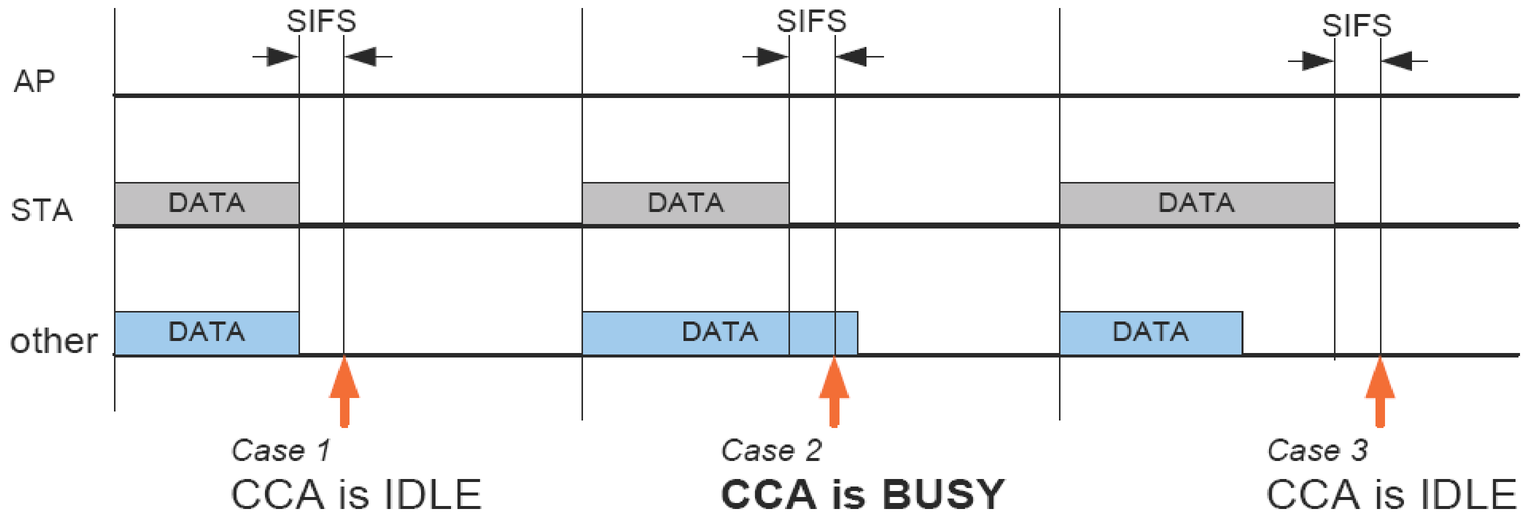


Fig. 5. Three possible cases of collision. In the second case, the collision can be detected via CCA detection.

This assumes no hidden terminals!

Performance Evaluation using ns-2 simulator

Simulation Setup:

- 802.11b with Frame Error Rate
- Ricean multi-path fading model
- Traffic is 'greedy' 1500 octet UDP packets
- CARA-1 :: only RTS Probing
- CARA-2 :: RTS Probing + CCA
- AWGN (additive white Gaussian noise) model::
  - the only impairment is the linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude. {Wikipedia}

One-to-One Topology

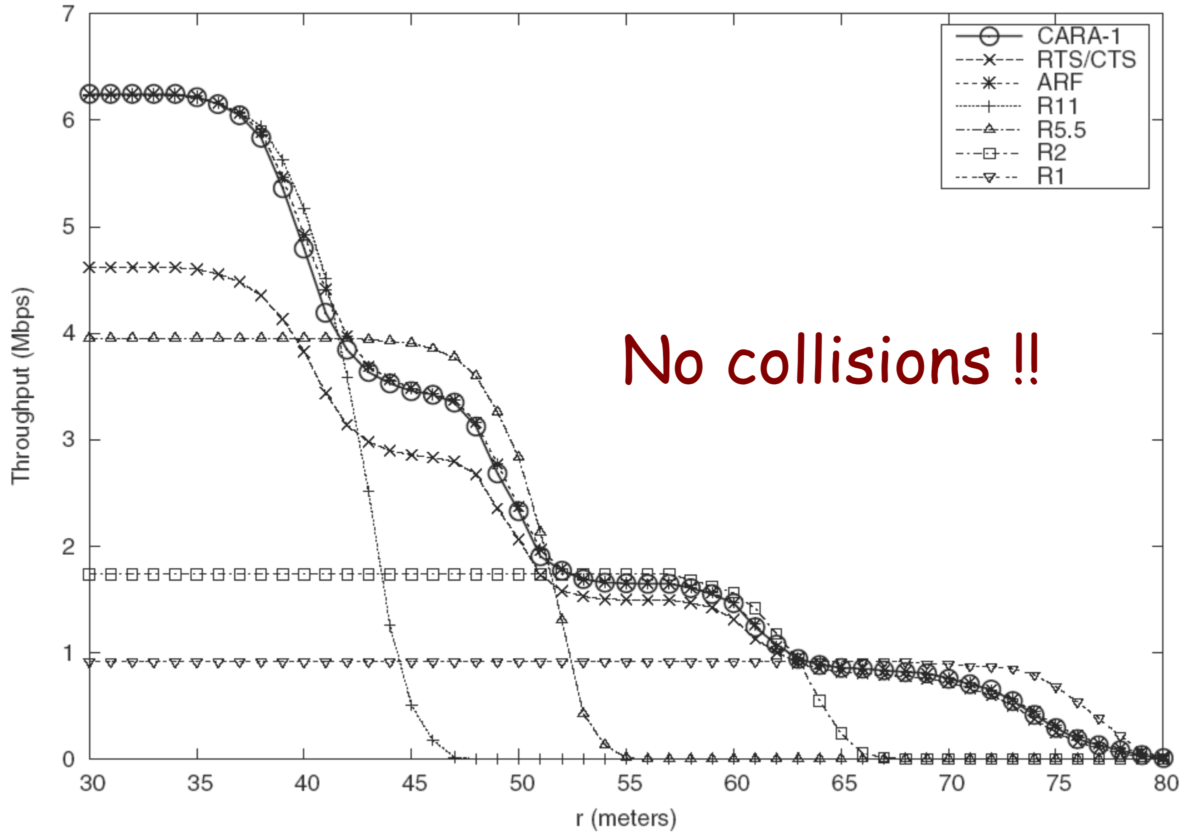


Fig. 6. Throughput comparison of our proposed rate adaptation scheme (CARA-1) against RTS/CTS, ARF, and single-rate schemes for one-to-one topology networks with various distance (r)

Star Topology Simulations

- Vary the number of contending stations evenly spaced on a circle with 10 m radius around the AP.
- AWGN wireless channel assumed.
- Note – from Figure 6, stations should be able to transmit at 11 Mbps at 10 m without being significantly effected by environment.

CARA-1 (with RTS Probing)

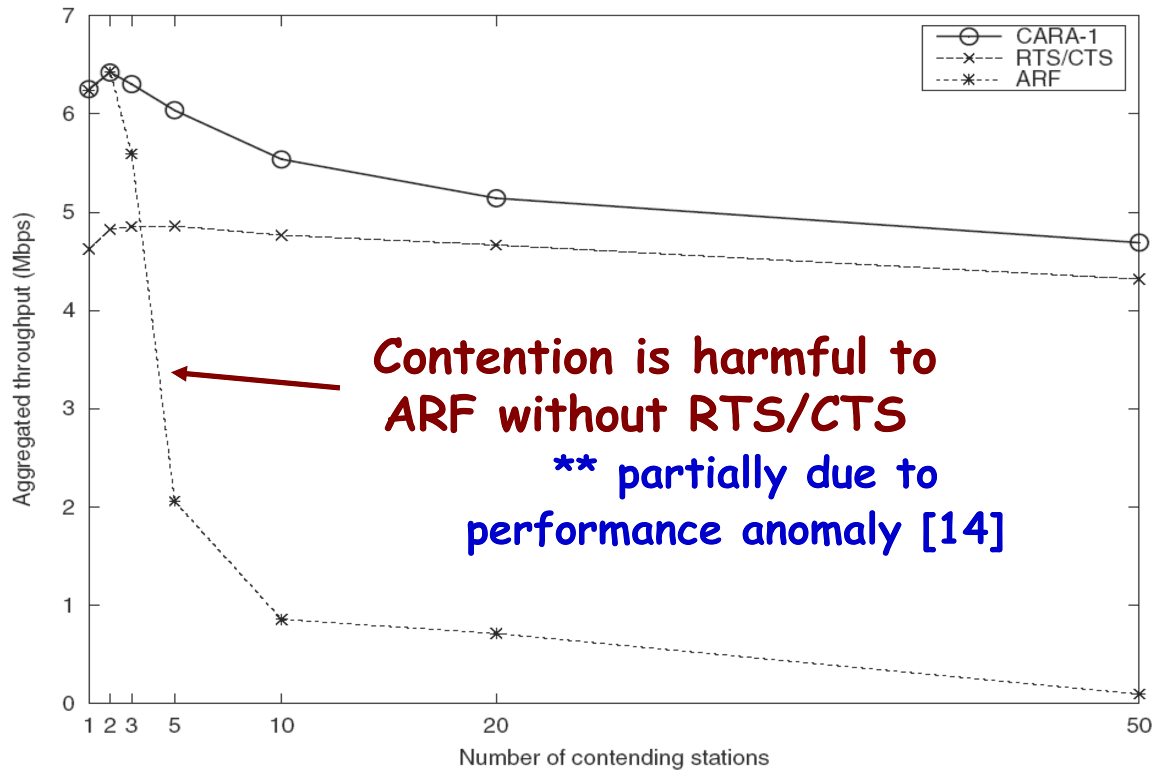


Fig. 7. Throughput comparison of our proposed rate adaptation scheme (CARA-1) against RTS/CTS and ARF for star-topology networks with various number of contending stations

Line Topology Simulations

- Assume a line topology with the AP at one end.
- Contending stations select data frame size randomly for each frame.
- Maximum distance between station and AP set to 70 meters to guarantee no hidden terminals.
- AWGN wireless channel assumed.
- Results in Figure 8 are averaged over 50 simulations.

CARA-2 (with CCA)

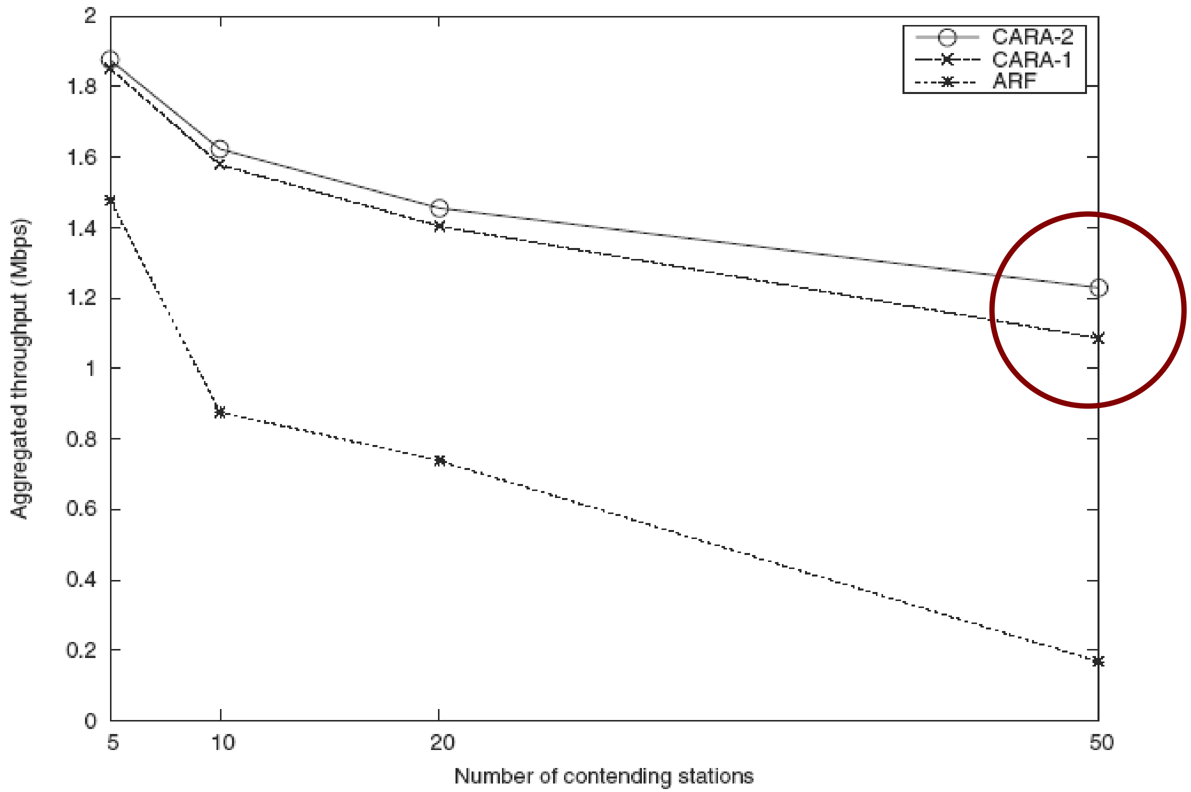


Fig. 8. Throughput comparison of our proposed rate adaptation schemes (CARA-1 and CARA-2) against ARF for line-topology networks with various number of contending stations with randomly chosen data frame sizes and stations' positions

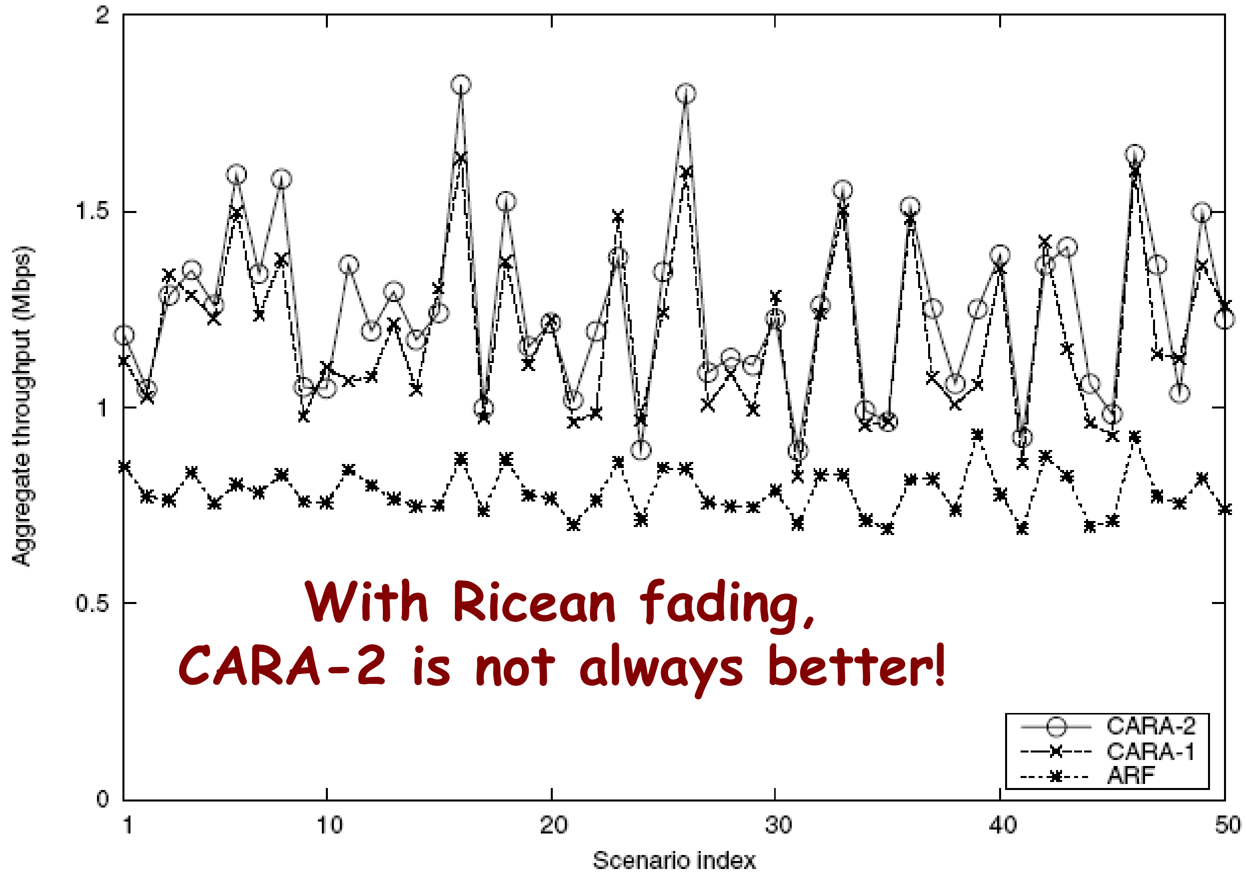
Random Topologies

- Nodes randomly placed within circle with 40 m radius centered on AP.
- Ricean K factor of 3 dB used to model indoor environment.

Two simulation sets:

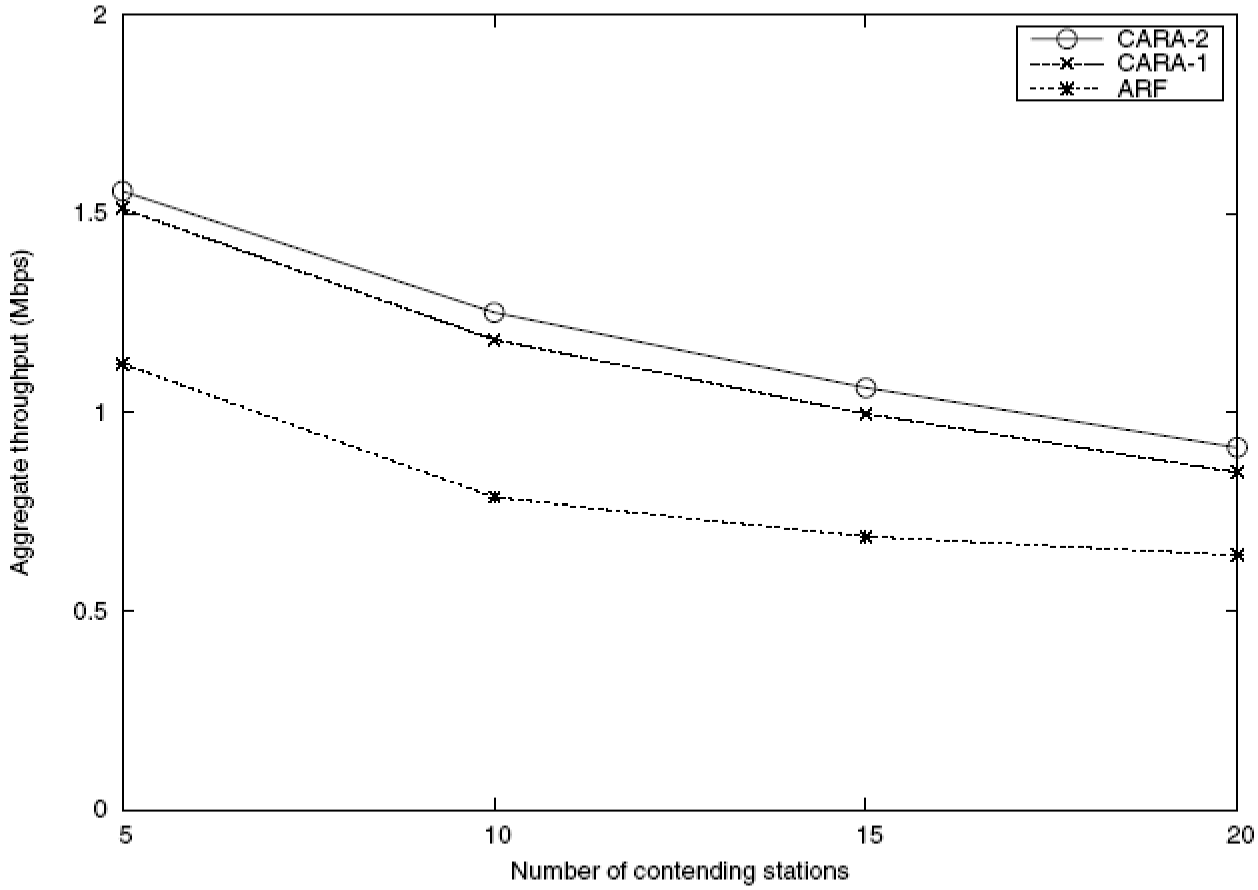
1. 50 distinct scenarios each with 10 randomly placed contending stations.
2. Vary the number of contending stations (5 to 20) and average results over 50 random topologies for each number of stations.

10 Random Stations



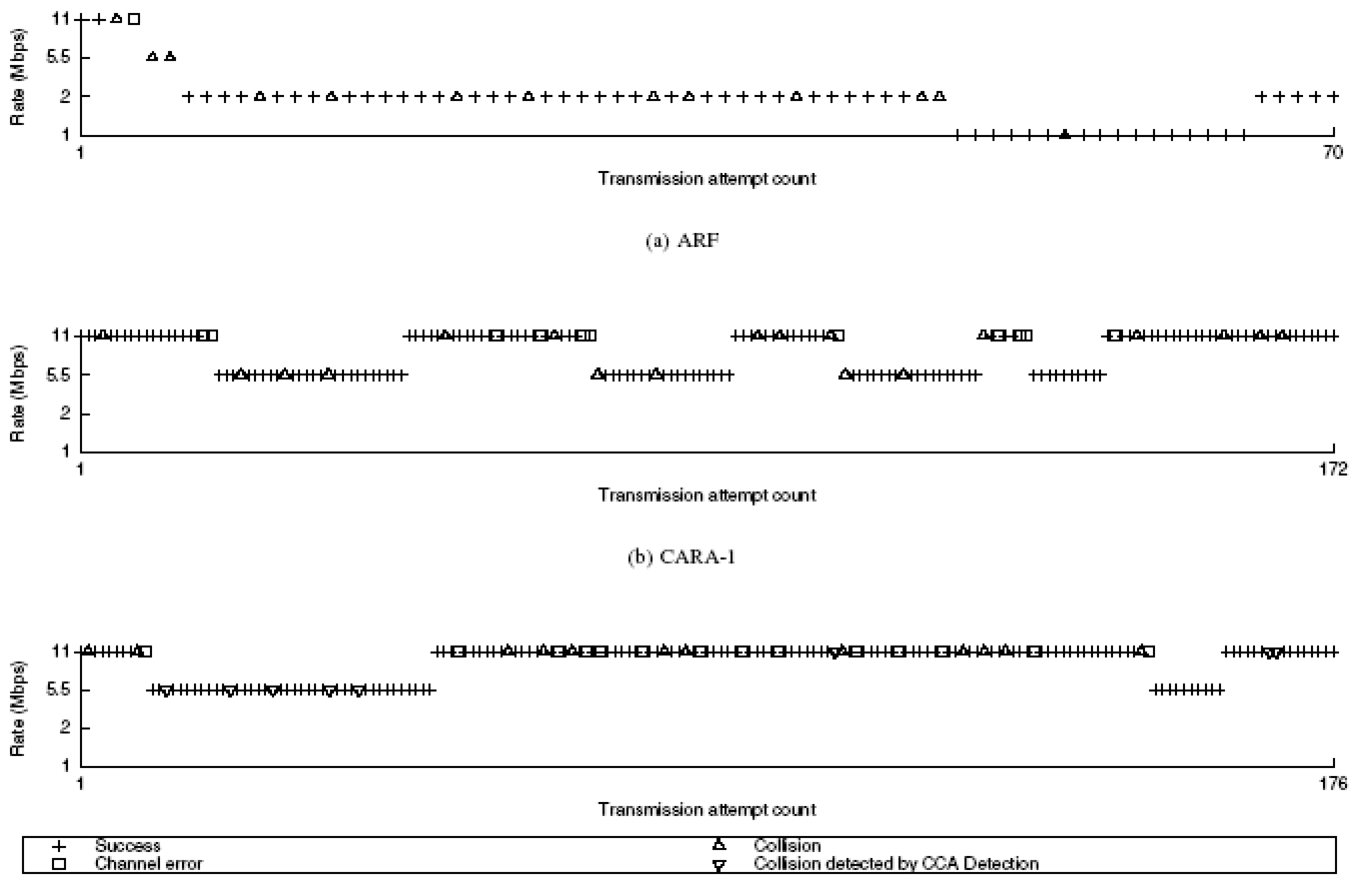
(a) 50 different scenarios when 10 stations contend

Varying Number of Stations



(b) Averaged results with various number of contending stations

Adaptability Comparison



(c) CARA-2

Fig. 10. Adaptability comparison of ARF and our proposed rate adaptation schemes (CARA-1 and CARA-2) when 5 stations are contending

Transmission Counts

TABLE II

COMPARISON OF THREE TESTING SCHEMES FOR THE 30-SECOND SIMULATION RUN

	ARF	CARA-1	CARA-2
# of tx attempts	1344	3092	3246
# of tx successes	1094	2518	2643
Throughput (Mbps)	1.58	3.37	3.49

Conclusions

- Two versions of CARA are proposed an evaluated using ns-2 simulation.
- The simulations show that CARA outperforms ARF in a variety of environments and scenarios.
- CARA uses RTS Probing and CCA to differentiate collisions from transmission failures due to channel errors.

Comments

- Authors did not look at modifying the algorithm to *increase* the data rate.
- Authors assumed **hidden terminals** were not possible and simulations were designed to avoid encountering this problem.
  - Note, RRAA warns of RTS oscillation with hidden terminals.
- Authors plan to implement *CARA* in the future using MADWIFI.

Thank You !!

CARA

Questions
and/or
Comments