Improving Spatial Reuse of IEEE 802.11 Based Ad Hoc Networks

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Introduction

- IEEE 802.11 ad hoc networks
  - Distributed Coordination Function (DCF)
    - Physical Carrier Sensing
    - Backoff mechanism
    - Exchange RTS/CTS
    - Virtual Carrier Sensing (VCS)

Introduction (cont.)

- Spatial reuse serves as one of the key factors in wireless network capacity analysis
- In [7]
  - Spatial reuse characteristics are used to examine the performance of IEEE 802.11 MAC in multihop networks
  - Current wireless LAN protocols do not function well in multihop ad hoc networks

Introduction (cont.)

- In [8]
  - RTS/CTS handshake mechanism is not always effective
    - the power needed for interrupting a packet reception is much lower than that for delivering a packet successfully.
  - The virtual carrier sensing implemented by RTS/CTS handshake cannot prevent all interferences as expected in theory.

802.11 Spatial Reuse Analysis

- Analysis of the spatial reuse in 802.11 virtual carrier sensing
- Introduce a metric to evaluate the spatial reuse

The Signal to Interference Ratio Model

- Successful reception of a packet depends on the signal to noise ratio at the receiver
- Propagation model: two-ray ground reflection model

The Signal to Interference Ratio Model (cont.)

- Two-ray ground reflection model

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}$$

d: distance between sender and receiver

Pr: received power

ht: heights of the transmitter antenna

hr: heights of the receiver antenna

Gt: antenna gains of transmitter

Gr: antenna gains of receiver

L: system loss

The Signal to Interference Ratio Model (cont.)

- Transmission Range (R_t)
  - A MAC frame can be successfully delivered
  - Its type/subtype (RTS, CTS, Data, etc.) field can be correctly identified
  - R_t is equal to 250 meters, according to the propagation model and for WaveLAN and ns-2

The Signal to Interference Ratio Model (cont.)

- Carrier Sense Range (R_s)
  - the power from the transmitter can be sensed, indicating the busy state of the medium
  - R_s is 550 meters as the common carrier sense range, according to the propagation model and the carrier sensing power threshold of WaveLAN

The Signal to Interference Ratio Model (cont.)

- Interference Range (R_i)
  - in receive mode will be interfered with by other transmitters and thus suffer a loss
  - R_i does not take a fixed value

The Signal to Interference Ratio Model (cont.)

- Signal to interference ratio (SIR)
  - Neglecting ambient noise

$$SIR = \frac{P_s}{P_i} = \left(\frac{d_i}{d_s}\right)^{\alpha} \geq CPThresh$$

Ps: signal power

Pi: interference power

ds: distance between sender and receiver

di: distance between other node and receiver

α: signal attenuation coefficient (4 in two-ray ground reflection model)

CPThresh: Capture Threshold (10 in ns-2)

The Signal to Interference Ratio Model (cont.)

- According to the SIR, the R_i is given by

$$R_i = d_s(CPThresh)^{1/\alpha} = k_{SIR} d_s$$

- k_{SIR} denote the multiplier, which depends on the SIR modle ($k_{SIR} = \sqrt[4]{10} = 1.78$ in ns-2)
- there is no fixed relation between R_i and R_t, R_i is proportional to the one-hop distance d_s.

Effectiveness of Virtual Carrier Sensing

- Sufficient condition

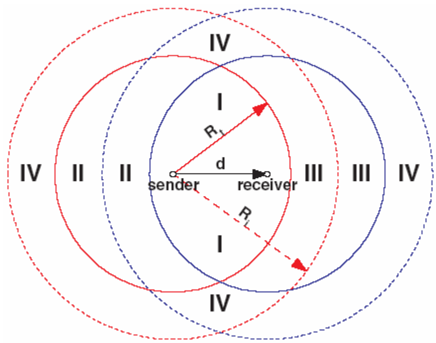
  If a node can overhear an RTS/CTS, then it is potentially able to interfere with the upcoming transmission.

- Necessary condition

  If a node is capable of interfering with an ongoing transmission, then it must be able to overhear the preceding RTS or CTS.

Effectiveness of Virtual Carrier Sensing (cont.)

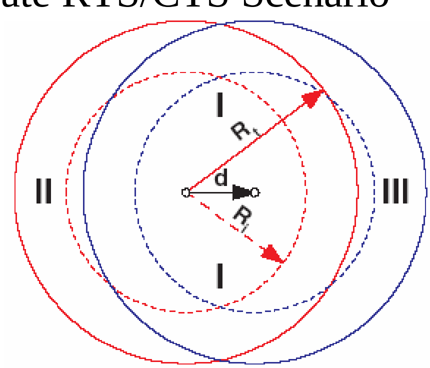
- Underactive RTS/CTS Scenario



Scenario I: Underactive RTS/CTS, 0.56Rt < d < Rt

Effectiveness of Virtual Carrier Sensing (cont.)

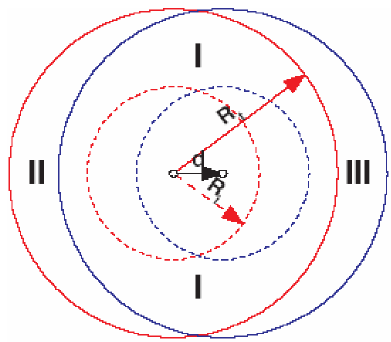
- Moderate RTS/CTS Scenario



Scenario II: Moderate RTS/CTS, 0.36Rt < d < 0.56Rt

Effectiveness of Virtual Carrier Sensing (cont.)

- Overactive RTS/CTS Scenario



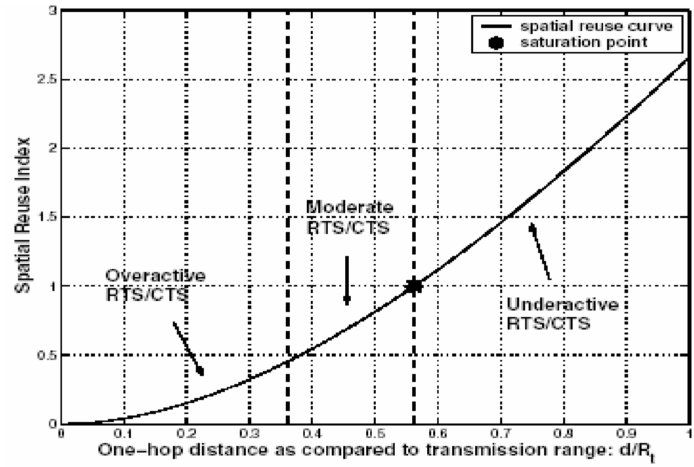
Scenario III: Overactive RTS/CTS, $d < 0.36R_t$ *(90 m)*

Evaluation of 802.11 Spatial Reuse

- The effectiveness of VCS is closely related to the efficiency of spatial reuse
- Spatial Reuse Index (SRI)

$$\mathrm{SRI} = \frac{\text{area of the region where interference may occur}}{\text{area of the region reserved by RTS/CTS to avoid interference}}$$

Evaluation of 802.11 Spatial Reuse (cont.)



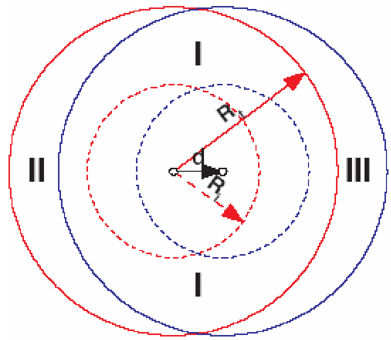
An Improved VCS Scheme and Experimental results

- Aggressive Virtual Carrier Sensing (AVCS)
  - Use overactive RTS/CTS scenario

		Sender's action		Receiver's action	
Zone	RTS/CTS detection	Normal VCS	Aggressive VCS	Normal VCS	Aggressive VCS
I	RTS&CTS	hold	hold	hold	hold
II	RTS only	hold	send RTS	hold	respond with CTS
III	CTS only	hold	send RTS	hold	respond with CTS

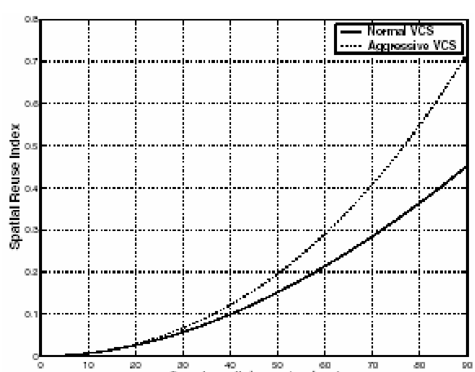
An Improved VCS Scheme and Experimental results (cont.)

- AVCS



An Improved VCS Scheme and Experimental results (cont.)

- Evaluation of AVCS



An Improved VCS Scheme and Experimental results (cont.)

- Why the node in Zone I cannot transmit?
  - Because the distance information is required.
  - With a more sophisticated MAC protocol that can handle distance measure, evaluation and dissemination, even better spatial reuse can be achieved.

An Improved VCS Scheme and Experimental results (cont.)

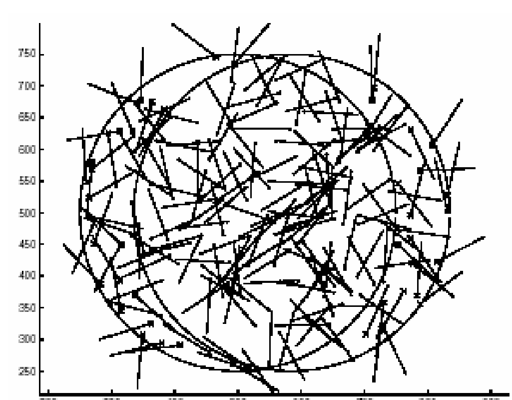
- Some problems when using the AVCS
  - Nodes in Zone II and III transmit while the original transmission is going on, the original source and destination nodes will not update their NAV
  - The probability of such collisions depends on the spatial distribution of traffic patterns and is likely to be small

An Improved VCS Scheme and Experimental results (cont.)

- Simulation Result
  - Using ns-2
  - The radio parameters assumed correspond to Lucent's WaveLAN
  - Randomly generate two pairs of nodes with the same one-hop distance
  - One-hop distance less than 90 meters
  - Test 200times

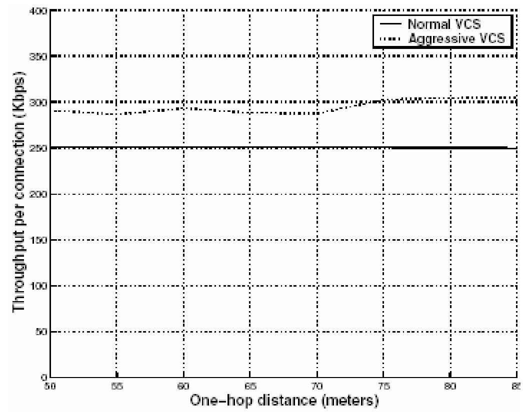
An Improved VCS Scheme and Experimental results (cont.)

- Simulation Result



An Improved VCS Scheme and Experimental results (cont.)

- Simulation Result



Conclusions

- In 802.11 ad hoc networks, the throughput and delay characteristics, depend on the spatial reuse characteristics.
- Depend on the one hop distances between the sender and the receiver, there are three scenarios with different spatial reuse characteristics.
- Using SRI demonstrated its effectiveness in evaluating the spatial reuse.

Conclusions (cont.)

- This paper proposed an AVCS scheme, this protocol is specifically designed to enhance the spatial reuse in the overactive RTS/CTS scenario.
- AVCS increased the spatial reuse and also the network throughput