Performance of Collision Avoidance Protocols in Single-Channel Ad Hoc Networks

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AD-HOC Networking SS 2004
Models and Methods

Christian Hümbert

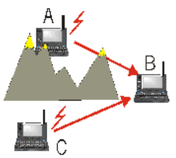
Outline of the talk

- Motivation
- A simple model for a CA-Protocol and its performance
- Numerical analysis of the performance and comparision with a second protocol
- Simulations
- Conclusion and Outlook

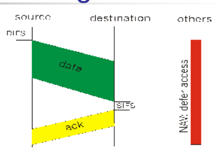
Motivation

Recall from Networking Course

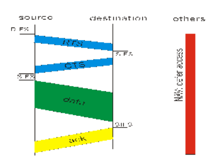
Hidden Terminal Effect



- Collision detection not possible
- Avoid collisions at receiver B

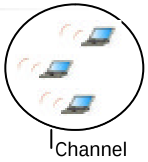


Standart CSMA Protocol



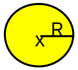
CSMA/CA Protocol with RTS/CTS

Model for the RTS/CTS CA-Protocol



Assumptions (to simplify the analysis):

- Nodes (Wlan Computers)
  - **randomly placed** on a plane (just 2-dimensional) with density l (**Poisson distributed**)
  - are **ready to transmit** independently in each time slot t with probability **p**
  - Have a **transmission** and **receiving range** of **R**
  - are under **heavy traffic**: there are always packets in their buffer
- Channel (physical region)
  - is a **circular** region with Radius **R'** (unknown)
  - its status is **only decided** by the successful and failed **transmissions within the region**
  - but we still **consider failed handshakes** initiated from inner nodes **going to nodes outside** the region



Model for the RTS/CTS CA-Protocol

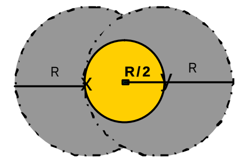
Remarks:

- The Probability, that i-Nodes are in the channel region is
$$p(i,R') = \frac{(l\,(pR'^2))^i}{i!} e^{-l\,(pR'^2)}$$
- Average Number N of Nodes within such a region is
$$N = l \cdot (pR^2)$$
- Time Slot t = d_{prop} + $d_{trans/recv}$ + $d_{carr.sens.}$ + $d_{process}$
- For simplicity t = 1 and all other Time units like RTS l_{RTS} , CTS l_{CTS}, Data l_{Data} , Ack l_{ACK} are normalized with regard to t

Model for the RTS/CTS CA-Protocol

- Channel region with Radius R‘

R‘:=R/2



Channel region

Communication area of Node x

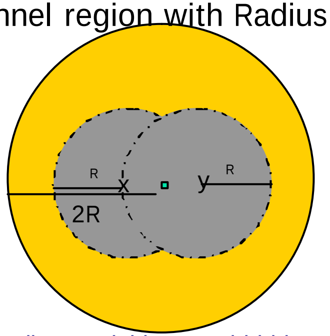
Communication area of Node y

All Nodes can communicate with each other

Model for the RTS/CTS CA-Protocol

- Channel region with Radius R‘

R‘:=2R



Channel region

Communication area of Node x

Communication area of Node y

$$R' = aR$$
$$0.5 \leq a \leq 2$$

Now all the direct neighbors and hidden nodes are also included

Model for the RTS/CTS CA-Protocol

- Our goal

  Derive a formula for the Performance of the RTS/CTS CA-Protocol

Throughput (A measure of Performance) = { Time spend on transmitting DATA } / { All the Time spend } (Time for transmitting RTS,CTS,ACK frames Waiting Time, Wasted Time for Failed Connections and also Time for Transmitting DATA)

Model for the RTS/CTS CA-Protocol

The Transmission Probability p‘ of a node

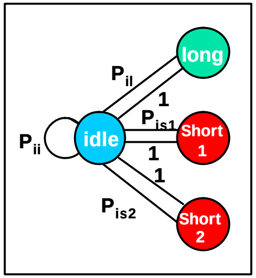
- ready to transmit with probability **p**
- **Readyness Prob. p $\neq$ Transmission Prob. p‘**

$$p' = p \cdot \mathrm{Prob}["\text{Channel is idle}"] = p \cdot \Pi_I$$

Chance to get the Throughput Formula
We still need Π_I

Model for the RTS/CTS CA-Protocol

A DTMC Model of the Channel around a Node



idle: Channel is sensed idle

State Holding-Time $T_{idle} = t$ (fixed)

long: Channel is busy for whole handshake phase

$$T_{long} = l_{RTS} + t + l_{CTS} + t + l_{DATA} + t + l_{ACK} + t = l_{RTS} + l_{CTS} + l_{DATA} + l_{ACK} + 4t$$

Short 1: Multiple Nodes transmit RTS packets: Collision

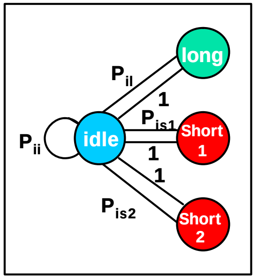
$$T_{short\,1} = l_{RTS} + t$$

Short 2: Special Case: Transmission initiated to a node outside the channel fails

$$T_{short\,2} = l_{RTS} + l_{CTS} + 2t$$

Model for the RTS/CTS CA-Protocol

A DTMC Model of the Channel around a Node



What are the Transition Probabilities ?

$$M = lpR'^2 = lp\,(aR)^2 = a^2 N$$

(M = Avg.Nr. of Nodes in the channel area)

$$P_{ii} = e^{-p'M}$$
$$P_{il} = p_s M e^{-p'M}$$
$$P_{is1} = 1 - (1 + Mp')e^{-p'M}$$
$$P_{is2} = 1 - (P_{ii} + P_{il} + P_{is1})$$

$\mathbf{p_s}$ = Probability that a node begins a successful 4-way handshake

Model for the RTS/CTS CA-Protocol

Calculating the Π_i

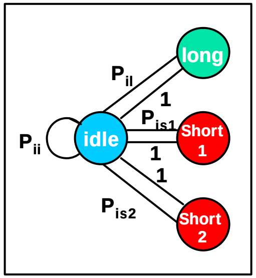
- Steady state probability

$$p_i = \frac{1}{2 - P_{ii}} = \frac{1}{2 - e^{-p'M}}$$

- Long run probability

$$\Pi_i = \frac{p_i T_{idle}}{p_i T_{idle} + p_l T_{long} + p_{s1} T_{short\,1} + p_{s2} T_{short\,2}} = \frac{p_i T_{idle}}{p_i T_{idle} + P_{il} T_{long} + P_{is1} T_{short\,1} + P_{is2} T_{short\,2}}$$

$$(p_i P_{il} = p_l, p_i P_{is1} = p_{s1}, p_i P_{is2} = p_{s2})$$



Model for the RTS/CTS CA-Protocol

Recall:

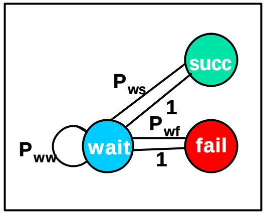
$$p' = p \cdot \mathrm{Prob}["\text{Channel is idle}"] = p \cdot \Pi_I$$

$$\text{Throughput} = \frac{\{\text{ Time spend on transmitting DATA }\}}{\{\text{ All the Time spend }\}}$$

- p‘ is almost determined
- Still Have to calculate Prob. p_s How?

Model for the RTS/CTS CA-Protocol

DTMC Model for a node x



wait: Node x defers for other nodes or backs off
State Holding-Time $T_{wait} = t$

succ: Node x can complete a successful 4-way handshake with other nodes

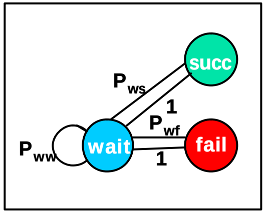
$$T_{succ} = T_{long} = l_{RTS} + l_{CTS} + l_{DATA} + l_{ACK} + 4t$$

fail: Node x initiates an unsuccessful handshake

$$T_{fail} = T_{short\,2} = l_{RTS} + l_{CTS} + 2t$$

Model for the RTS/CTS CA-Protocol

DTMC Model for a node x



Transition Probabilities

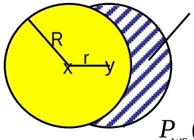
$$P_{ww} = (1-p')e^{-p'N}$$

$$P_{ws} = ??$$

$$P_{wf} = 1 - (P_{ww} + P_{ws})$$

Model for the RTS/CTS CA-Protocol

Derivation of Probability P_{ws}



„hidden“ area B(r) for x

$$B(r) = pR^2 - 2R^2 q(\frac{r}{2R}),\ q(t) = \arccos(t) - t\sqrt{1-t^2}$$

P_{ws} depends on the distance between x and y

$$P_{ws}(r) = P_1 \cdot P_2 \cdot P_3 \cdot P_4(r)$$

P_1 = Prob.{x transmits in a slot} = p‘

P_2 = Prob.{y does not transmit in the slot} = 1-p‘

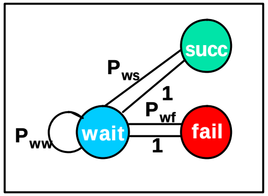
P_3 = Prob.{none of the terminals within R of x transmit in the same slot} = $e^{-p'N}$

$P_4(r)$ = Prob.{none of the terminals in B(r) transmits for $(2l_{RTS}+1)$ slots}

$$P_{ws} = 2p'(1-p')e^{-p'N} \cdot \int_0^1 r e^{-p'N[1-2q(\frac{r}{2})/p](2l_{RTS}+1)} dr$$

Model for the RTS/CTS CA-Protocol

DTMC Model for a node x



Steady-state Probabilities

$$p_w = \frac{1}{2-P_{ww}} = \frac{1}{2-(1-p')e^{-p'N}}$$

$$p_s = p_w P_{ws} = \frac{P_{ws}}{2-P_{ww}} = \frac{P_{ws}}{2-(1-p')e^{-p'N}} = p_s$$

Model for the RTS/CTS CA-Protocol

Formula for the Performance of the RTS/CTS CA-Protocol

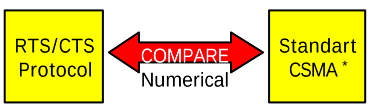
$$\text{Throughput} = \frac{\{\text{ Time spend on transmitting DATA }\}}{\{\text{ All the Time spend }\}}$$

$$Th = \frac{p_s \cdot l_{DATA}}{p_w T_w + p_s T_s + p_f T_f}$$

Part II Numerical Results

- Is the RTS/CTS mechanism effective ??

  Not a overhead of transmissions ?

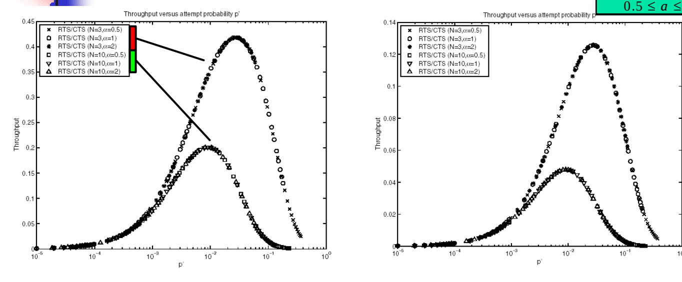


* This Standart CSMA Protocol without RTS/CTS mechanism has been analyzed by Wu and Varshney „Performance Analysis of CSMA and BTMA Protocols in Multihop Networks“

Part II Numerical Results

a's influence

Recall: $R' = aR$, $0.5 \le a \le 2$



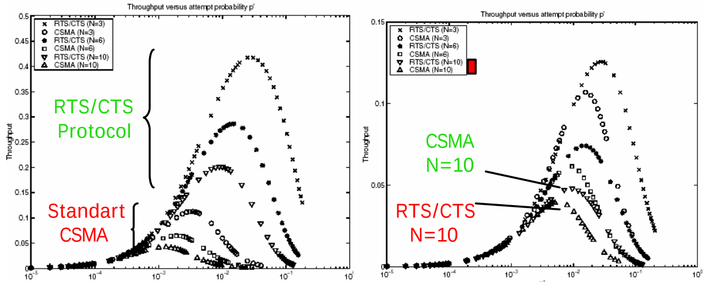
(a) long data packet: $l_{data} = 100\tau$ (b) short data packet: $l_{data} = 20\tau$

$(l_{rts} = l_{cts} = l_{ack} = 5\tau)$

The troughput is largely unaffected by **a,** so **a:=1**

Part II Numerical Results

Comparision between RTS/CTS and Std.CSMA



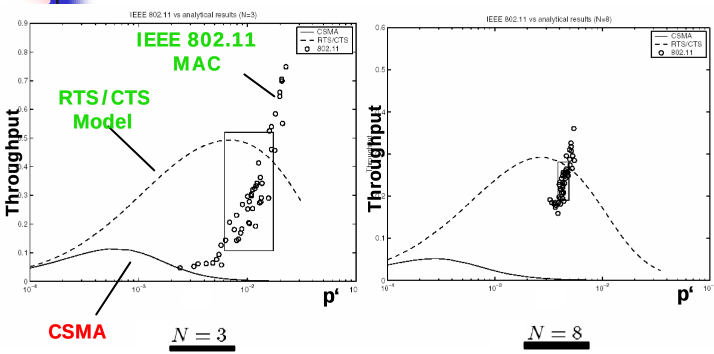
CA becomes ineffective when N increases

(a) long data packet: $l_{data} = 100\tau$ (b) short data packet: $l_{data} = 20\tau$

Part III Simulations

- Network Simulator *GloMoSim 2.0*
- Channel Bitrate 2 Mbps
- Circular Network of **Radius 3R**
  Nodes outside this circle have NO influence
- The IEEE 802.11 MAC Protocol operates in a region, while our **Analysis** gives **average** performance
- Each node has a constant-bit traffic generator with data packet size 1460 bytes
- The neighbours are randomly chosen

Part III Simulations



Part III Simulations

Results

- For small N: big variance between Simulation and Analysis Results
  Reasons:
  - **IEEE 802.11** Protocol cannot ensure collision free data packets (50% of data packets cannot be acked)
  - **Unfairness** of the exponential backoff procedure
- For large N: Simulation Performance correlates well with extended analysis

Conclusion

„Simple“ Model of a RTS/CTS – data – ACK handshake Protocol with Collision Avoidance

⇨ Performance Formula

The RTS/CTS Protocol beats the CSMA Prot.

⇨ Importance of Collision Avoidance

With a **slowly** increasing Nr. of WLAN Nodes

⇨ Performance degrades **rapidly**

Outlook Improvements

- Reduce the time slot parameter
  ⇨ reducing transmission power
  ⇨ reducing length of control overhead
- Piggyback ACKs or ACK optional
- Adaptive Algorithm to get the best p‘ for a group of N nodes