More Capacity with the CSMA/IA MAC Protocol in IEEE 802.11s Wireless Mesh Networks

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Overview

- Motivation
  - IEEE 802.11 Mesh Networks
  - Radio Resource Management

- Carrier Sense Multiple Access with **Collision Avoidance** (CSMA/CA): IEEE 802.11
  - Medium Access
  - Rate Adaptation

- Carrier Sense Multiple Access with **Interference Avoidance** (CSMA/IA)
  - Idea
  - Realization

- Evaluation

- Conclusion
Classic IEEE 802.11 Wireless Network

Wired Infrastructure

Portal / Access Point (AP)
Station
Radio Link
IEEE 802.11s Wireless Mesh Network (WMN)
Radio Resource Management

• Goal:
  – Efficient usage of available radio resources in the Wireless Mesh Network (WMN)

• Taking into account:
  – Needs and properties of users, e.g. traffic load and station position
  – Interference between links

Efficient radio resources management increases the capacity of IEEE 802.11s WMNs

• Focus here:
  – When to transmit? Interference Avoidance
  – How to transmit? Rate Adaptation
IEEE 802.11 – Channel Access

- **Carrier Sense Multiple Access (CSMA):**
  - Collision Avoidance (CA):
    - Increase range for random wait on transmission failure
  - **Carrier Sensing:**
    - Physical CS:
      Channel busy if received power > -82dBm
    - Virtual CS:
      Channel busy indicated by overheard frames, e.g. RTS/CTS
IEEE 802.11 – Rate Adaptation

• Rate Adaptation: selects modulation coding scheme (MCS) for transmissions
  – Trade-Off: robustness versus nominal bit rate
  – Out of the scope of 802.11 standard

• Common strategies
  – Auto Rate Fallback (ARF):
    • Transmitter determines MCS based on success statistics
  – Receiver Based Auto Rate (RBAR)
    • Transmitter requests link quality information (LQI)
    • Receiver responds with LQI
    • Transmitter determines appropriate MCS and sends data

Radio Resource Management is separated into two steps
  1. Determine if channel is idle (CSMA/CA + Carrier Sensing)
  2. If idle, select MCS and transmit
Carrier Sense Multiple Access with Interference Avoidance (CSMA/IA)

- **Idea:**
  - Combined planning of transmission time and rate adaptation

- **Realization:**
  - Apply traffic shaping
    - Channel usage becomes regular $\rightarrow$ predictable
    - LQI from past becomes more precise
  - Measure channel occupancy
  - Defer from transmission in slots with expected interference
CSMA/IA – Key Aspects

- Transmission Scheduling
- Channel Measurement
  - needs
  - enables
- Resource Estimation
  - determines
  - supports
- Information Exchange
  - supports
CSMA/IA – Channel Measurement

- **Measurement:**
  - Differentiate channel state
    - Idle
    - Transmitting (Tx)
    - Receiving (Rx)
    - Interference (Busy)
  - SNR of incoming beacon frames

- **Weighting:**
  - Determine mean for measurements over current and previous superframes

- **Prediction:**
  - Slots often used are considered to be busy during next superframe
  - Considering slots after period with no usage as idle
Periodic Broadcast of Information in beacons:

- List with SNR values of received beacons, together with corresponding station address
- Bitmap:
  - Interference (no reception possible)
  - Incoming transmissions (neighbour station shall defer from transmitting)

In contrast to RTS/CTS: Neighbouring stations can receive simultaneously
CSMA/IA – Resource Estimation

• Measure transmitted/offered traffic for:
  – Last 4 superframes
    compensate prediction errors
  – Previous superframe
    quickly adjust to changes in traffic behaviour

• Allocate additional slots if below threshold
  – Preferably next to existing transmission windows
  – Amount depends on currently used slots, channel prediction and ratio of traffic not transmitted

• Implicit release of unused slots
  – Change of slot usage noticed in measurement and weighting process
CSMA/IA – Transmission Scheduling

- Transmission only during:
  - slots already used in previous superframes
  - additionally allocated

- Actual transmission in transmission windows always ends in last slot
  - Reduction of variance in channel usage
  - Corresponding ACK always in the same slot
Evaluation – Simulation Description

Simulation of wireless mesh network in urban surrounding

- Mesh points: access points for 802.11 stations & portals to the Internet
- Network coverage 1km² with as few mesh points as possible
- Wireless channel model: IMT-A Urban Micro
- LOS/NLOS Links: randomized for each link, depends on distance between stations
- Traffic load: 100 client station, randomly positioned, with downlink to uplink ratio of 9:1
Evaluation - Metric

- Maximum network capacity under strict fairness constraints

\[ \forall s_i : \frac{\text{trans}_{s_i}}{\text{offered}_{s_i}} \geq 1 - \varepsilon, \]

\( s_i \) : transmitter i

\( \text{trans}_{s_i} \) : transmitted traffic

\( \text{offered}_{s_i} \) : offered traffic

\( \varepsilon \) : tolerance margin
Evaluation - Results

25 simulated deployments, differing in topology and traffic at mesh points
Mean network capacity & 95% confidence interval

- **ARF**: inappropriate choice of MCS due to frequent changes of the interference situation
- **RBAR**: suffers from interfered RTS → select MCS with low bit rate and long transmission durations
- **FutureCS**: traffic scheduling leads to interference avoidance, best MCS selection for transmissions
Conclusion

• **CSMA/CA**
  - Randomized channel access + unpredictable interference
  - No appropriate MCS selection
  - Capacity reduction

• **CSMA/IA**
  - Traffic shaping + information exchange
  - Implicit medium reservation
  - Joint selection of transmission time and MCS allows for capacity increase
Thank you for your interest
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NAV Settings for RTS/CTS

STA C
STA D
STA A
STA B

Carrier Sense Range
Station C

Carrier Sense Range
Station D

time

RTS
CTS
DATA

overheard

NAV (RTS)

NAV (CTS)

RTS
CTS
DATA

ACK

SIFS
SIFS
SIFS
• Transmitters 1 and 3 are hidden from each other
• Interference only occurs at receiver 2
• Station 3 dominates channel access over station 1
• RTS/CTS: Station 1 suffers from increasing backoff due to failed handshake (ARF) or interfered RTS frames $\rightarrow$ low MCS (RBAR)
• Transmitters 1 and 3 are hidden from each other
• Interference in case of simultaneous DATA and ACK transmissions
• High MPDU aggregation → low relative retransmission rate
• Rate adaptation on DATA/ACK interference does not avoid collisions
• RTS/CTS: strict separation of channel access degrades capacity
IMT-A Urban Micro Wireless Channel

- Shadowing fading
  random, log-normal distributed

- LOS
  Path loss function: \( PL(d, f_c) = 22.0 \log_{10}(d) + 28.0 + 20 \log_{10}(f_c) \)
  Shadowing fading: \( \sigma = 3 \)

- NLOS
  Path loss function: \( PL(d, f_c) = 36.7 \log_{10}(d) + 22.7 + 26 \log_{10}(f_c) \)
  Shadowing fading: \( \sigma = 4 \)

- Probability for LOS link
  \( P_{\text{LOS}}(d) = \min(18/d,1) \left( 1 - \exp(-d/36) \right) + \exp(-d/36) \)