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

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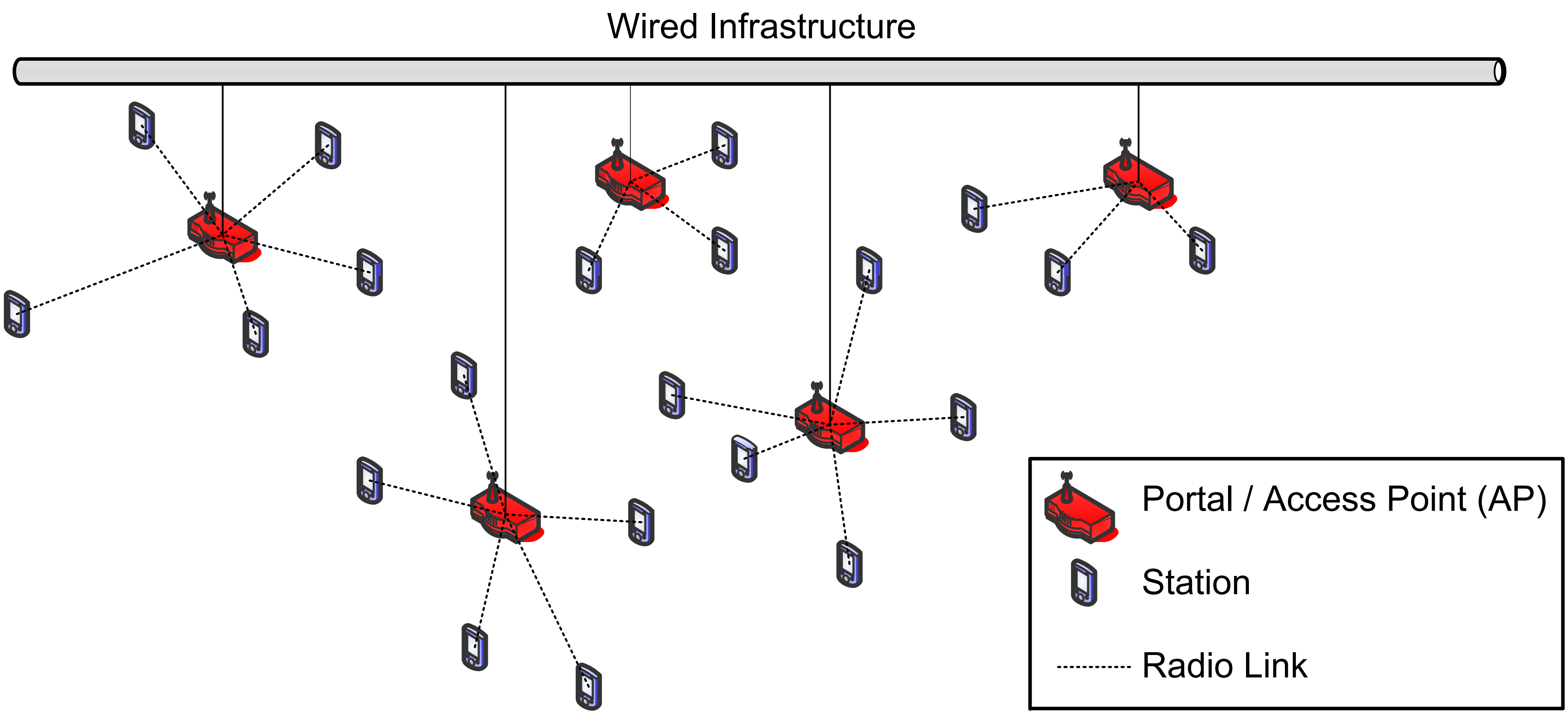
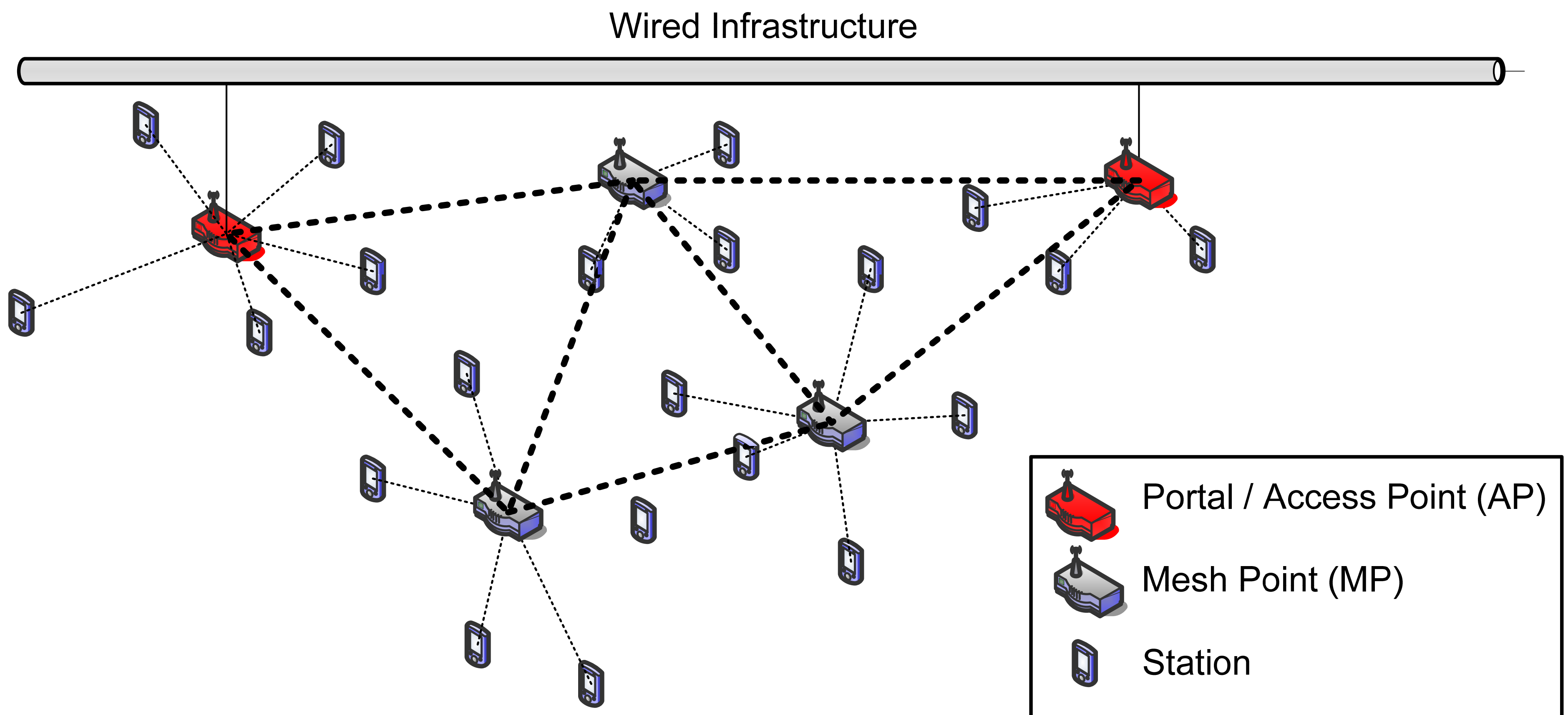
Overview

- 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



IEEE 802.11s Wireless Mesh Network (WMN)



Radio Resource Management

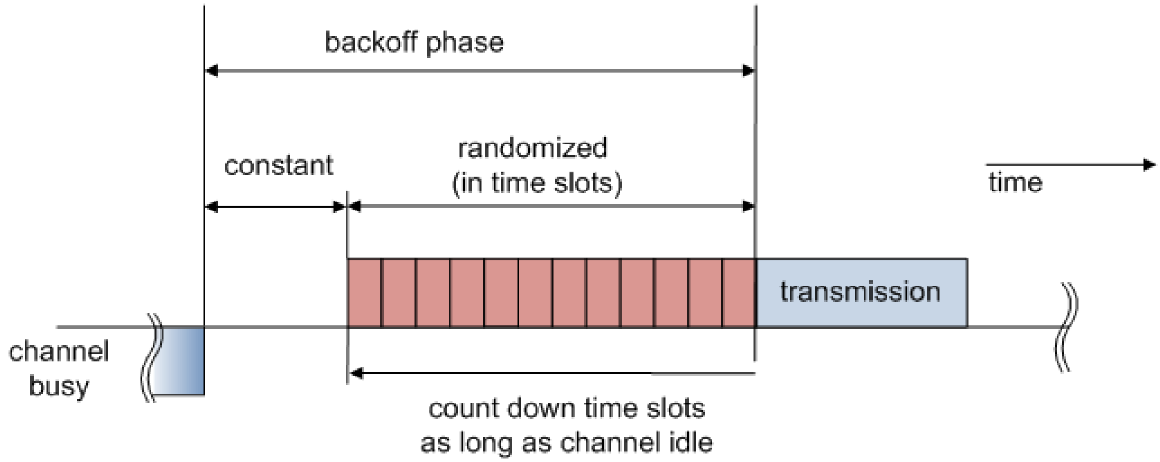
- Goal:
  - Efficient usage of available radio resources in the Wireless Mesh Network (WMN)
- Taking into account:
  - Needs and properties of users, e.g. traffic load and station position
  - Interference between links

⇒ 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

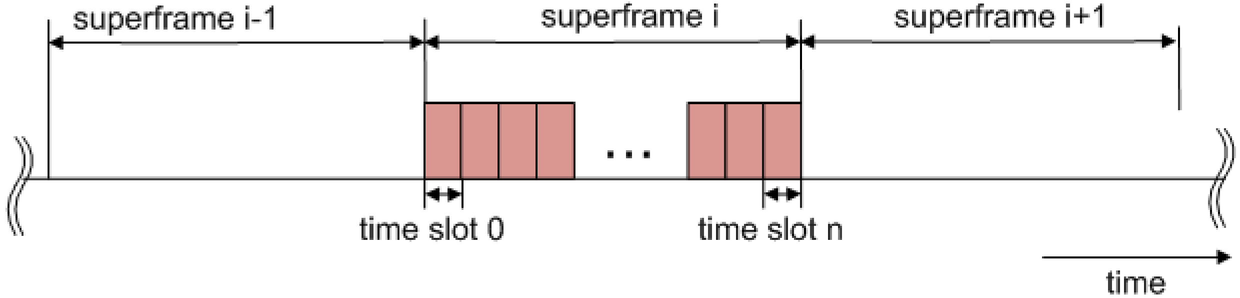
- Rate Adaptation: selects modulation coding scheme (MCS) for transmissions
  - Trade-Off: robustness versus nominal bit rate
  - Out of the scope of 802.11 standard
- Common strategies
  - Auto Rate Fallback (ARF):
    - Transmitter determines MCS based on success statistics
  - Receiver Based Auto 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

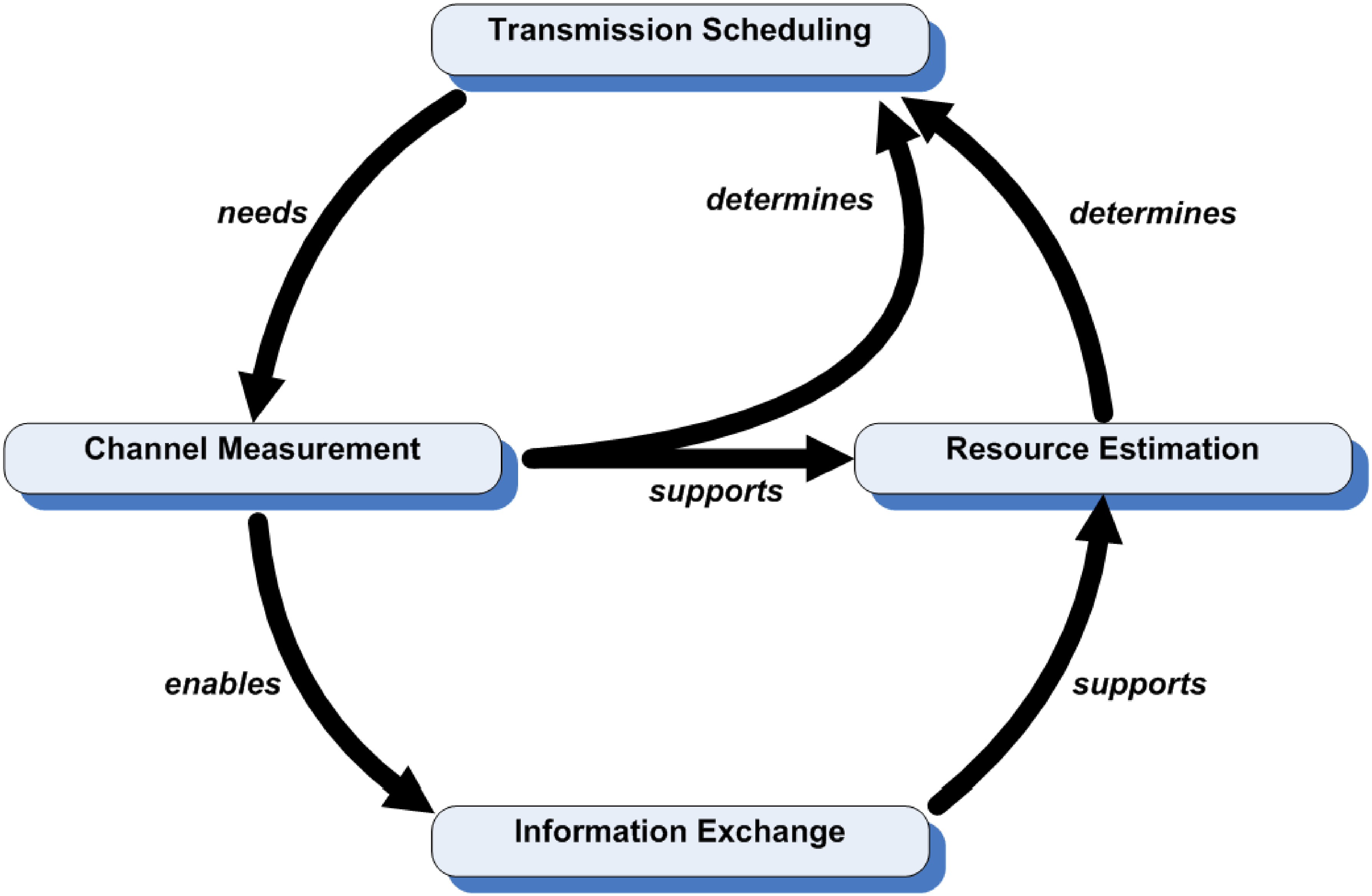
Carrier Sense Multiple Access with Interference Avoidance (CSMA/IA)

- Idea:
  - Combined planning of transmission time and rate adaptation
- Realization:
  - Apply traffic shaping
    - Channel usage becomes regular → predictable
    - LQI from past becomes more precise
  - Measure channel occupancy

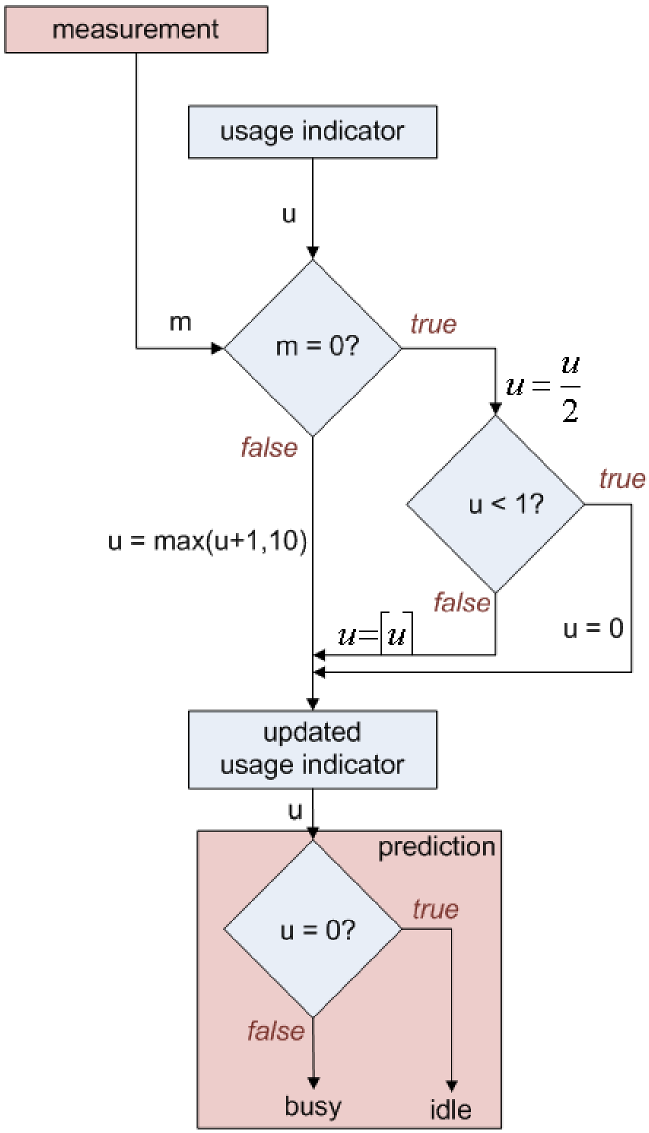


  - Defer from transmission in slots with expected interference

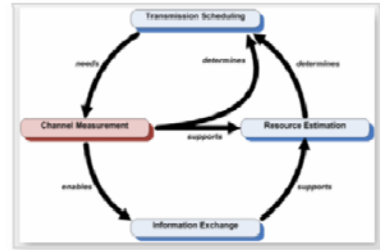
CSMA/IA – Key Aspects



CSMA/IA – Channel Measurement

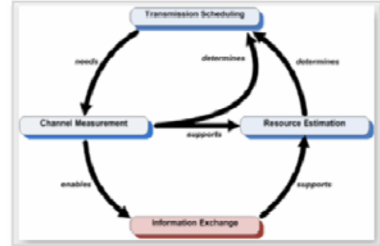


- Measurement:
  - Differentiate channel state
    - Idle
    - Transmitting (Tx)
    - Receiving (Rx)
    - Interference (Busy)
  - SNR of incoming beacon frames



- 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

CSMA/IA – Information Exchange

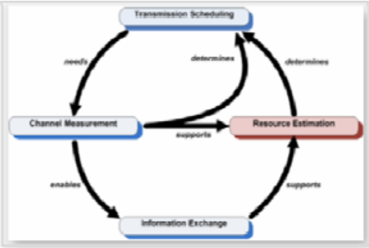


Periodic Broadcast of Information in beacons:

- 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 simultaniously

CSMA/IA – Resource Estimation

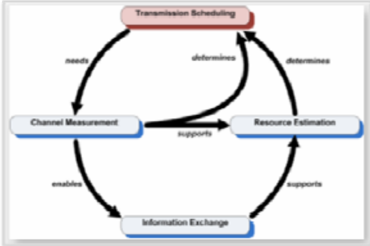


- Measure transmitted/offered traffic for:
  - Last 4 superframes
    ⇨ compensate prediction errors
  - Previous superframe
    ⇨ quickly adjust to changes in traffic behaviour

- 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

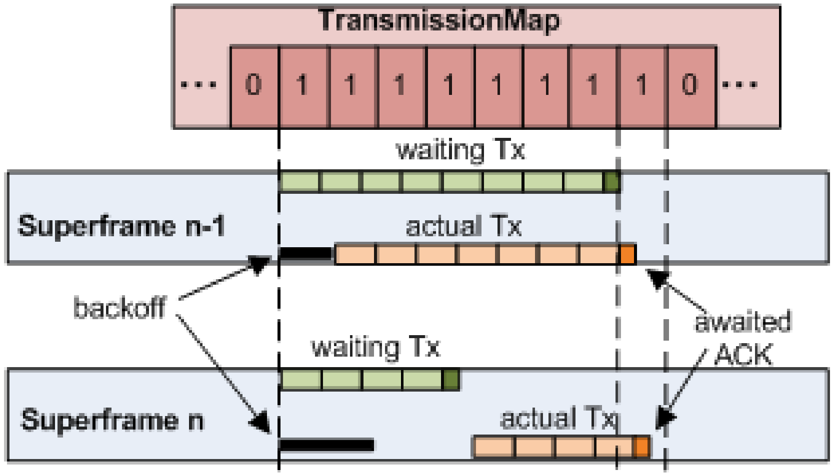
- Implicit release of unused slots
  - Change of slot usage noticed in measurement and weighting process

CSMA/IA – Transmission Scheduling



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

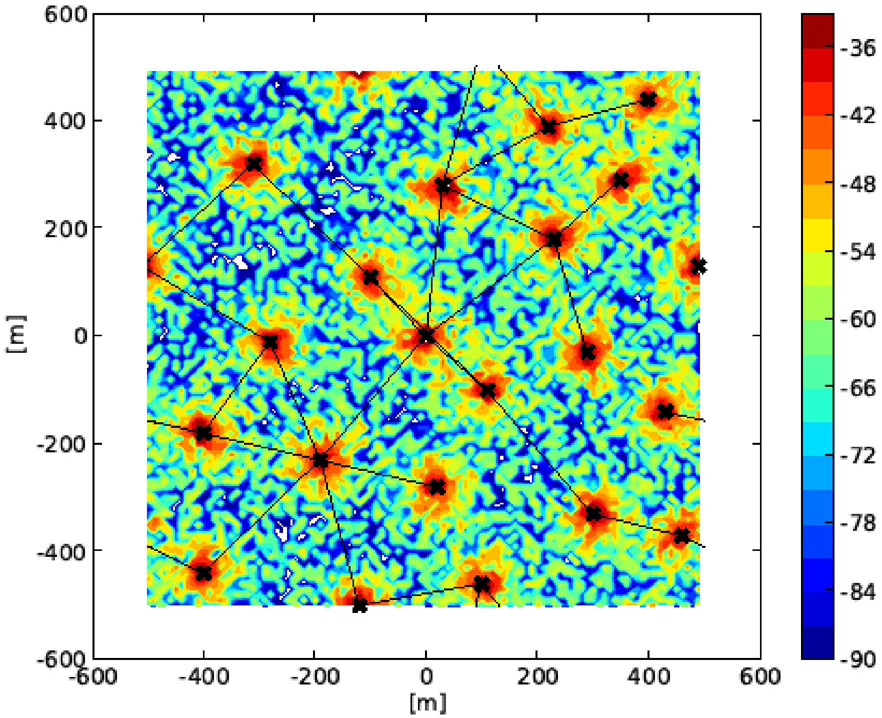
- Actual transmission in transmission windows always ends in last slot
  - Reduction of variance in channel usage
  - Corresponding ACK always in the same slot



Evaluation – Simulation Description

Simulation of wireless mesh network in urban surrounding

Example network coverage [dBm]

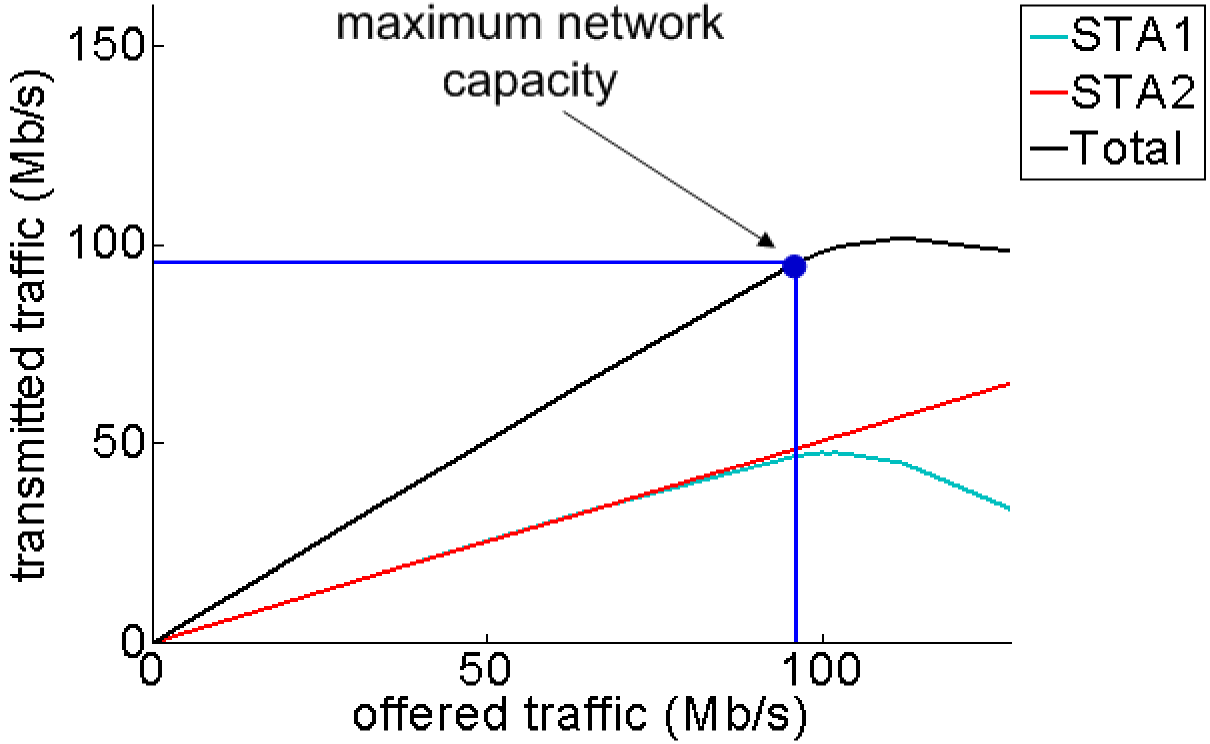


- Mesh points: access points for 802.11 stations & portals to the Internet
- Network coverage 1km^2 with as few mesh points as possible
- Wireless channel model: IMT-A Urban Micro
- LOS/NLOS Links: randomized for each link, depends on distance between stations
- Traffic load: 100 client station, randomly positioned, with downlink to uplink ratio of 9:1

Evaluation - Metric

- Maximum network capacity under strict fairness constraints

$$\forall s_i : \frac{trans_{s_i}}{offered_{s_i}} \geq 1 - \varepsilon,$$



s_i : transmitter i

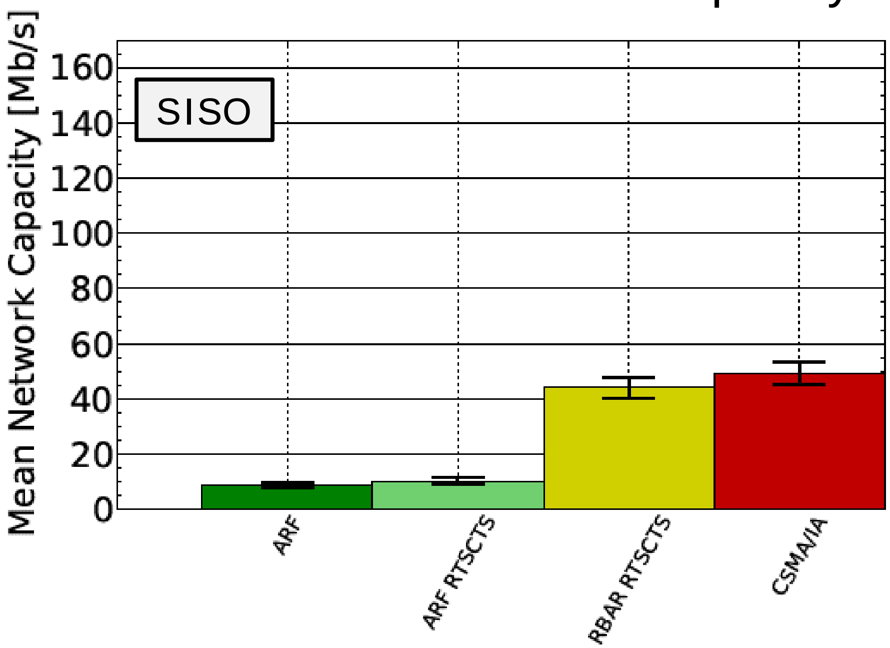
$trans_{s_i}$: transmitted traffic

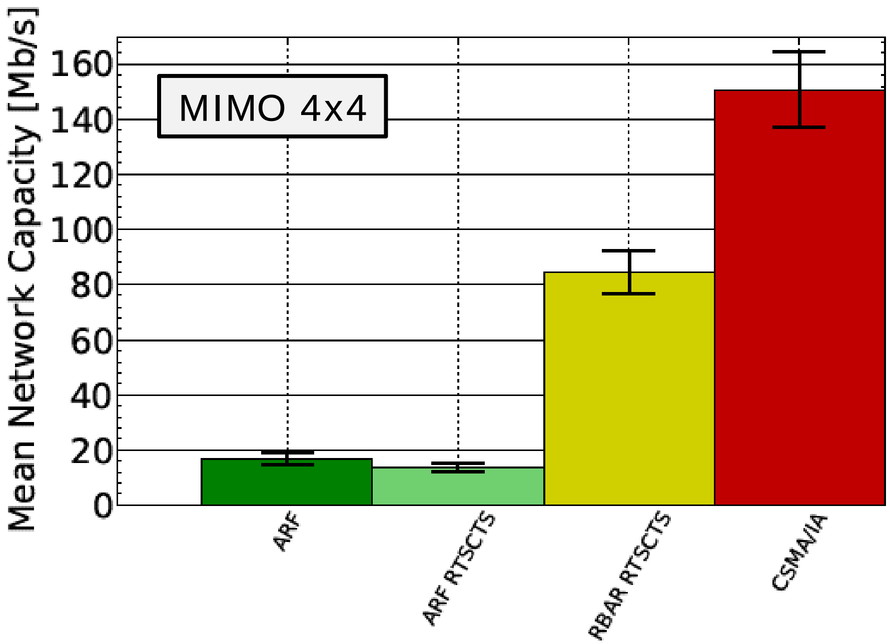
$offered_{s_i}$: offered traffic

ε : 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

The End

Thank you for your interest

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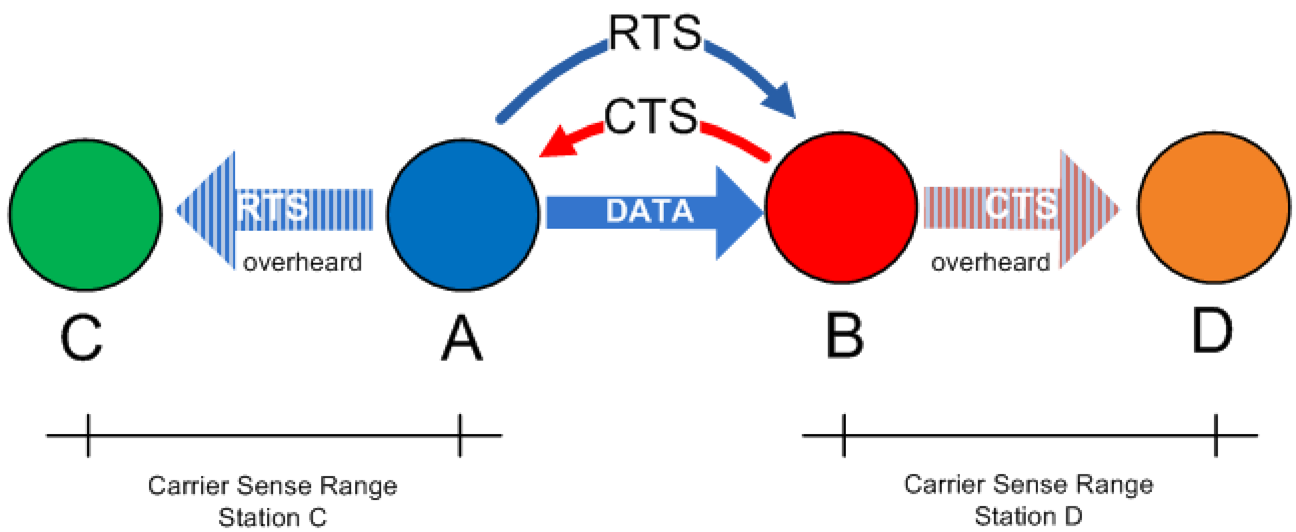
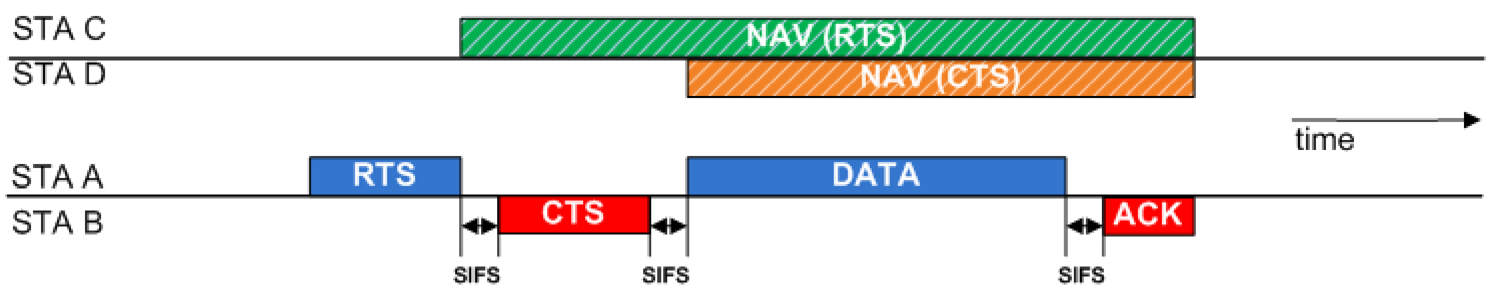
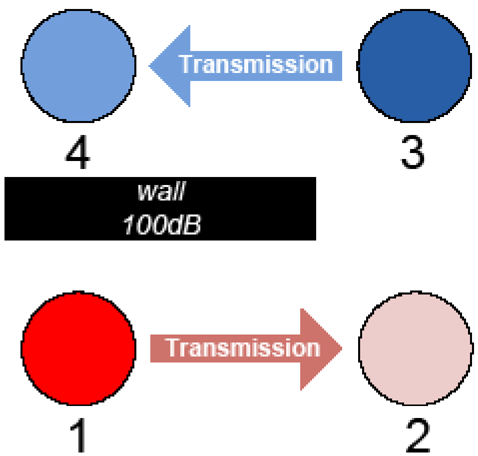
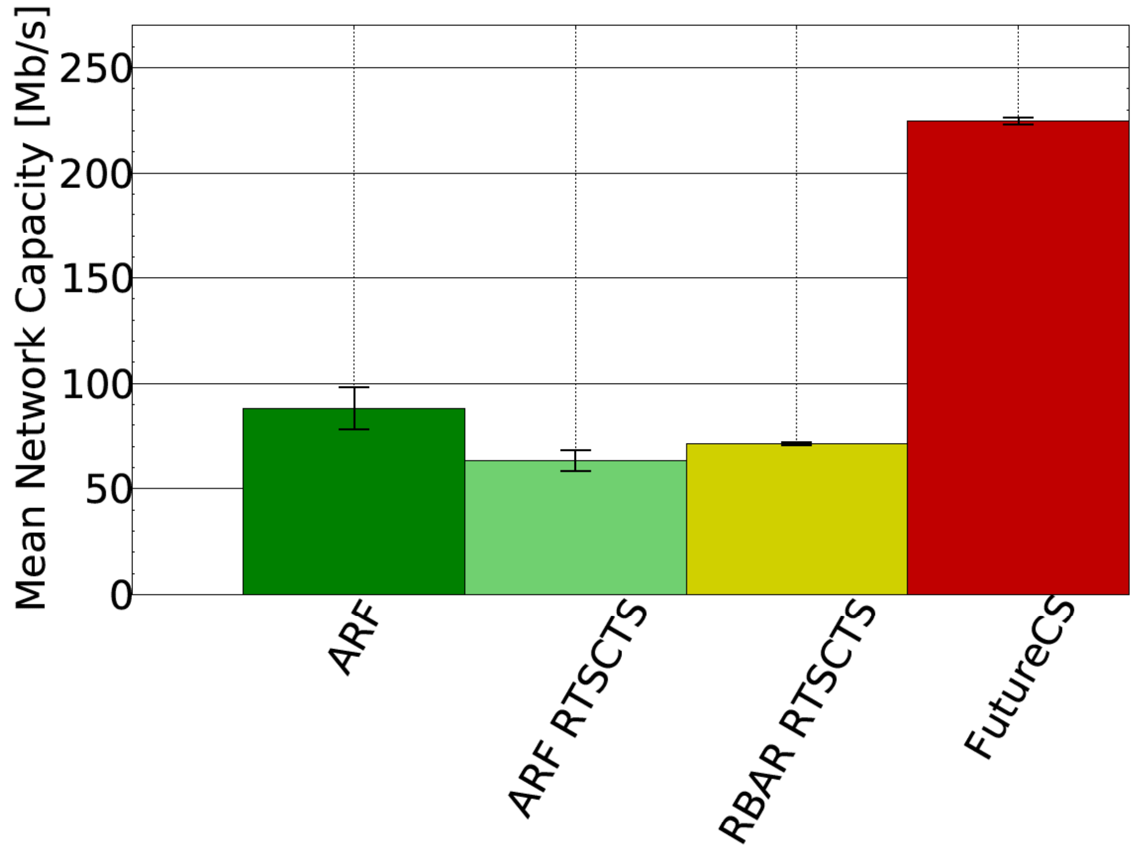
NAV Settings for RTS/CTS





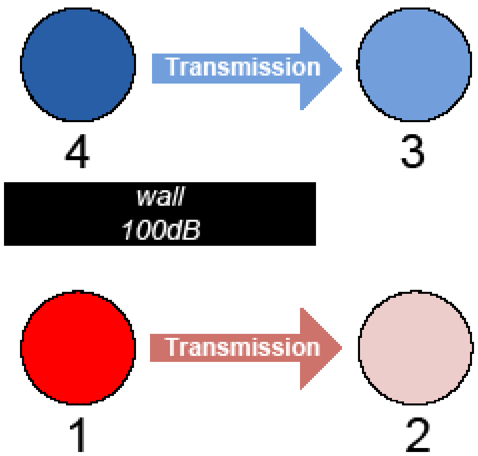
Starvation of Transmitter

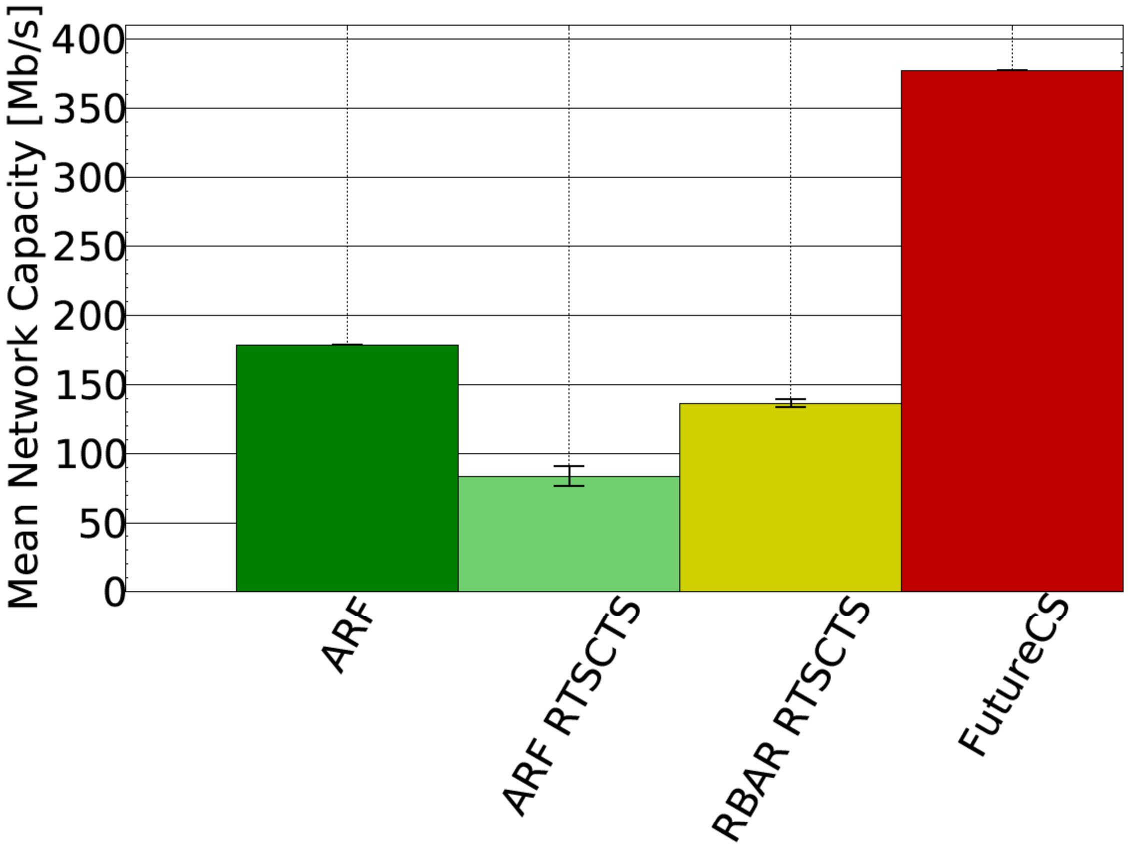




- Transmitters 1 and 3 are hidden from each other
- Interference only occours at receiver 2
- Station 3 dominates channel access over station 1
- RTS/CTS: Station 1 suffers from increasing backoff due to failed handshake (ARF) or interfered RTS frames → low MCS (RBAR)

Hidden Nodes / Exposed Receivers





- Transmitters 1 and 3 are hidden from each other
- Interference in case of simultanious DATA and ACK transmissions
- High MPDU aggregation → low relative retransmission rate
- Rate adaptation on DATA/ACK interference does not avoid collisions
- RTS/CTS: strict seperation 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

  $P_{LOS}(d) = \min(18/d,1)\,(1-\exp(-d/36)) + \exp(-d/36)$