Contention and Traffic Load-aware Association in IEEE 802.11 WLANs: Algorithms and Implementation

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Outline

- Association in 802.11 WLANS
- Proposed Metrics
- Proposed Algorithms
- Experimental Evaluation
- Conclusion

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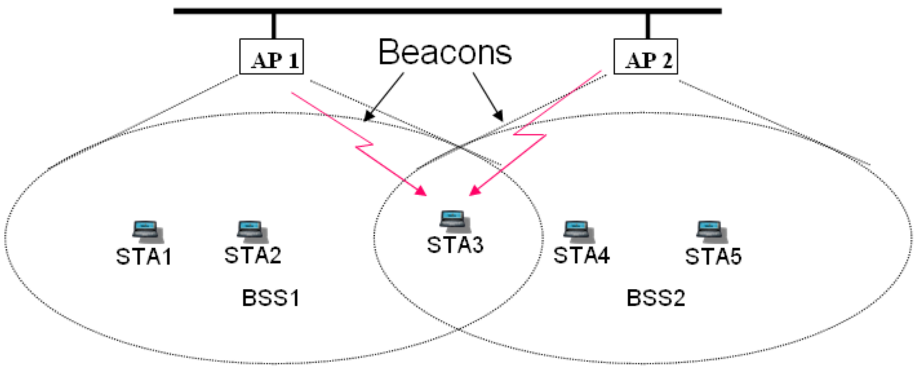
Association in 802.11 WLANS

- In IEEE 802.11 WLANs, each station (STA) has to first associate with an access point (AP), before it can start transmitting data to other nodes in the network.

- IEEE 802.11 standard defines **RSSI – based Association Policy**



- A STA simply selects the AP from which it has received the strongest signal during the scanning process.

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Association in 802.11 WLANS

- **Main problems in the standard mechanism:**
  - RSSI is not an appropriate decision factor for user association (high RSSI values cannot directly indicate high throughput)
  - RSSI is an indicator for the Downlink (DL), but not for the Uplink (UL) channel conditions

- **User performance relies on several factors:**
  - Channel Contention: contending nodes and their individual Physical Layer Transmission (PHY) rates.
  - AP Load: associated STAs and their individual PHY rates.
  - Interference: on the channel an AP offers.

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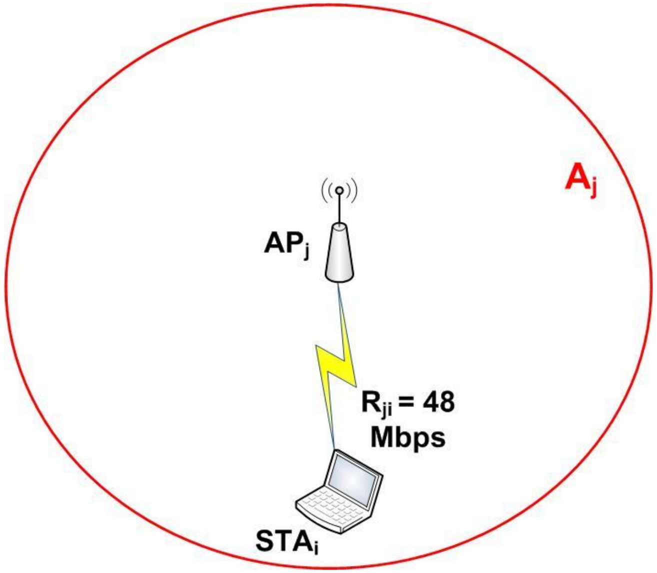
Proposed Metrics - Contention



- **STA_i** : Station under Association
- **A_j**: 1-hop neighborhood of transmitter node AP_j
- **T_{ij}** : Expected Throughput performance of STA_i if it associates with AP_j
- Single Transmitter in the contention domain using PHY rate **R_{ji}**
- $T_{ij} \leq R_{ji}$

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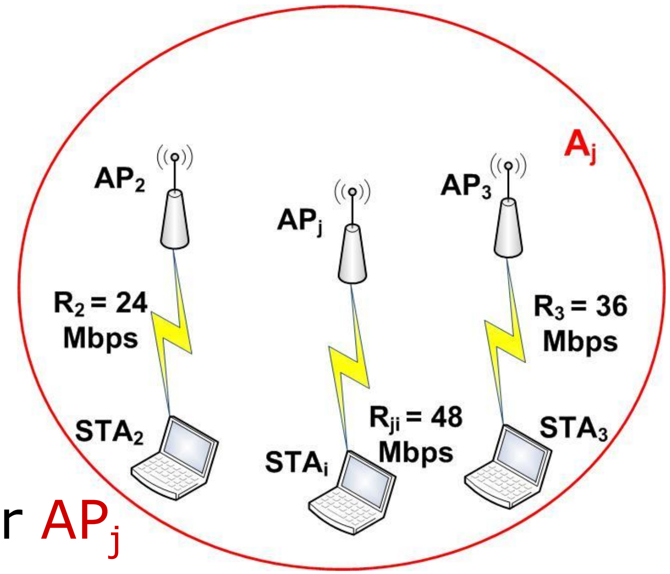
Proposed Metrics - Contention

$$T_{ij} = \frac{1}{\frac{1}{R_{ji}} + \sum_{k=1}^{|A_n|} \frac{1}{R_k}}$$



- **A_j**: 1-hop neighborhood of transmitter AP_j

- Multiple Transmitters in the contention domain using different PHY rates **R_k**

- Ignores MAC layer overhead, retransmissions and assumes that all flows consist of equal packet lengths

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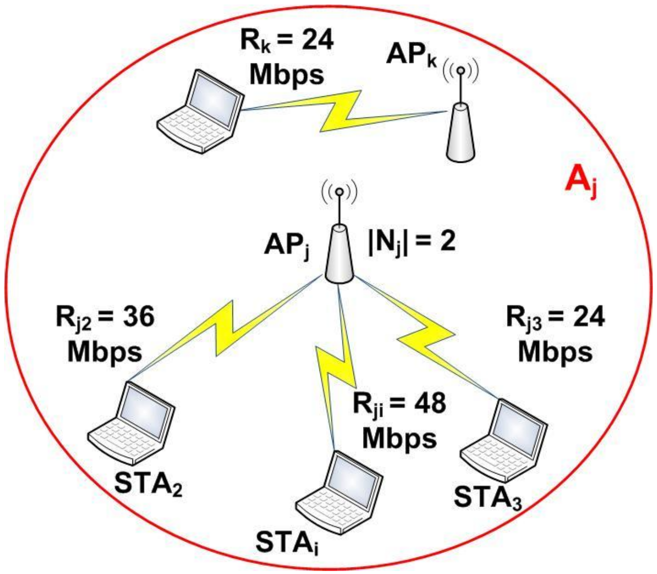
Proposed Metrics – AP load

$$T_{ij}^{down} = \frac{1}{\left(\frac{1}{R_j} + \sum_{k=1}^{|A_j|} \frac{1}{R_k}\right) \cdot (|N_j| + 1)}$$



- **N_j**: associated users of AP_j
- **A_j**: 1-hop neighborhood of transmitter AP_j
- We assume that the number of frames destined to each associated STA is equal.

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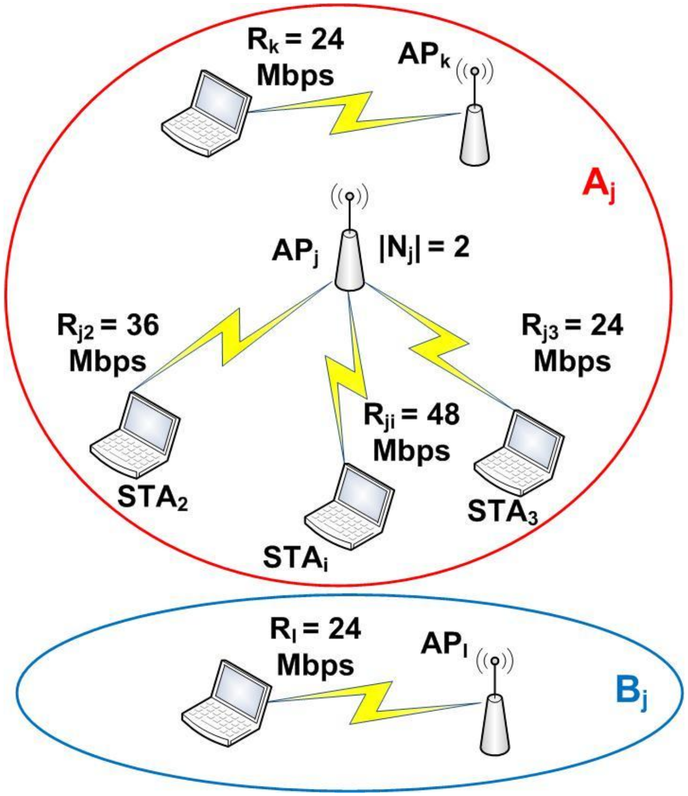
Proposed Metrics - Interference

$$T_{ij}^{down} = \frac{1}{\left(\frac{1}{R_j} + \sum_{k=1}^{|A_j|} \frac{1}{R_k}\right) \cdot (|N_j| + 1) + \sum_{l=1}^{|B_j|} \frac{1}{R_l}}$$



- **B_j**: 2-hop neighborhood of AP_j
- **N_j**: associated users of AP_j
- **A_j**: 1-hop neighborhood of AP_j

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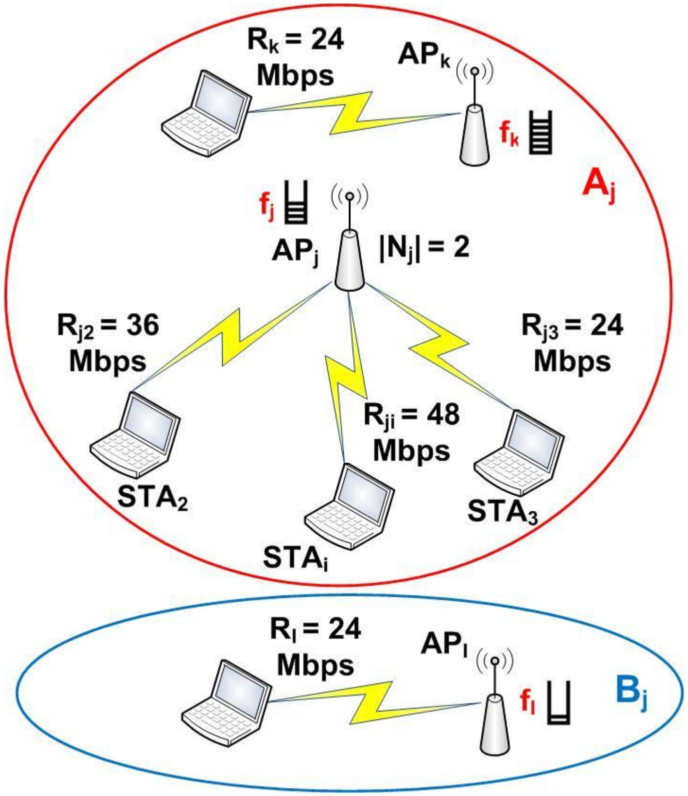
Proposed Metrics - Traffic

$$T_{ij}^{down} = \frac{1}{\left(\frac{f_j}{R_j} + \sum_{k=1}^{|A_j|} \frac{f_k}{R_k}\right) \cdot (|N_j| + 1) + \sum_{l=1}^{|B_j|} \frac{f_l}{R_l}}$$



- **B_j**: 2-hop neighborhood of AP_j
- **N_j**: associated users of AP_j
- **A_j**: 1-hop neighborhood of AP_j
- **f_n**: factor capturing the rate with which packets leave the TX queue of node n

$$f_n = \min\{\lambda_n, \mu_n\}$$

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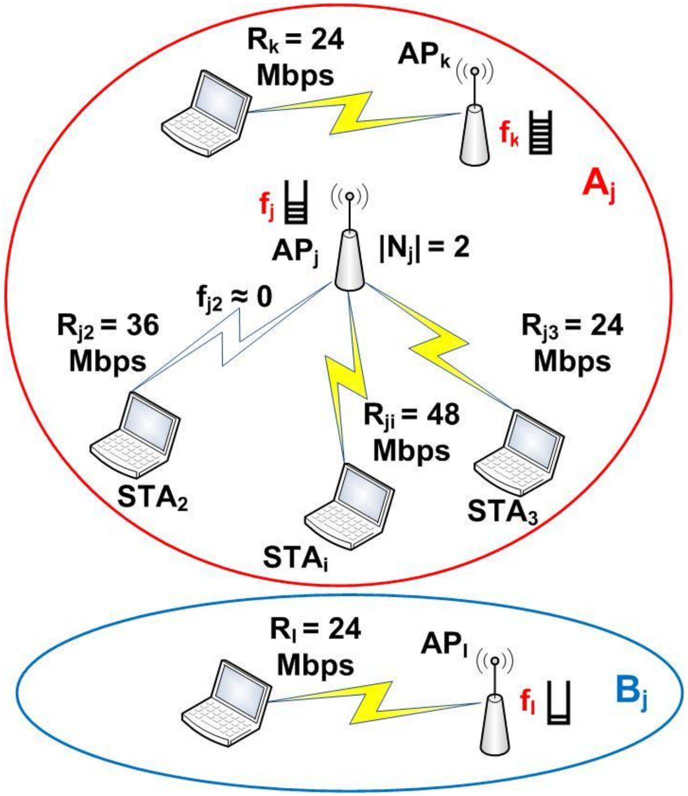
Proposed Metrics - Traffic

$$T_{ij}^{down} = \frac{1}{\left(\frac{f_j}{R_j} + \sum_{k=1}^{|A_j|} \frac{f_k}{R_k}\right) \cdot (|N_j| + 1) + \sum_{l=1}^{|B_j|} \frac{f_l}{R_l}}$$



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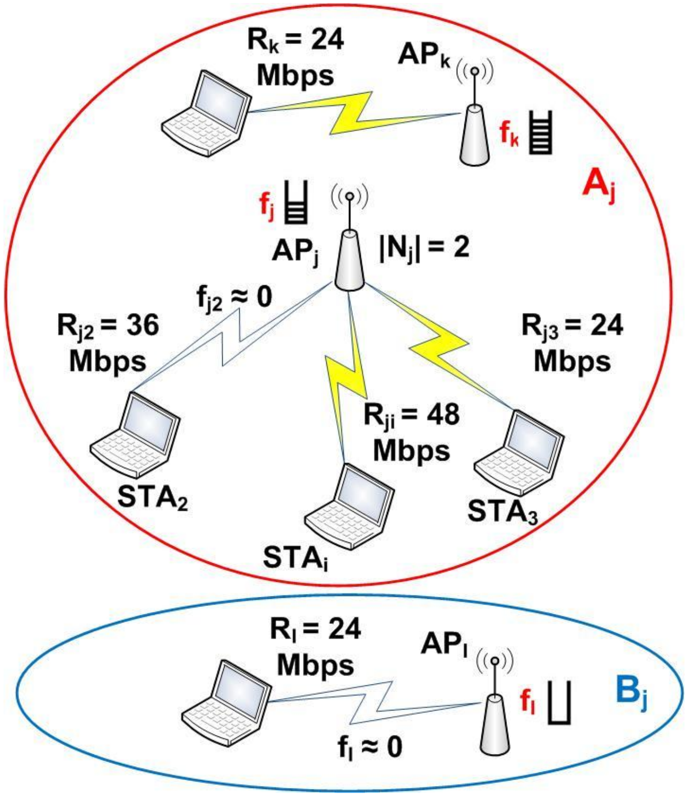

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Proposed Algorithms

- **Association**
  - Uplink metric:

$$T_{ij}^{up} = \frac{1}{\frac{f_i}{R_{ij}} + \sum_{k=1}^{|A_i|} \frac{f_k}{R_k} + \sum_{l=1}^{|B_i|} \frac{f_l}{R_l}}$$

  - Each TX periodically transmits Neighbor Report packets including PHY rate, "1-hop" Neighbors list
  - APs extend the Beacon frames by including their average PHY rate and the number of associated STAs
  - APs constantly monitor their "1-hop", "2-hop" neighborhoods
  - STAs perform background scanning , because Neighbor sets depend on the operating channel.
  - Finally, STA_i selects the AP_j that offers the maximum calculated metrics
- **Handoff:**
  - H1: Scanning Triggering threshold

  if the initial performance is reduced by H1% => BG scanning
  - H2: Background scanning interval

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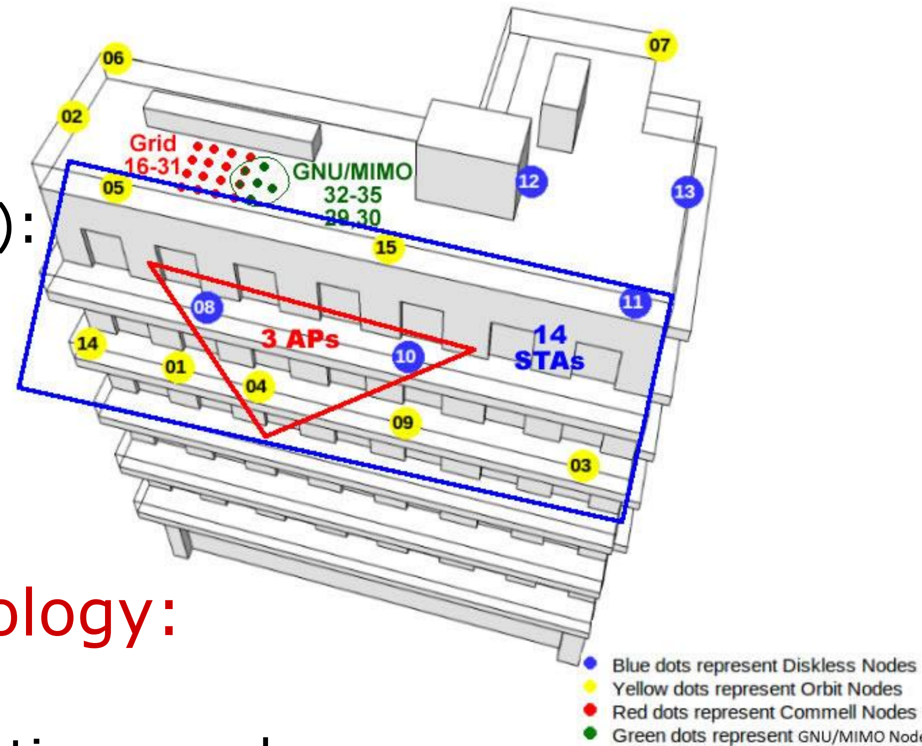
Experimental Evaluation

- NITOS Testbed:
  - 3 APs: 04, 08, 10
  - 14 STAs (double ifaces): 14, 01, 04, 09, 03 05, 15, 11



- Measurement Methodology:
  - Iperf UDP mode
  - Each experiment run 5 times and lasts for 10 minutes
  - Average the results of the 5 experiments

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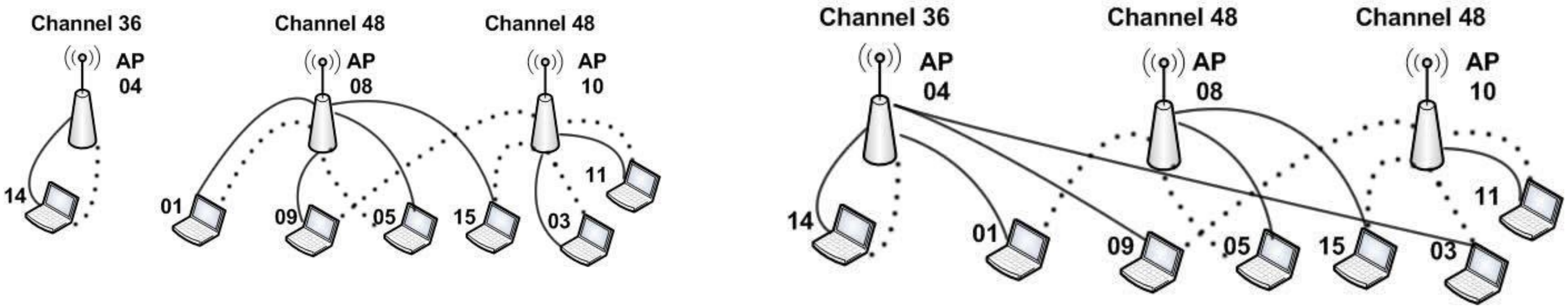
Downlink Experiment 1



- AP_{08} and AP_{10} operate on channel 48.
- AP_{04} operates on channel 36.

- The AP_s generate UDP traffic of varying rate.

- With the RSSI approach AP_{04} has only 2 associated STA_s .

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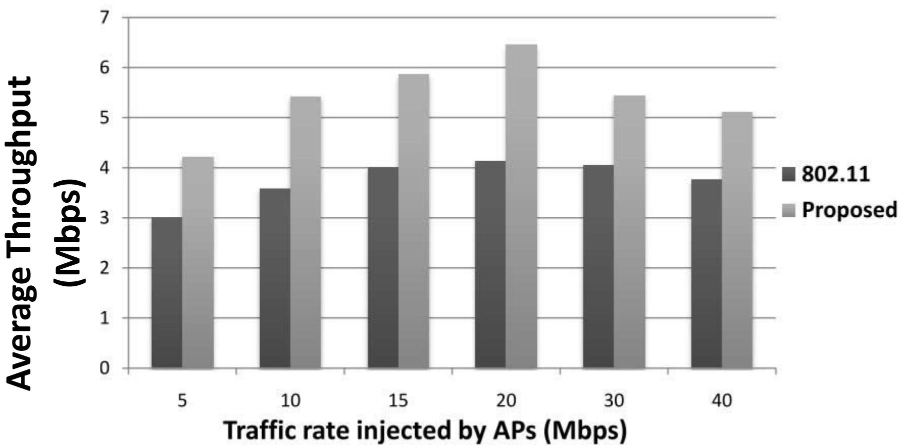
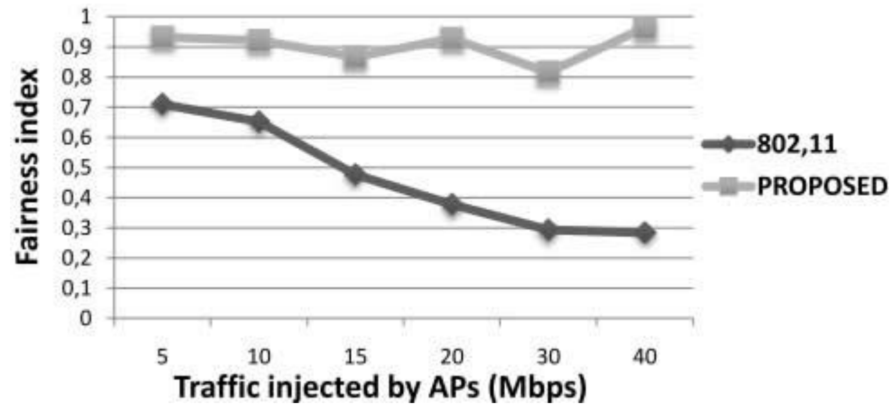
Downlink Experiment 1





- Our approach leads 5 STA_s to associate with AP_{04} .

- Maximum throughput in the case of 20 Mbps / flow leading to an increase of **62,5%** .

- The RSSI approach leads to associations that favor only a subset of nodes, resulting in low Fairness index values.

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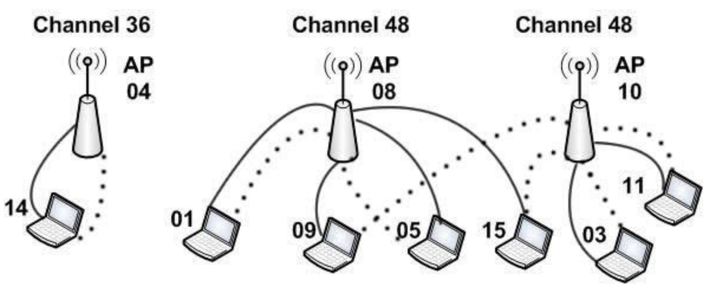
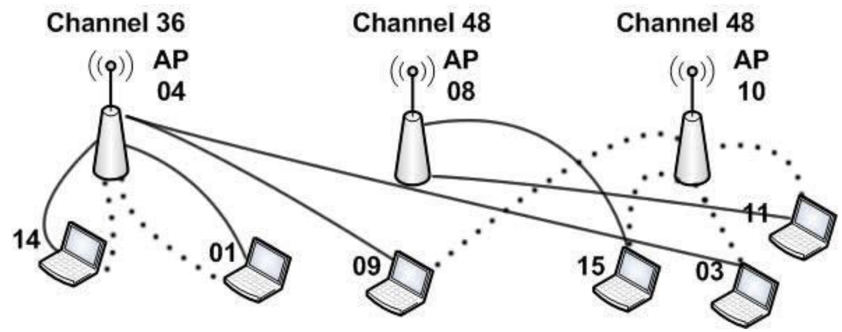
Downlink Experiment 2





- 12 STA_s are activated

- An extra flow of varying traffic rate is activated, belonging to an adjacent cell operating on channel 48

- AP_{04} is operating on channel 36, while all other sources operate on channel 48

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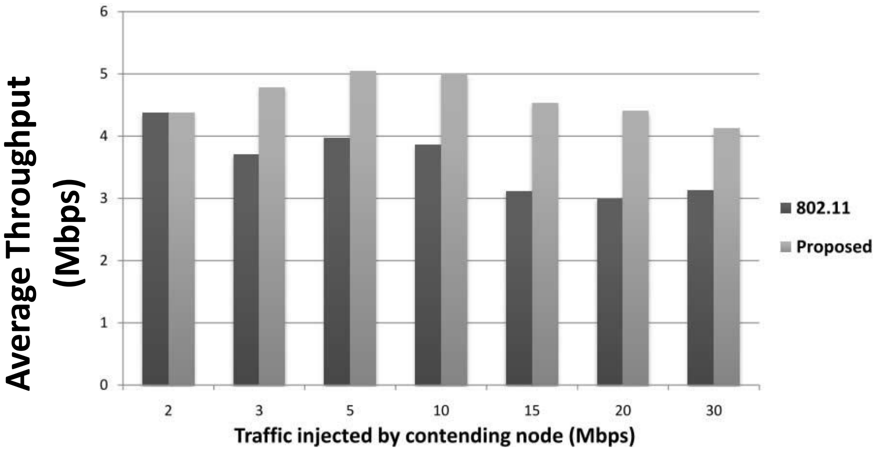
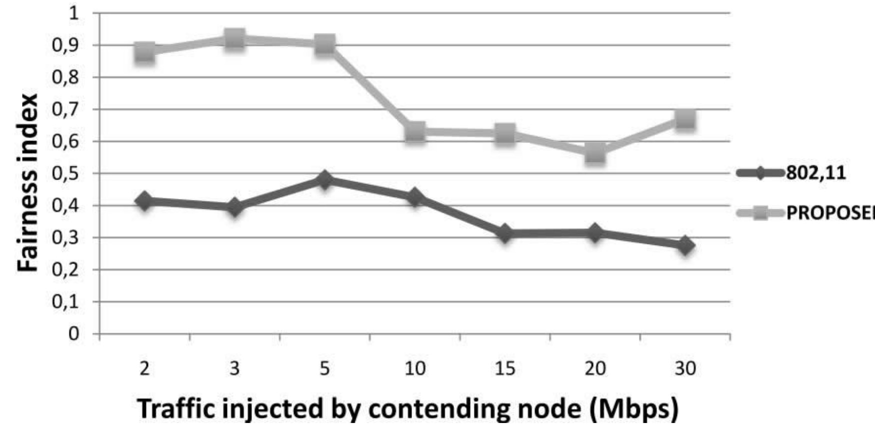
Downlink Experiment 2





- Our approach leads 6 STA_s to associate with AP_{04}

- As the traffic rate of the contending node increases above 10 Mbps the performance of all STA_s falls.

- High Fairness index values till the rate of 5 Mbps/flow.

- Performance is topology dependent.

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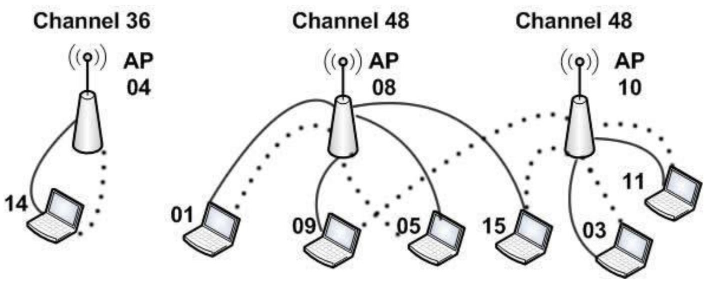
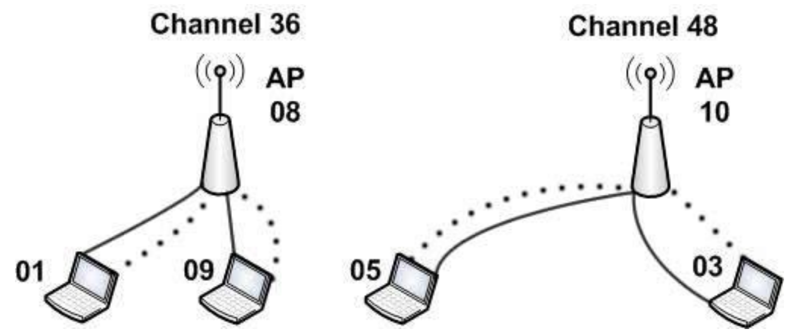
Uplink Experiment





- AP_{08} and AP_{10} on different channels, 8 STA_s.
- Multiple varying rate traffic flows, generated by the STA_s.
- With the RSSI approach AP_{08} has only 3 associated STA_s .

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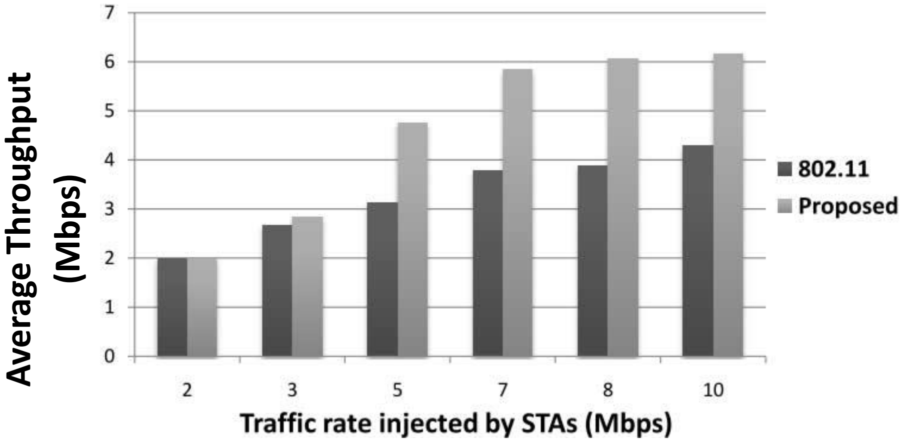
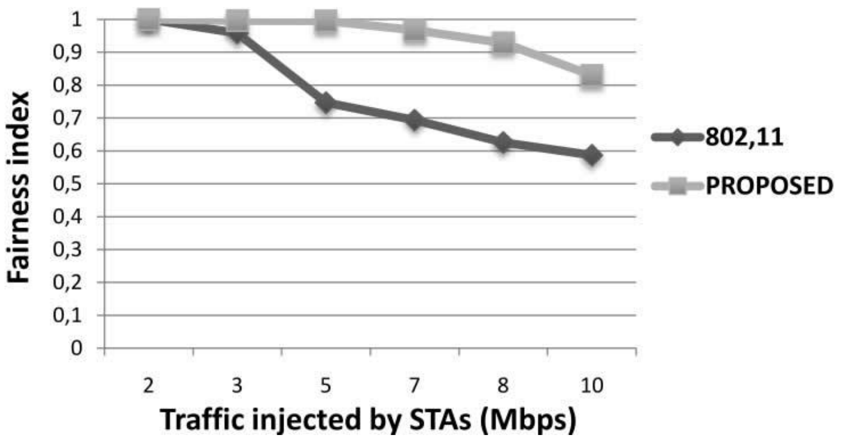
Uplink Experiment





- Our approach balances the AP load: 4 STA_s associated with each one of the AP_s.

- In the cases of 2 and 3 Mbps/flow there is no significant difference in the average performance.

- Great increase above the rate of 5 Mbps/flow.

- High Fairness index values even in high load per flow.

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Conclusions and Future work

- Novel association scheme capturing the effects of contention, interference both on UL and DL.
- Manages to adapt to realistic traffic conditions.
- Far better performance (+62,5%) compared with the standard RSSI-based approach.
- Nearly equal sharing of throughput among the intended receivers, even in high load conditions.

- Altruistic extension: each STA considers the overall performance of the network as well.
- Joint consideration of our user association approach with a dynamic frequency selection (DFS) mechanism.

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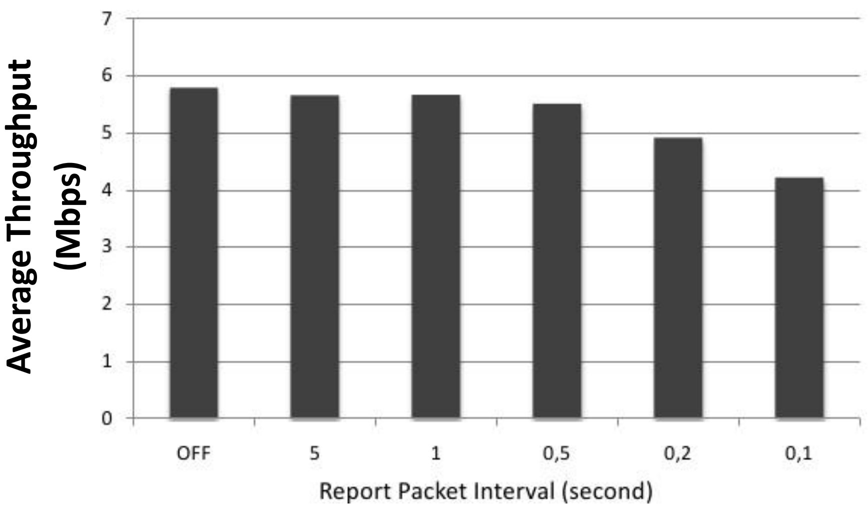
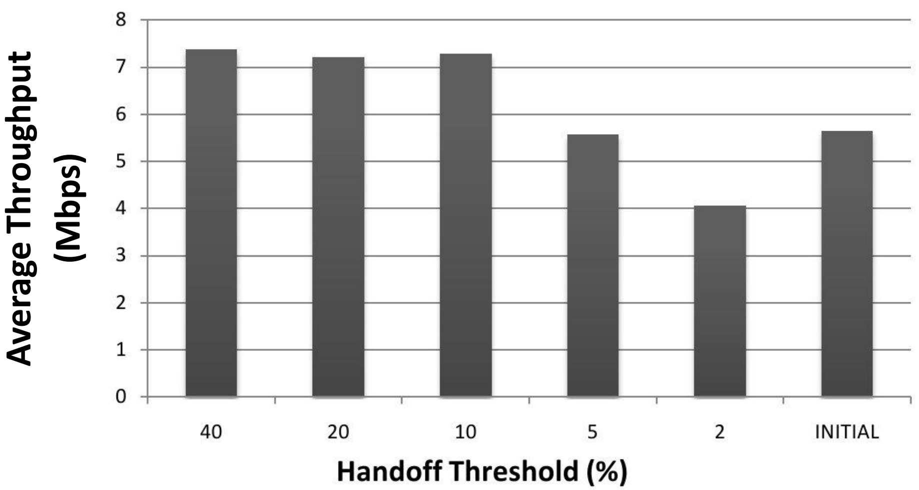
Thank You!

More Experiments





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Jain's fairness index

$$\mathcal{J}(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \cdot \sum_{i=1}^{n} x_i^2}$$

- Equal partitioning achieves index values of **1**.
- If only **k** of **n** flows receive equal throughput and others get none index is **k/n .**

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