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Optimal Mapping of Stations to Access Points in Enterprise WLANs

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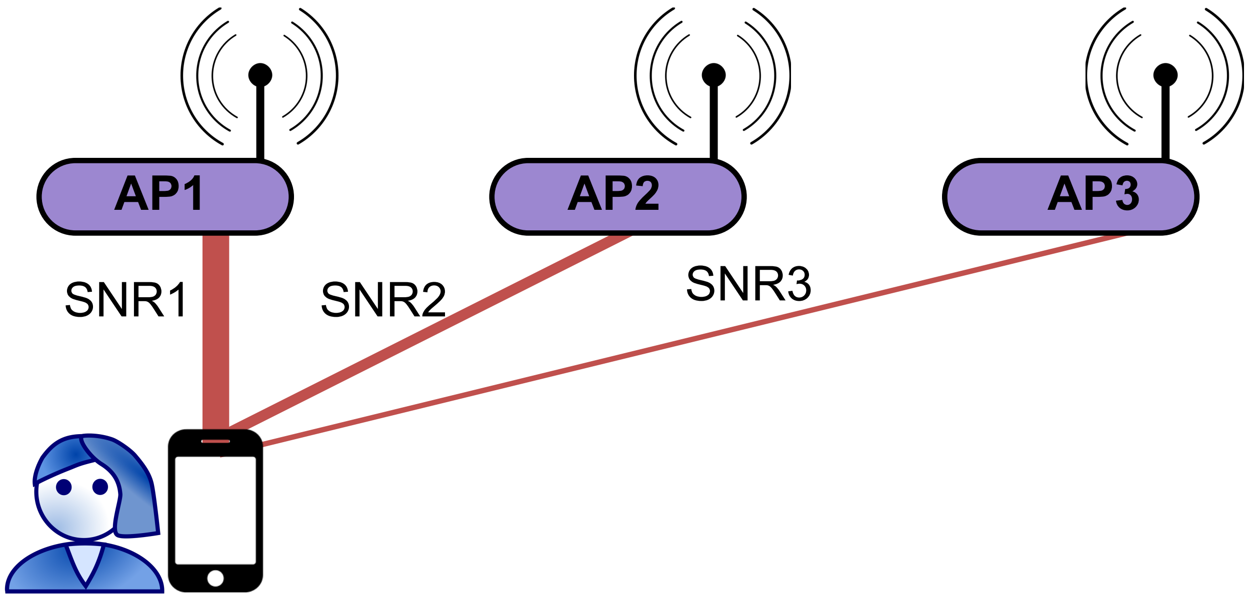
Motivation

- WiFi efficiency is crucial
- Current approach: client decides on which AP to connect
- User-AP association not efficient, *sticky user problem*
- Enterprise WLANs can use their centralised controllers to allocate WiFi resource more efficiently

Problem 1: AP loads not considered



User connects to the link with the highest SNR

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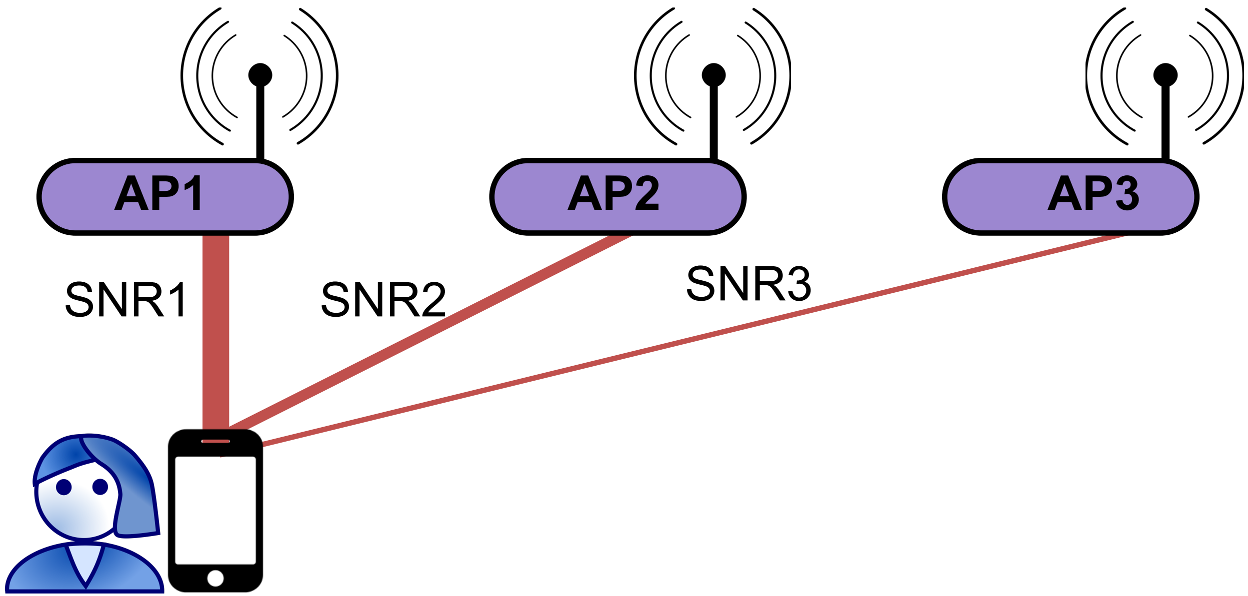

User connects to the link with the highest SNR

Problem: high SNR does not always mean high throughput, airtime share is also important

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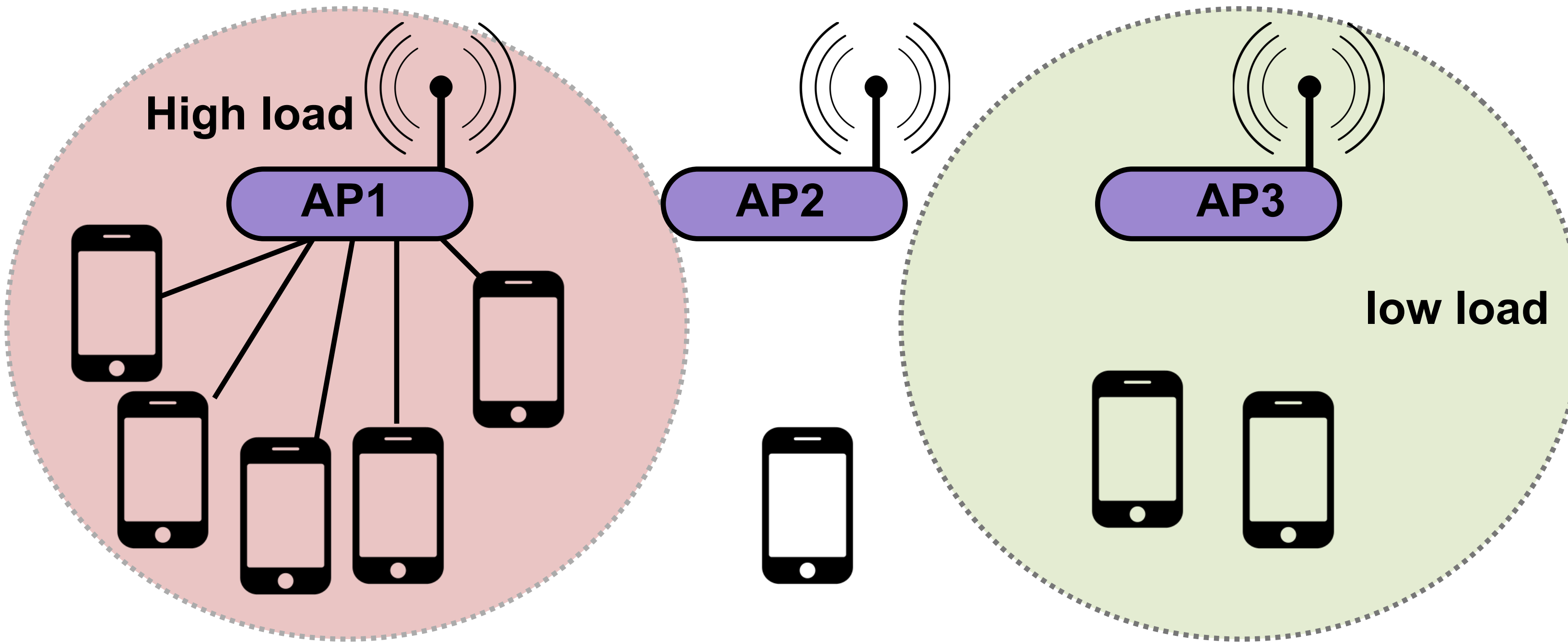

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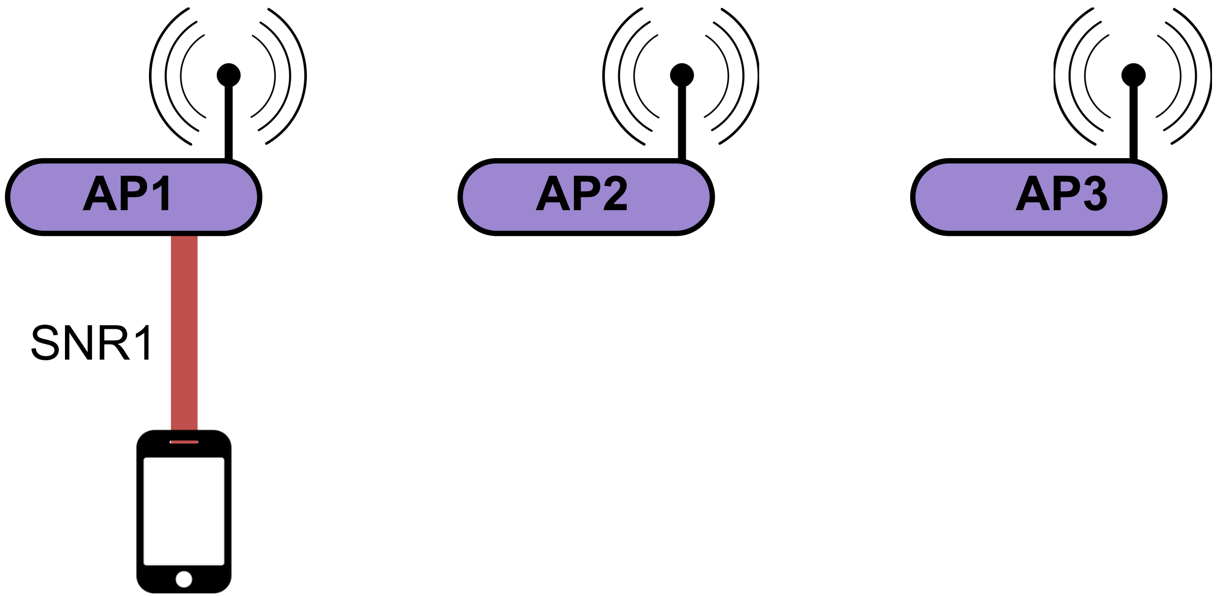
Problem 2: sticky-user problem

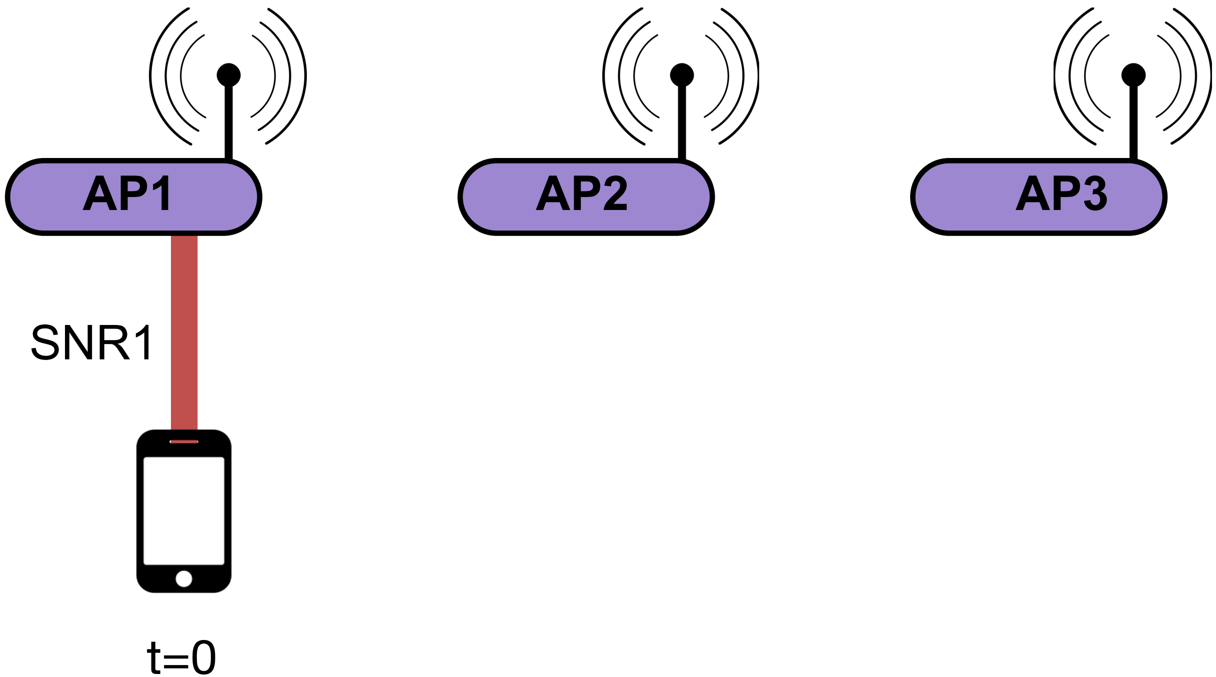


User remains connected to its AP until its link SNR is below some threshold SNR

Problem: an optimal link may become suboptimal due to client mobility or changes in AP load

C

Problem 2: sticky-user problem



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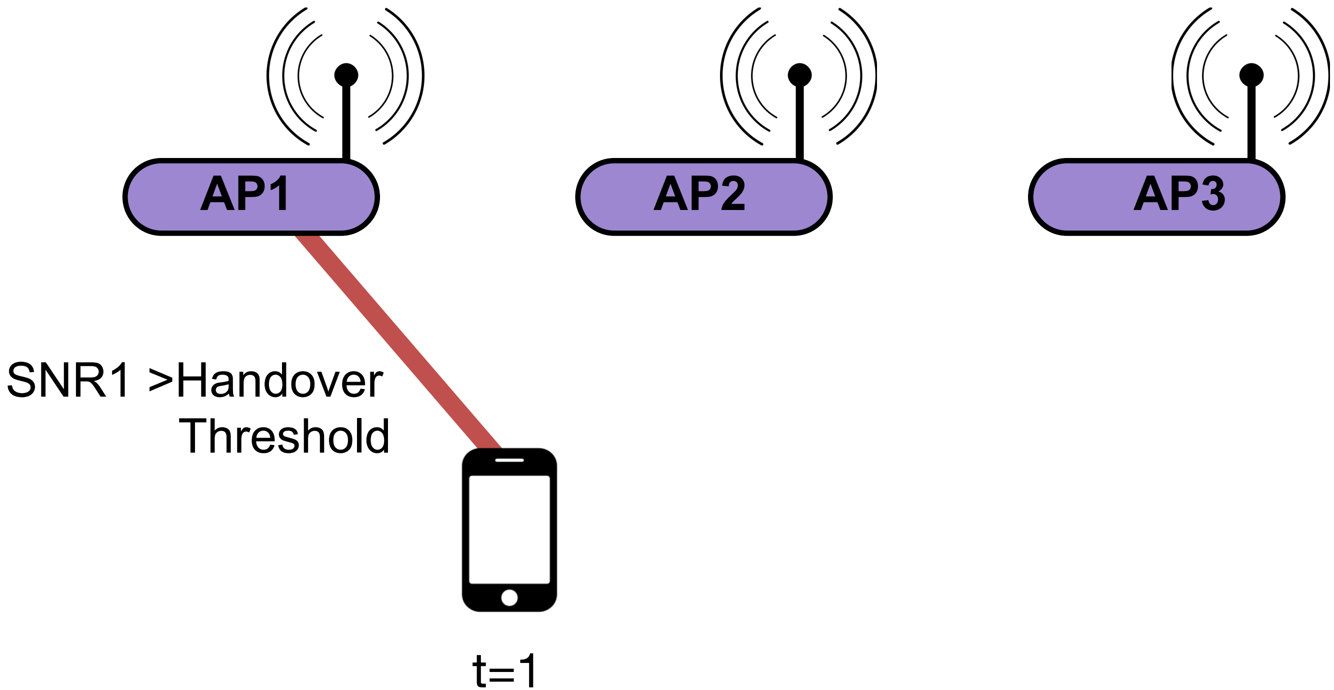

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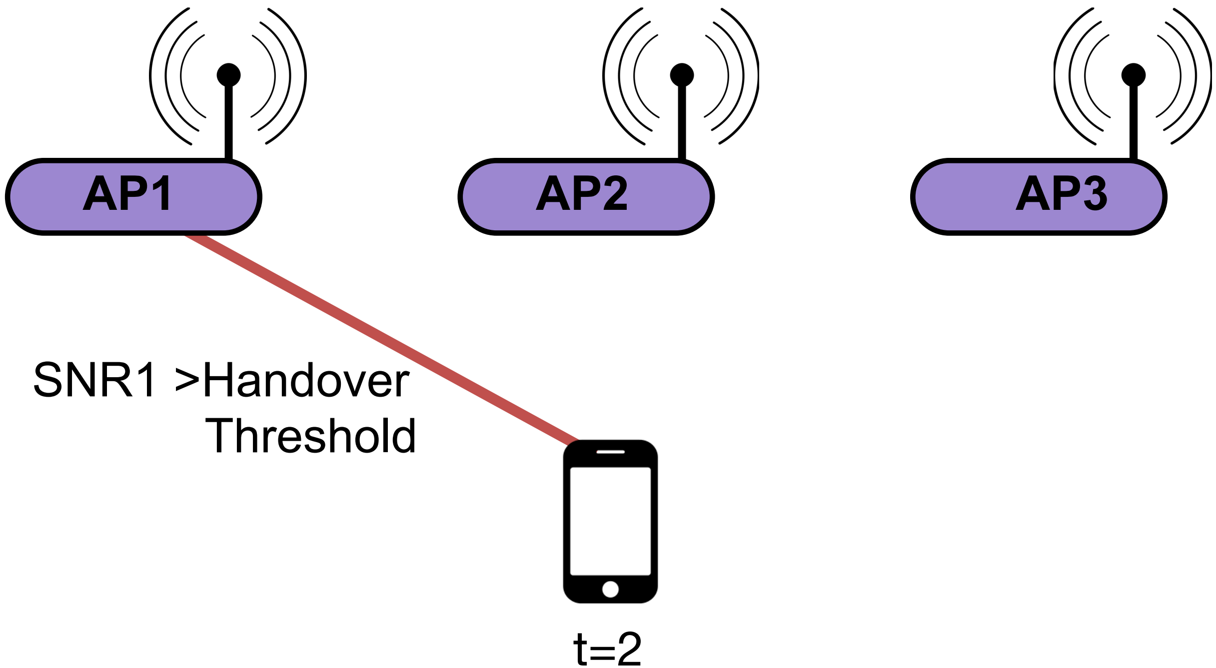

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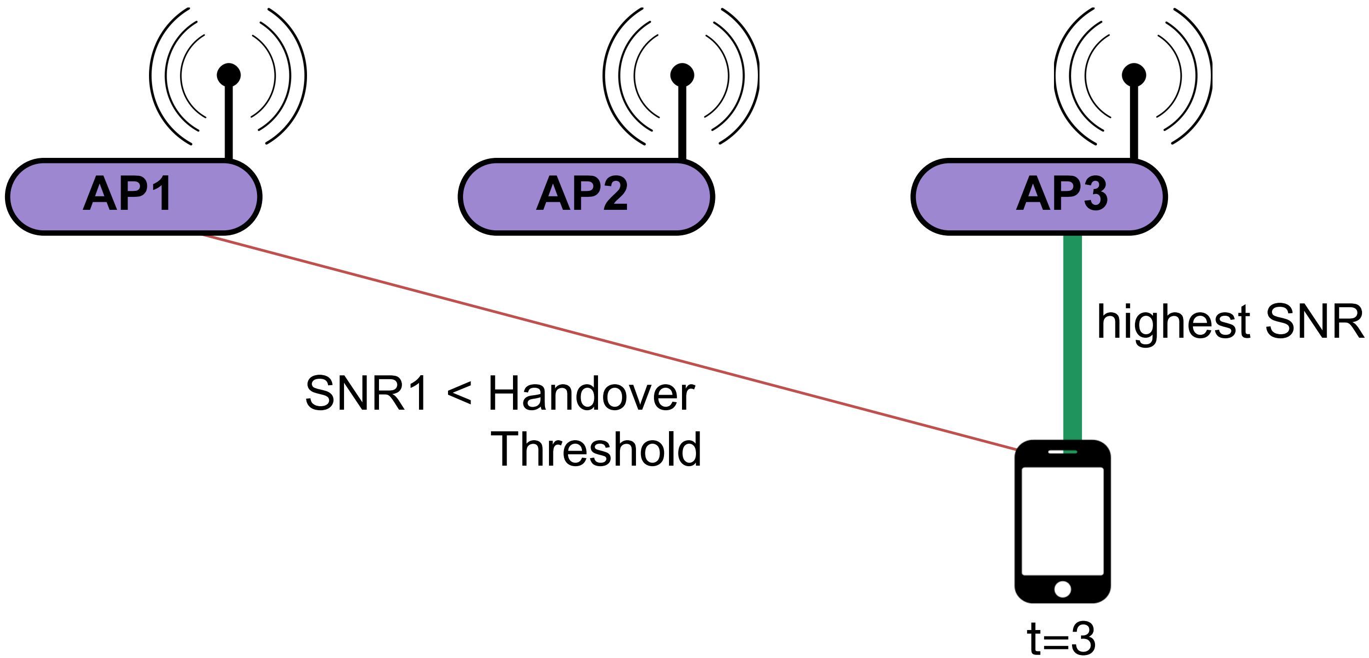
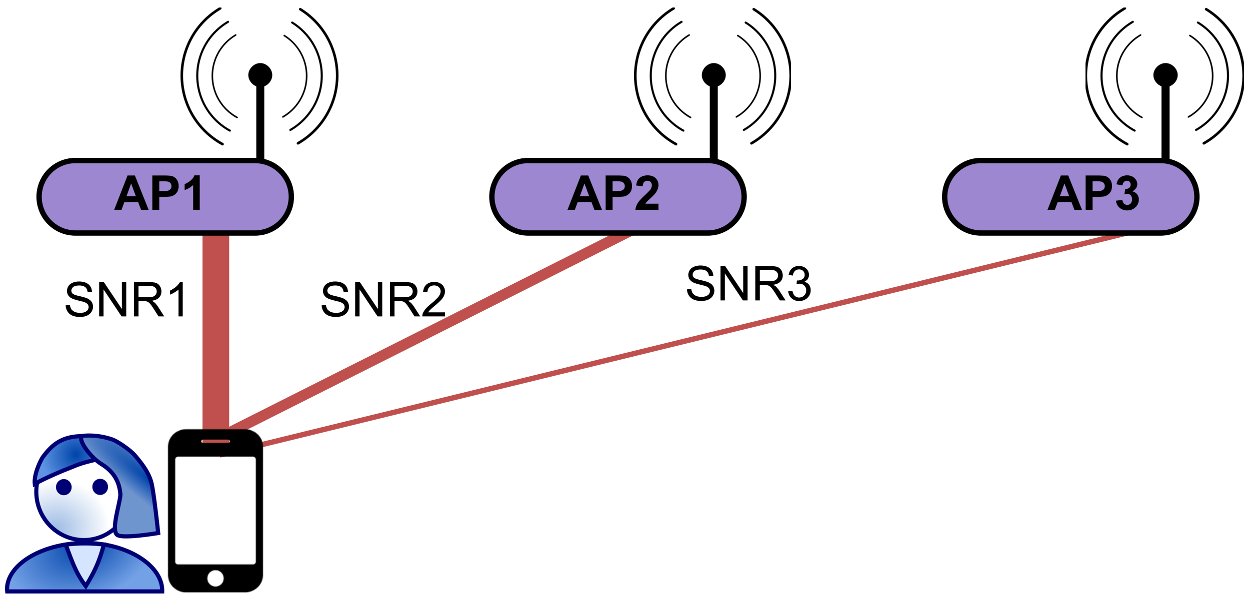


Handover at t=3

Between t=0 and t=3, decreasing/low user throughput

Current station-AP association is inefficient



- Client-driven decision based only on the link SNR (load of APs ignored)
- no handovers until the link SNR is very low

Our approach

- Client-driven decision based only on SNR (load of APs ignored)
  - **Infrastructure-driven considering also AP-loads, link SNRs, and user's application requirements**

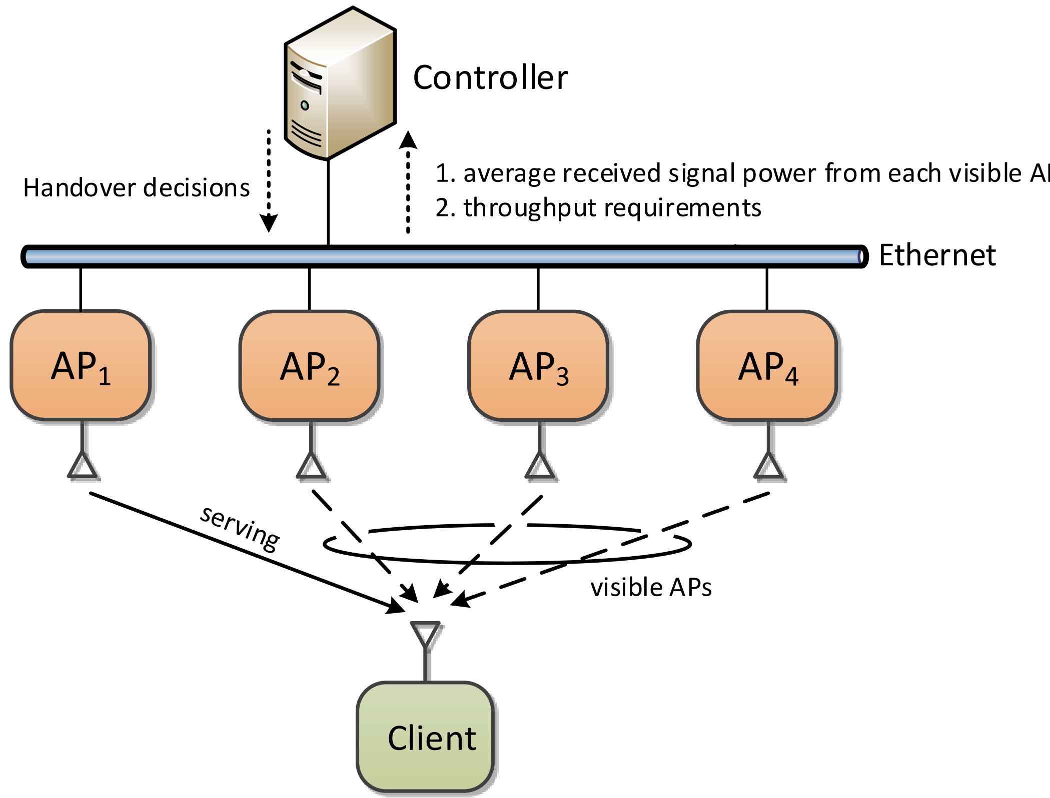
- No handovers until the link SNR is very low
  - **Periodically to react timely to changes in network dynamics**
  - **and client-driven if the controller is not active**

Our approach in comparison with the literature

- Infrastructure controls the handover/user-AP association decision
  - handover costs ignored
  - not-periodic assignment
  - only at the time of network joining is still suboptimal
- Periodic assignment schemes:
  - How often to periodically trigger controller?

System Model: enterprise WLAN setting

- Controller
- APs
- Ethernet connection between APs and the controller



Controller

- **Which AP should each user be connected to?**

Assumptions

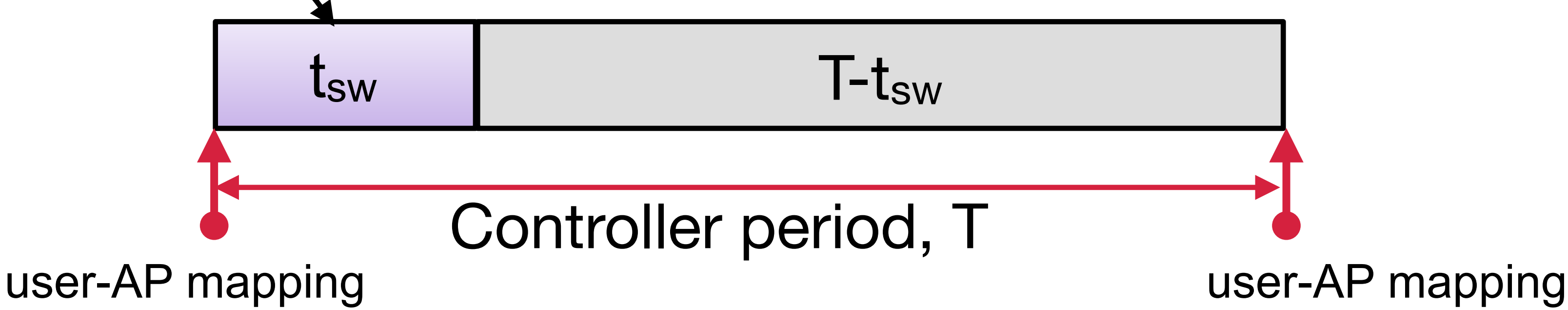
- Only downlink throughput
- WiFi AP shares the airtime **equally** among its users' DL traffic
- Some user applications, e.g., video, require **minimum throughput** for satisfactory user experience
- APs know the SNR of each link to the users

Periodic user-AP mapping

- Controller triggers user-AP mapping periodically, **every T time units** known as **controller period**
  - How to set the period T?
    - **short:** what is the cost/overhead of handover?
      - how does it affect WiFi throughput?
    - **long:** may not react fast enough to highly mobile users
- How should the controller decide on user-AP association?
  - Goal: proportional-fair user throughputs

Airtime share under handover-latency

- Periodic decision: T
- Handover latency: t_{sw}
- Number of total users connected to AP j: n_j
- Number of switching users to AP j: n_j^{sw}



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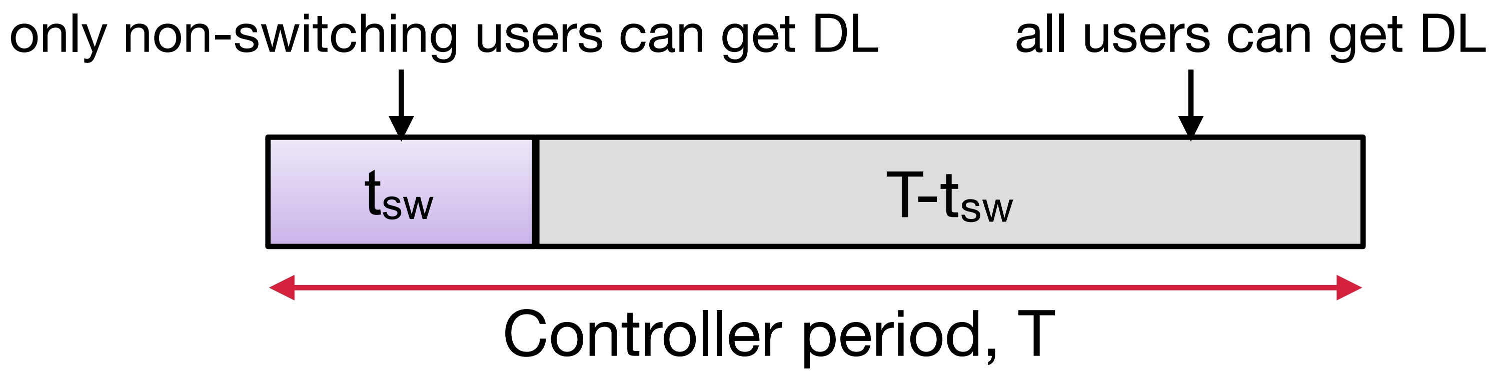

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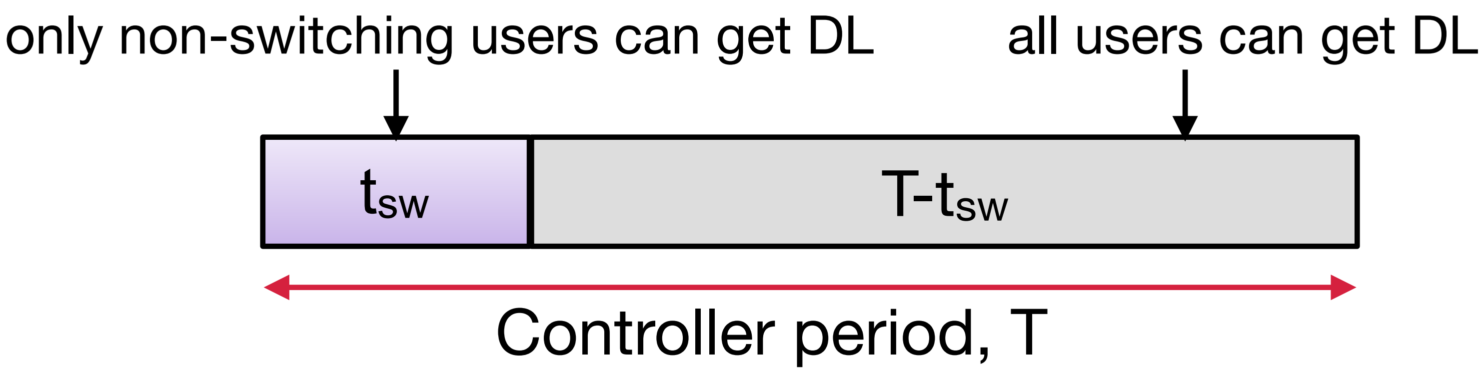
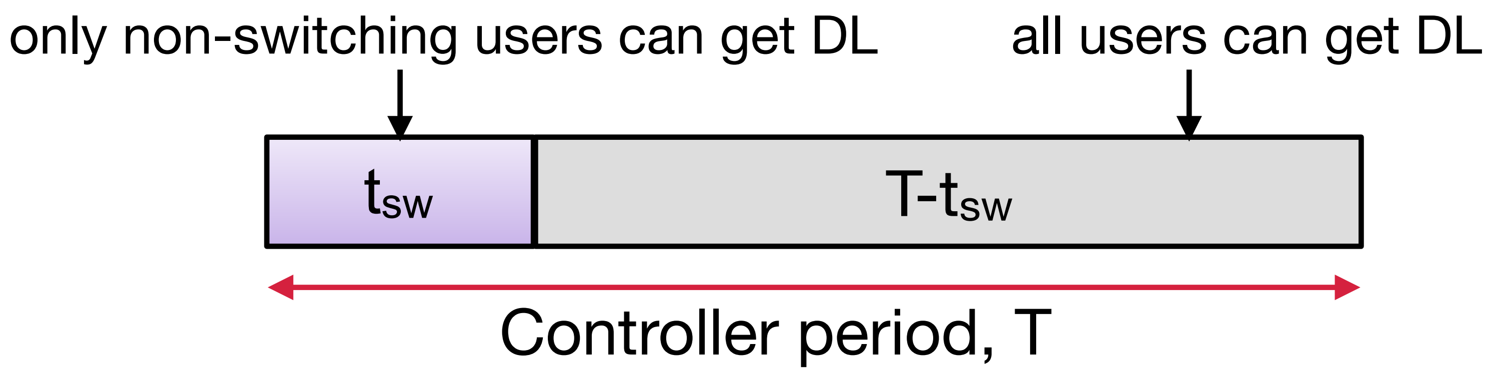


- Airtime for a switching user: $$\alpha_{i,j}^{sw} = \frac{T - t_{sw}}{T} \cdot \frac{1}{n_j}$$
- Airtime for non-switching user: $$\alpha_{i,j} = \frac{t_{sw}}{T} \cdot \frac{1}{n_j - n_j^{sw}} + \frac{T - t_{sw}}{T} \cdot \frac{1}{n_j},$$

Airtime share under handover-latency



EXPECTED: may not be true if the controller period is long!

- Airtime for a switching user: $$\alpha_{i,j}^{sw} = \frac{T - t_{sw}}{T} \cdot \frac{1}{n_j}$$

EXPECTED

- Airtime for non-switching user: $$\alpha_{i,j} = \frac{t_{sw}}{T} \cdot \frac{1}{n_j - n_j^{sw}} + \frac{T - t_{sw}}{T} \cdot \frac{1}{n_j},$$

Throughput and utility of a user

- Throughput = airtime x Shannon capacity
- Utility:
  - Logarithmic function of throughput to ensure proportional fairness
  - minimum needed airtime of an application must be ensured

Throughput of user i if served by AP j

Allocated airtime

Utility

Needed airtime

$$\mathcal{R}_{i,j} = \begin{cases} \log(1 + R_{i,j}), & \text{if } \beta_{i,j} \geqslant \alpha_{i,j}^{min} \\ 0, & \text{otherwise.} \end{cases}$$

Optimal user-AP assignment

$$\mathbf{P1}: \max_{\mathbf{X}=[x_{i,j}]} \sum_{AP_j \in \mathcal{A}} \sum_{u_i \in \mathcal{U}} \log\left(1+x_{i,j} r_{i,j}(\alpha_{i,j}^{sw}\phi_i+\alpha_{i,j}(1-\phi_i))\right) \quad (8)$$

$$\sum_{AP_j \in \mathcal{A}} x_{i,j} \leqslant 1 \qquad \forall u_i \in \mathcal{U} \quad (9)$$

$$x_{i,j} \leqslant v_{i,j} \qquad \forall u_i \in \mathcal{U}, \forall \mathbf{AP}_j \in \mathcal{A} \quad (10)$$

$$\sum_{u_i \in \mathcal{U}} x_{i,j}\alpha_{i,j}^{min} \leqslant 1 \qquad \forall \mathbf{AP}_j \in \mathcal{A} \quad (11)$$

$$x_{i,j}\alpha_{i,j}^{min} \leqslant \alpha_{i,j}^{sw}\phi_i + \alpha_{i,j}(1-\phi_i), \forall u_i \in \mathcal{U}, \forall \mathbf{AP}_j \in \mathcal{A} \quad (12)$$

$$\alpha_{i,j}^{sw} = \frac{T - t_{sw}}{T \cdot \sum_{u_i \in \mathcal{U}} x_{i,j}} \quad (13)$$

$$\alpha_{i,j} = \frac{t_{sw}}{T \cdot \sum_{u_i \in \mathcal{U}} x_{i,j}(1-\phi_i)} + \frac{T - t_{sw}}{T \cdot \sum_{u_i \in \mathcal{U}} x_{i,j}} \quad (14)$$

$$x_{i,j} \in \{0, 1\} \qquad \forall u_i \in \mathcal{U}, \forall \mathbf{AP}_j \in \mathcal{A}. \quad (15)$$

Please see the details in the paper

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Heuristics

- **Highest-SNR** AP association (h-SNR)
  - client-driven handover run **periodically**
- **Airtime-aware** AP association (AIR)
  - Assign each randomly picked user to the AP that can provide the highest **airtime*rate** product
- **Demand-aware** AP association (DAW)
  - Ensure that a new assignment does not violate the **minimum rate requirements** of the already assigned users

Comparison of heuristics

Heuristic	AP load	HO cost	Demand	Distributed
CD	-	-	-	✓
h-SNR	-	-	-	✓
AIR	✓	✓	-	-
DAW	✓	✓	✓	-

- Baseline: **CD,** the client-driven conventional approach
- **DAW** is the most advanced scheduler, but cannot be run distributedly

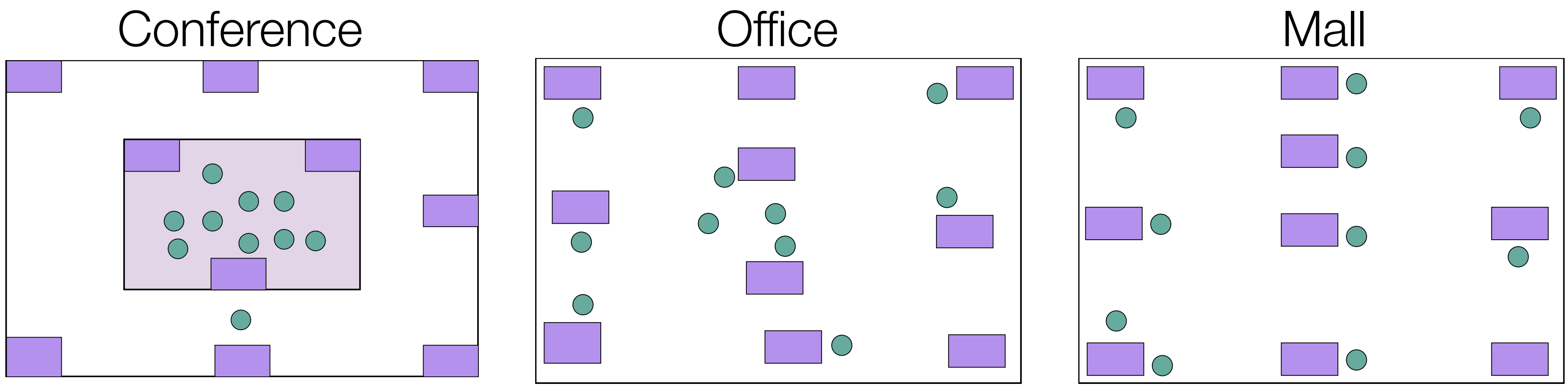
Performance Analysis

- Comparison with traditional approach (Client-Driven, CD)
- Optimality analysis (see the paper)
- Impact of various parameters:
  - controller period
  - handover cost
  - user density

Setting

- area = (150m, 100m)
- Num stations = 80
- Num APs = 10
- user speed: [1,5] m/s, random-waypoint mobility
- switching latency = 0.2 s
- minimum throughput requirements: [5,15] Mbps
- user-AP links: Keenan-Motley channels
- Fairness metric calculated every 5 time units
- 100 time slots, 100 repetitions

Scenarios



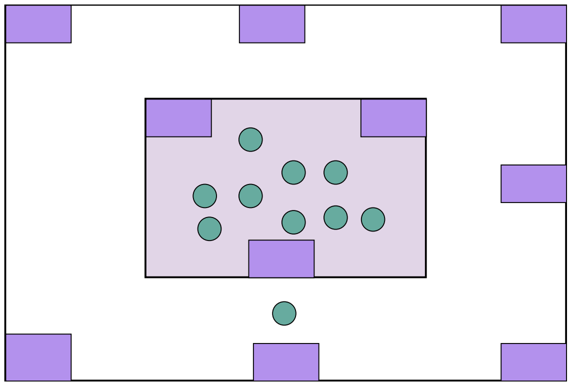
- 90% users are in the conference room
- 10% outside

- Grid-like topology
- Skewed user distribution

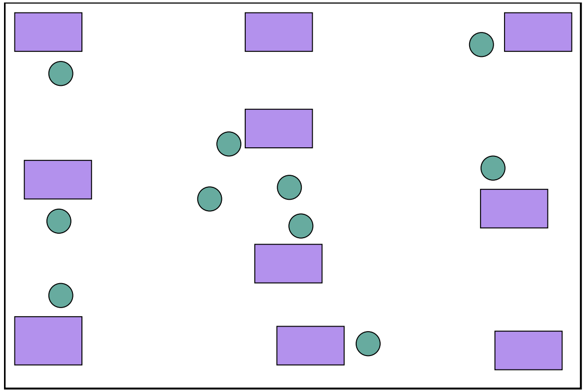
- Grid topology
- Uniform user distribution

Scenarios

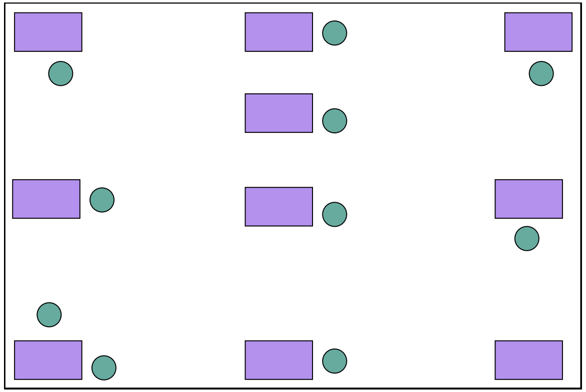
Conference



Office



Mall



- 90% users are in the conference room
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- Grid-like topology
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- Grid topology
- Uniform user distribution

- density balance: homogeneity of user distribution across APs (independent of association scheme, only-geometry dependent)

Scenarios

- Frequency assignment: graph colouring problem
- Bandwidth of each AP: total bandwidth/chromatic number of the graph

Table 3: Scenarios

Scenario	Fraction of mobile users	Fraction of users with throughput demand
Conference	0.5	0.3
Office	0.3	0.5
Shopping mall	0.9	0.3

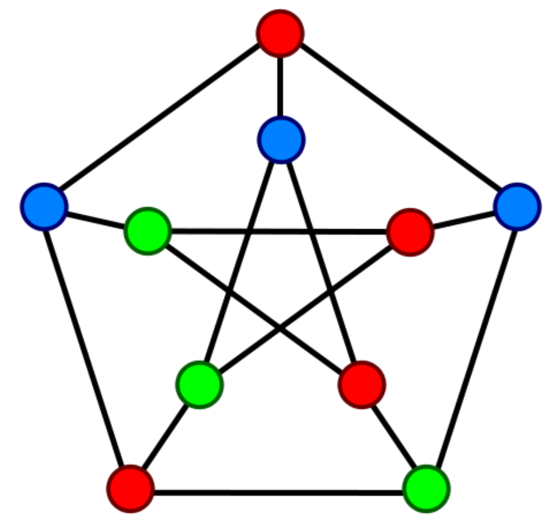
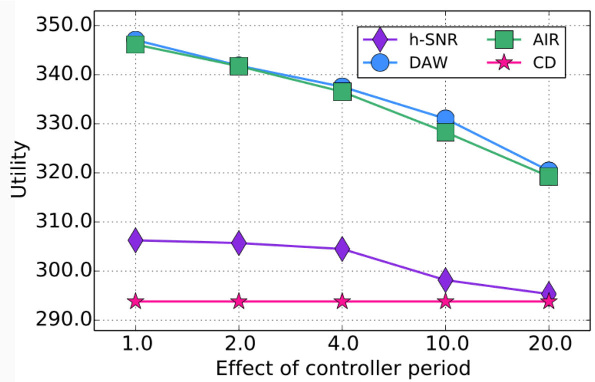
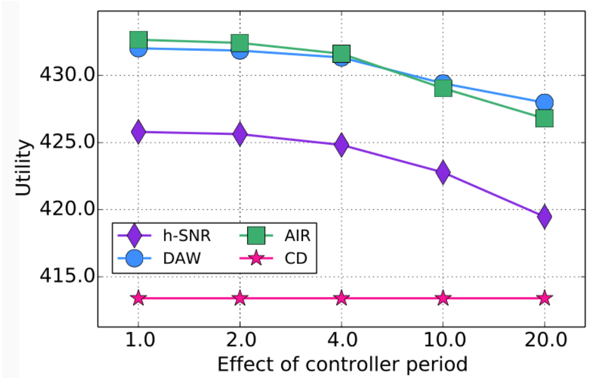
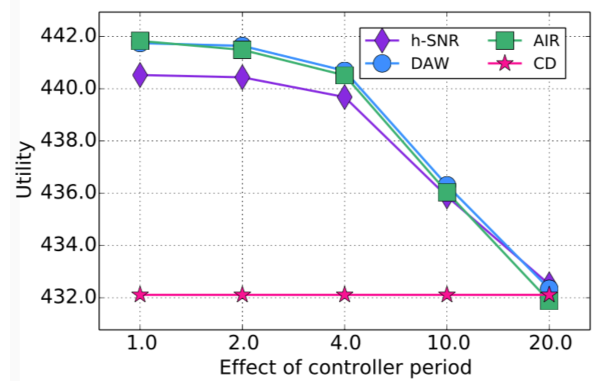


figure: Public Domain, https://commons.wikimedia.org/w/index.php?curid=1386753

Performance metrics

- Utility (objective of our optimization problem)
- Fraction of satisfied users
- Fairness across user throughputs
- Load balance of APs
- Gain in weakest user's performance over CD
- Probability of handover

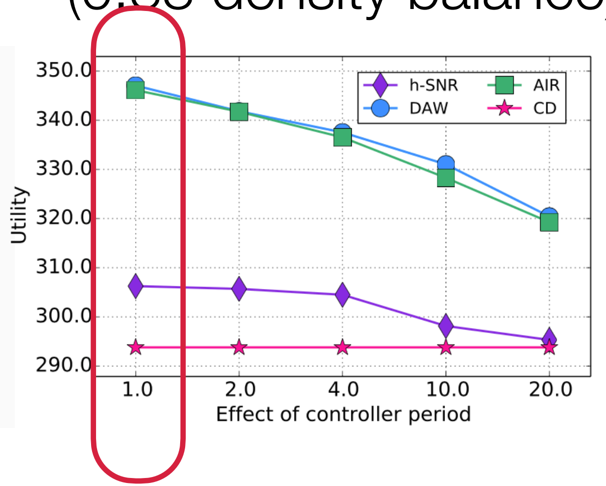
Impact of controller period

Conference (0.33 density balance)	Office (0.76 density balance)	Mall (0.95 density balance)
		

- Controller period : {1, 2, 4, 10, 20} number of time slots (timeslot=1 s)

Impact of controller period

Conference
(0.33 density balance)



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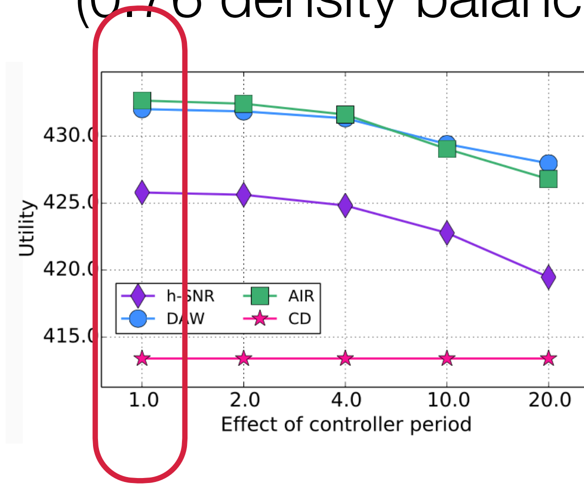
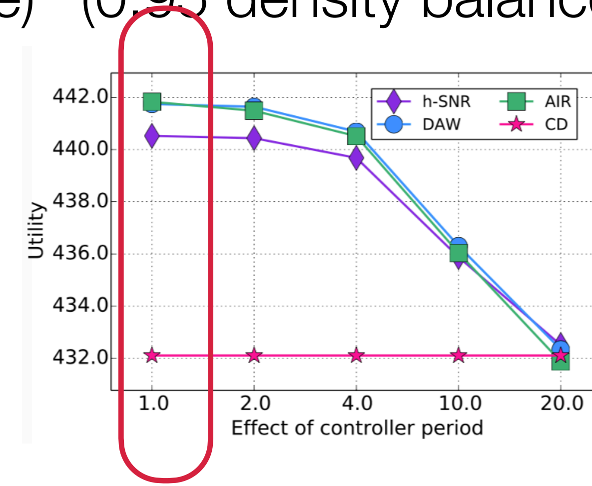


Mall
(0.95 density balance)



- Utility at T=1

Impact of controller period

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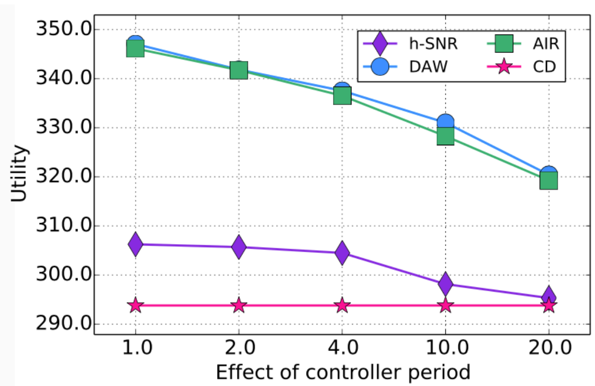

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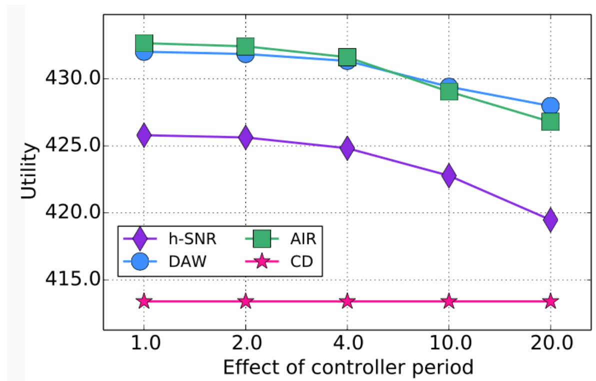

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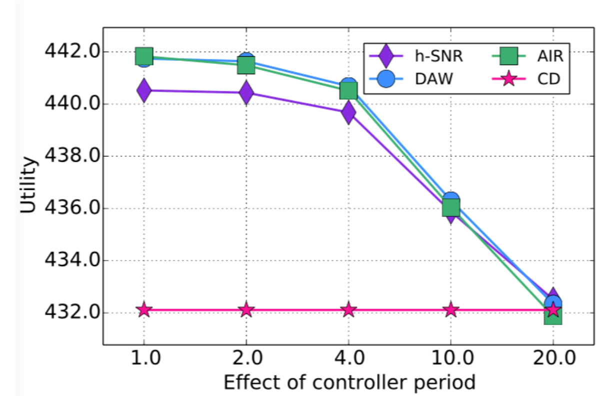
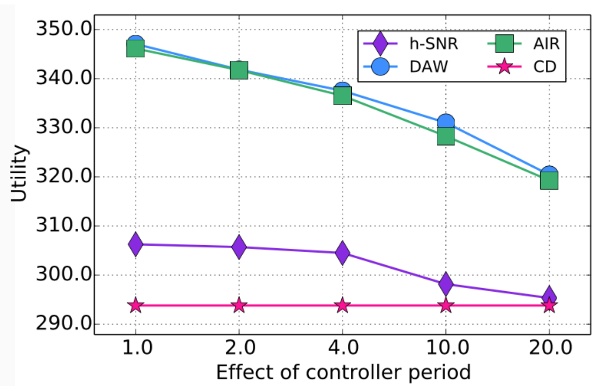


- utility improvement over CD: 18%, 5%, 2% by **DAW for each scenario**
- improvement in weakest user's perf: 120%, 73%, 71% by **DAW**
- **Most improvement in Conference setting with low density balance**

Impact of controller period

Conference
(0.33 density balance)



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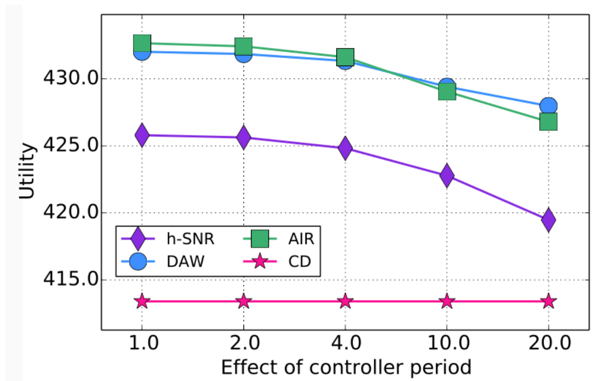

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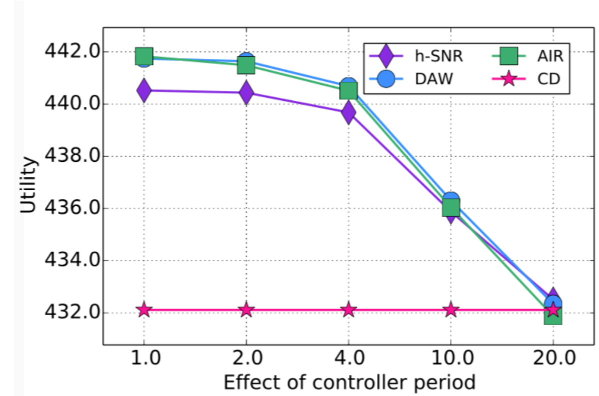


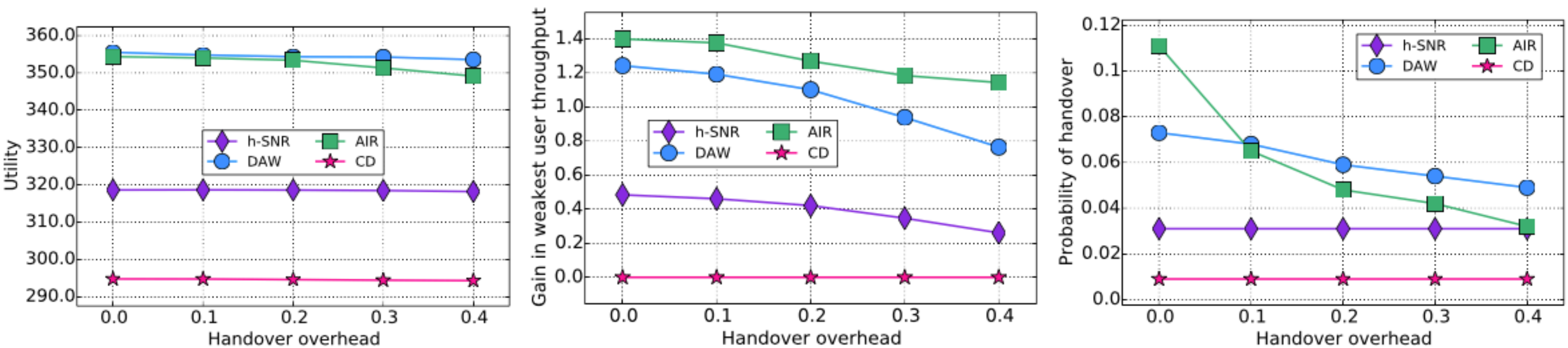
- Most improvement in Conference setting with low density balance
- Even highest-SNR can achieve significant improvement over CD
- Difference among schemes become less relevant for longer periods

Impact of controller period

- More analysis on AP load balance, probability of handover in the paper

Impact of handover cost

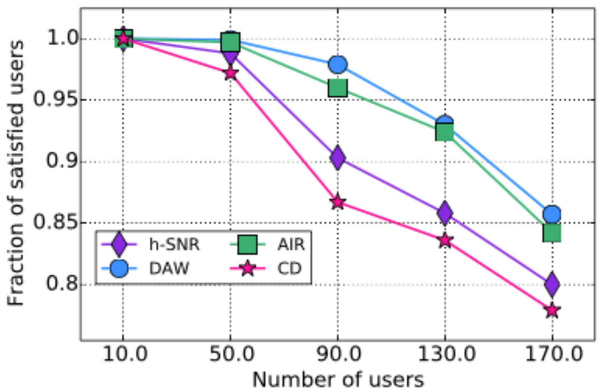
- Conference setting
- Assume all users are mobile



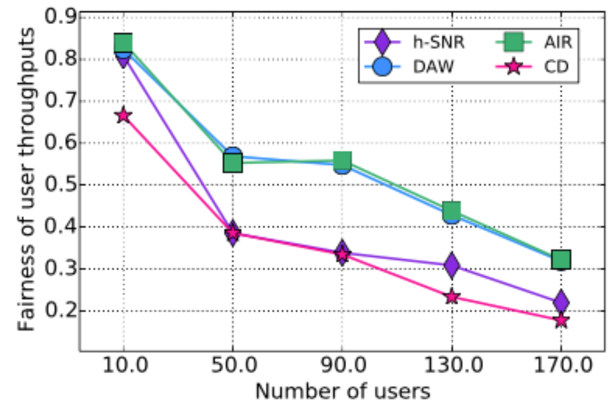
(a) Utility. (b) Gain in the weakest user throughput. (c) Probability of handover.

- Airtime conserved (less airtime for switching, more airtime for non-switching)
- Decrease in the weakest user's throughput gain

Impact of user density



(b) Fraction of satisfied users.



(c) AP load balance.

- Conference scenario (0.3 fraction of users with min-throughput demand)
- Decreasing user satisfaction and fairness with increasing density
- Gap between DAW and naive schemes increases

Conclusions and future work

- infrastructure-driven user-AP association decision for enterprise-WLANs
- periodic scheme considering not only link qualities but also handover cost, AP loads, and user application requirements
- highest improvement for deployments with low density balance like conference scenario
- periodic assignment provides performance improvement for client-driven highest SNR based association scheme
- future work:
  - uplink traffic to be considered
  - realistic mobility models
  - implementation on real hardware

Conclusions and future work

- infrastructure-driven user-AP association scheme for enterprise-WiFis
- periodic scheme considering handover cost, link qualities, AP loads, and user application requirements
- highest improvement for deployments with low density balance like conference scenario
- periodic client-driven achieves also higher performance
- future work:
  - implementation on real hardware
  - uplink traffic to be considered
  - realistic mobility models

Thank you!

www.hiit.fi/u/bayhan

References

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