EFFICIENT Wi-Fi deployments

The basics

Just some common sense rules put together in a nice set of colorful slides

Eduard Garcia-Villegas
Dept. of Network Engineering
eduardg@entel.upc.edu
Efficient Wi-Fi deployments

- Big vs. small
- Analyze requirements
- #STAs and #Needed radios
- Available channels
- Reuse factor
- Dimensioning cells
- Optimization
In the era of ubiquitous Internet...

Wireless internet access can be a traumatic experience due to
- Many concurrent users (dense scenarios)
- Coexistence (older/slower devices, other technologies sharing the band, etc.)
- ...
- POOR DESIGN
Coverage-driven design

- In the past: maximize cell size && minimize costs
  - Optimize AP location and increase cell size → less APs needed (lower cost)
  - Problems:
    - more devices per AP (lower per STA throughput)
      - Reduced efficiency due to higher collision probability
Coverage-driven design

- In the past: maximize cell size && minimize costs
  - Optimize AP location and increase cell size $\rightarrow$ less APs needed (lower cost)
  - Problems:
    - Longer distances AP $\leftrightarrow$ STA mean worse signal quality and, hence, more robust (slower) PHY rates are used
      » Capacity of the whole cell is reduced
      » Longer tx time $\rightarrow$ more power consumed and more collisions
Coverage-driven design

- In the past: maximize cell size & minimize costs
  - Optimize AP location and increase cell size → less APs needed (lower cost)
  - Problems:
    - More hidden nodes → more collisions
    - Power mismatch: AP (high tx power) and STA (low tx power)
      » STA can hear the AP, but the AP can't hear the STA
      » If you want a big cell, increase the antenna gain, not the tx power!
Wi-Fi deployments: big vs. small (4)

- **Coverage-driven design**
  - In the past: maximize cell size && minimize costs
    - Optimize AP location and increase cell size → less APs needed (lower cost)
    - It has problems in present (dense) deployments.

- **Other key aspects**
  - KPI requirements
  - Client and AP capabilities
    - Are modern ≥ 11n capable (how many antennas)? Coexistence with 11a/b/g? Dual band?
  - Propagation phenomena
    - Outdoor/indoor? APs mounted on ceiling, walls or floor?
  - User density
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Analyze requirements
Wi-Fi deployments: requirements

- The first thing is to identify key performance indicators (KPI)
  - Minimum bandwidth required to satisfy supported applications
  - Maximum latency tolerated
  - Expected Min-Avg-Max number of active devices

- Examples (per-user requirements):
  - School
    - **BW**: <3Mbps (video streaming; desktop/file sharing)
    - **Delay tolerance**: low (video streaming; intranet login)
    - **Users**: Min-Avg-Max = up to 30 per classroom
  - Convention center (1500 att.)
    - **BW**: <1 Mbps (web browsing; e-mail)
    - **Delay tolerance**: Medium
    - **Users**: “educated guess”
      - 70% will connect Wi-Fi device
      - 50% simultaneously
      - $1500 \times 0.70 \times 0.5 = 525$
Wi-Fi deployments: #STAs and radios

- Capacity-driven design (rule of thumb)
  - **Example 1** school (<3Mbps x 30 users per classroom):
    - 20 STAs per AP → each classroom served by two radios (two APs or one dual band AP)
      - Assume homogeneous (IT-controlled) 11n 2x2 devices
      - Good signal quality (high rates available) → STAs achieve ~80Mbps of net throughput (isolated)
      - Allow future growth: AP utilization ≤ 75% → 75/(100*3Mbps/80Mbps) = 20 STAs per AP
  - **Example 2** convention center (<1Mbps x 525 users)
    - 32 STAs per AP → 525/32 = 16 – 17 radios
      - Assume heterogeneous (BYOD) devices
      - Diverse signal quality → STAs achieve ~40Mbps of net throughput
      - AP utilization ≤ 80% → 80/(100*1Mbps/40Mbps) = 32 STAs/AP
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Available channels
Wi-Fi deployments: channels (1)

- Capacity limited by the scarcity of available spectrum
  - 2.4GHz ISM band
    - Only three non-overlapping channels (1,6,11)
    - Four (almost) non-overlapping channels (1,5,9,13) \( \to \text{where available} \)
Wi-Fi deployments: channels (2)

- Capacity limited by the scarcity of available spectrum
  - 2.4GHz ISM band
    - Only three non-overlapping channels (1, 6, 11)
    - Four (almost) non-overlapping channels (1, 5, 9, 13) → where available
      - Not available in all regulatory domains (e.g. North Americas)
      - Many devices default to Americas config. → will see coverage gaps in the areas served by APs in Ch13.
    - Highly congested: coexistence with WPANs, cordless phones, baby monitors, microwave ovens...
  - 5GHz ISM band
    - 15-21 non-overlapping channels in different sub bands
    - Highly variable from one regulatory domain to another
      - Some channels only for indoor use, others require DFS
      - Different tx power limits...
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Reuse Factor
Wi-Fi deployments: reuse factor

#Radios Needed

- **Reuse Factor** = \frac{\text{Available Channels}}{	ext{Reuse Factor}}

- If Reuse Factor ≤ 1 → LUCKY YOU!
- Otherwise, each channel is shared among **Reuse Factor** APs → INTERFERENCE!

  - Minimize interference by.
    - Carefully dimensioning cells
    - Smart channel management
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Dimension the cell
Wi-Fi deployments: dimension cells (1)

- What is the cell radius?
  - Max distance at which frames can be decoded
    - $P_t$ is tx power
      - Decreases with MCS (to avoid distortion)
    - $S_r$ is receiver sensitivity
      - Increases with MCS
      - $R_r$ reception range
    
    $$P_r \approx \frac{P_t}{d^\alpha} \rightarrow R_r \approx \left( \frac{P_t}{S_r} \right)^{1/\alpha}$$
    
    - $d$ is the distance tx $\rightarrow$ rx
    - $\alpha$ is the path loss exponent
  
  - Different radius depending on targeted MCS
Wi-Fi deployments: dimension cells (2)

- How to set cell radius for Wi-Fi small cells?
  - Reduce AP’s tx power
    - Reduces interference over other cells
    - Avoids AP/STA power mismatch
    - Reduces suitable rates
Wi-Fi deployments: dimension cells (3)

- How to set cell radius for Wi-Fi small cells?
  - Reduce AP’s tx power
    - Reduces interference over other cells
    - Avoids AP/STA power mismatch
    - Reduces suitable rates
  - Increase min tx rate of the cell
    - Reduces performance anomaly and allows higher average rate
      - Avoid “sticky” STAs
    - Possible unsupported devices
      - Accept, at least, 802.11b@11Mbps?
Wi-Fi deployments: dimension cells (4)

- BUT...interference goes beyond the cell edge
  - Carrier Sense Range \( (R_c) \)
    - Max distance at which frame preamble can be detected and, hence, prevent concurrent transmissions in the same channel.
      - Only 3dB SNR is enough! (>200m outdoors)
      - Behavior improved in IEEE 802.11ax
  - Beyond Carrier Sense Range
    - Transmitted frames are just noise
Wi-Fi deployments: dimension cells (5)

- Coverage strategy for maximal densification
  - Reduce reuse distance
    - **Low gain** directional antennas
  - **AP placement**
    - **Overhead**: AP installed on the ceiling/lamp posts facing down
    - **Side**: AP installed on walls/pillars
    - **Floor**: under floor/under seat (stadiums or auditoriums)
    - Even consider mounting APs behind walls/obstacles and avoid LoS (enriches multipath diversity leveraged by MIMO)
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Finishing touches
Wi-Fi deployments: channel plan (1)

- Dynamic and unpredictable spectrum utilization
  - License-free bands!
- Intelligent channel assignments are required
Automatic and dynamic channel assignments aimed at reducing interference → maximizing performance

- APs gather information of the environment
  - Number of APs detected
  - Power received from neighboring APs
  - Portion of time the channel was reported busy/idle by CCA
Automatic and dynamic channel assignments aimed at reducing interference → maximizing performance

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  - Number of APs detected
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  - Portion of time the channel was reported busy/idle by CCA
- Ideally, client STAs too (and report via IEEE 802.11k)
Automatic and dynamic channel assignments aimed at reducing interference → maximizing performance

- APs (ideally, STAs too) gather information of the environment
  - Number of APs detected
  - Power received from neighboring APs
  - Portion of time the channel was reported busy/idle by CCA

- Distributed approach (autonomous APs)
  - Each AP periodically (and asynchronously) scans the medium and chooses the least congested channel → local optimum
  - Alternatively, APs collaborate (exchange information) to produce better decisions

- Centralized approach (controller-based)
  - APs send periodic reports to a controller
    - Knowing the whole picture and having more resources (i.e. CPU, memory, etc.) controller runs a sophisticated optimization algorithm → global optimum
Wi-Fi deployments: channel plan (5)

- Other considerations
  - Partially overlapping channels
    - Chaotic environments (many rogue/unmanaged APs in random channels): take the most of the spectrum by allowing the whole channel set (not only non-overlapping)
  - Channel bonding
    - 40MHz or 80MHz channels provide higher rates but require more free spectrum → not recommended in dense scenarios
  - Single Channel Architecture (SCA), aka Channel Blanket
    - All APs use the same channel and the same (virtual) BSSID so that all STAs “see” one single AP
      - Seamless handover: controller decides AP delivering DL traffic
      - Larger collision domain (although DL is scheduled by controller)
Wi-Fi deployments: load balancing (1)

- Wi-Fi users are quasi-static and tend to concentrate in space & time → *hot spots*
  - Clients (i.e. traffic) unevenly distributed among APs
    - Some APs (channels) congested and some others underutilized
  - Load Balancing techniques could increase ability to satisfy QoS requirements
    - Load Balancing techniques widely used in cellular networks
    - Take advantage of overlapping areas between neighboring cells
      - Clients can be served by several BSs
      - System decides the best BS for a client depending on BSs’ loads
    - Not directly applicable to Wi-Fi WLANs
      - Clients decide association and roaming, not the network
Load balancing with client-driven association in WLANs

- Typically, client STAs decide best AP based on RSSI measurements (i.e. strongest Beacon or Probe Response Frame)
  - Uneven distribution of users → uneven distribution of load
- Some APs broadcast load information (BSS Load element) and some clients do care about it
- Network-oriented client-driven load balancing
  - Band steering: encourage utilization of the 5GHz band
    - If AP or controller detect a STA sending Probe Requests in the two bands → do not send responses through 2.4GHz radios, only through 5GHz
  - Disassociation/blacklisting
    - Network decides STA’s best AP → the rest of APs ignore that STA requests (if already associated, current AP sends Disassociation frame)
  - Cell Breathing: adapt size of the cell
    - Congested APs reduce tx power of Beacons and Probe Responses → underutilized APs do the opposite
Example of cell breathing

- Reduce power of Beacons and Probe Responses
  - do not reduce power of data frames since this will reduce suitable rates and increase error rate
Example of cell breathing

- Reduce power of Beacons and Probe Responses
  - do not reduce power of data frames since this will reduce suitable rates and increase error rate
Don’t forget the wires!

- Data/power wires to APs
  - If not...multihop or mesh-based wireless distribution system
- Uplink pipe
  - Imagine all this headache for just a DSL WAN connection...
Some references (1)

- **Load balancing**

- **Sensitivity control**
Some references (2)

- Channel management
Course offered at:

Master's degree in Applied Telecommunications and Engineering Management

IoT & Ubiquitous IP