Optimization of Wi-Fi Network Configurations Using Genetic Algorithms for Co-Channel Interference Mitigation

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202412- Introduction to Optimization Processes Using AI Techniques | PPGESE - CTJ

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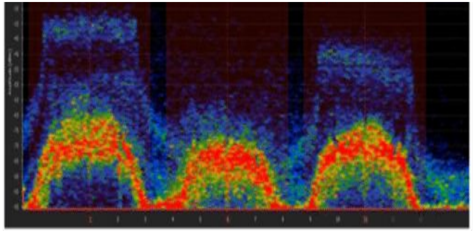
Objectives

1. Present the problem to be solved.
2. Introduce the techniques and tools to be utilized.
3. Describe the problem modeling.
4. Showcase the solutions obtained.
5. Results and parametric analyses.
6. Final conclusion.

The Problem

Co-channel interference is a primary factor affecting data transmission performance in Wi-Fi networks.



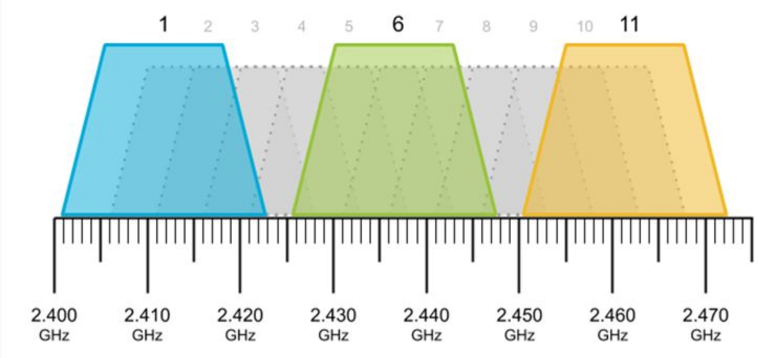
This occurs when two or more Wi-Fi access points (APs) share the same channel.

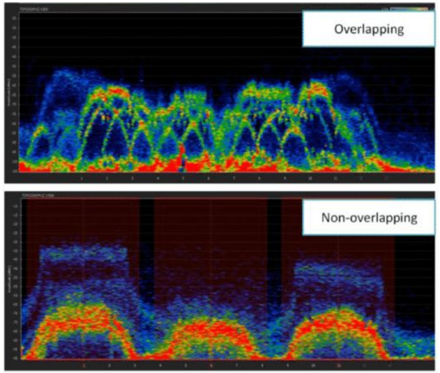
For instance, in residential buildings with multiple apartments using Wi-Fi, interference is inevitable.

The Problem

In the 2.4 GHz band, the Wi-Fi protocol provides 11 channels. However, in practice, only three channels (1, 6, and 11) are recommended to avoid adjacent channel interference, which can destructively affect transmitted data.

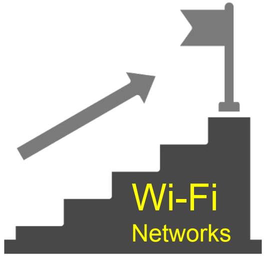
When there are more than three APs, channel sharing becomes necessary, leading to co-channel interference.





The Problem

Goal:



“ Given a set of N access points (APs),
determine the optimal channel configuration (1, 6, or 11)
for each AP to **minimize the average interference**
across the network. “

Problem Modeling

Interference Definition

For a **finite number "N"of APs** within a mutual interference area:

A) **When APs share the same channel**

They impact each other.
The interference at each AP is defined by the RSSI (Received Signal Strength Indicator) values of neighboring APs.

For each AP, the average interference I_{APi} is calculated as:

$$I_{APi} = (RSSI_1 + RSSI_2 + \ldots + RSSI_N) / N$$

Problem Modeling

B) General Interference Representation

In general, the interference of each AP, **according to the configured channel**, can be represented as:

$$I_{APi} = (\sum RSSI_j * C1_{ij}) / N$$

donde **j:** ranges from **1** to **N**

$$Cij \begin{cases} 0 \text{ if } APi \text{ and } APj \text{ are on different channels} \\ 1 \text{ if they are on the same channel.} \end{cases}$$

$RSSI_i = 0$ as an AP cannot interfere with itself.

Problem Modeling

C) Community Interference (I_{com})

For the entire AP community, the average interference value of the AP community is defined as:

$$I_{com} = (I_{AP1} + I_{AP2} + ... + I_{APN}) / N$$

The goal is to find a channel configuration combination such that the value of Icom is minimized.

Optimization Methodology

Solution Approach: Utilize **Genetic Algorithms** (GAs) to find the **optimal channel configuration.**

Key reasons for choosing **GAs** include:

- The combinatorial nature of the problem.
- The efficiency of GAs in exploring large and unstructured search spaces.
- Their ability to avoid local optima by exploring diverse initial configurations.

Tools and Techniques

GitHub WiFiGenetics-poc

For the present work, **two Python codes were developed:**

1 - A **code 1** to **simulate RSSI data** captures from the APs.

2 - A **code 2** to apply the **genetic algorithm** and generate a file with the final AP channel configuration.

```
POP_SIZE = 100
MAX_GENERATIONS = 1000
STAGNATION_LIMIT = 200
MUTATION_RATE = 0.02
ELITISM = 1
CHANNELS = [1, 6, 11]
```

- The code calculates **Icom** (the average community interference) in the **worst-case scenario**, where **all APs** are using the **same channel** (6).
- This serves as **a baseline to compare** with the **Icom** obtained **after optimization with AG.**

OUTPUT OF CODE 1

rssi_matrix.csv

CODE 1

Criar_arquivo_RSSI-10APs.py

CODE 2

Otimizacao_WiFi_com_AG_v2.py

OUTPUT OF CODE 2 - FILE

APs_Canais_Configuração.csv

OUTPUT OF CODE 2 - DISPLAY

```
Icom with all APs on channel 6: 0.6228437355829444
Stagnation Reached: Optimization stopped at generation: 366
Best Solution Found: [11, 6, 6, 6, 1, 1, 11, 11, 1, 6]
Icom Minimum Achieved:: 0.1415246720938096
A file APs_Canais_Configuracao.csv was created with the final
configuration.
```

For the analysis, a community of 10 APs was considered, hence **N=10**. The developed codes allow calculations for other values of N.

Application of Genetic Algorithms

A. Solution Encoding (Chromosome Representation)

- Each solution (individual) in the population is represented as a vector of length N.
- Where N is the number of APs.
- Each gene in the chromosome corresponds to an AP, and the gene's value represents the channel assigned (1, 6, or 11).

  For example, for N=5, a solution could be: [1, 6, 11, 6, 1]

B. Initial Population

- A random initial population of P individuals is generated. (For example, P=100 indivíduals).

- Each individual representing a random channel configuration.

Application of Genetic Algorithms

C. Fitness Function (Evaluation)

- For each individual (chromosome), calculate Icom:
  - For each APi, identify APs sharing the same channel.
  - Sum their RSSI values and divide by N to compute IAPi.
  - Calculate the average of all IAPi values to obtain Icom.

$$\mathrm{fitness}(individuo) = \frac{1}{I_{com}(individuo)}$$

- The fitness is the inverse of Icom (higher fitness = lower interference).
- I_{com} directly quantifies co-channel interference across a community of N APs. By minimizing I_{com}, higher fitness values are achieved, representing channel configurations with reduced interference and better overall network performance.

Application of Genetic Algorithms

D.Genetic Operators

D.1 Parents Selection: Individuals are selected for reproduction using methods such as:

- Roulette Wheel Selection
- Crossover (Genetic Operators): Two individuals (parents) combine to produce offspring.
- A one-point crossover is used: the chromosome is split at one point, and genes are recombined.

Example:

Parent A: [1, 6, 11, 6, 1]
Parent B: [11, 6, $\underbrace{1}_{\text{Gene 3}}$, 11, 6]

One-point crossover (split at gene 3):

Child 1: [1, 6, (from B) 1, 11, 6]
Child 2: [11, 6, (from A) 11, 6, 1]

Application of Genetic Algorithms

D2. Mutation

- Mutation is applied to maintain diversity in the population and prevent premature convergence.
- With a low probability (e.g., 1%), a gene in the chromosome is mutated.
- The mutation may consist of changing the channel assigned to an AP to another different channel.
- Example: If the gene value is "6," it can be randomly altered to "1" or "11."

D3. Elitism (Replacement)

- After generating the new population from the current one, elitism is applied.
- Elitism consists of retaining one or more of the best individuals from the previous generation to ensure that the quality does not deteriorate across generations.
- One individual is retained.

E Stopping Criteria

The stopping criteria include either reaching 1000 iterations or observing no significant improvement over 200 generations.

Results and Parametric Analyses

In all executions of the code, the comparison consistently yielded a lower value:

I_{com} Optimized = 0.141524 vs. I_{com} with all APs on channel 6 = 0.622843…

OUTPUT OF CODE 2 - DISPLAY

```
Icom with all APs on channel 6: 0.6228437355829444
Stagnation Reached: Optimization stopped at generation: 366
Best Solution Found:: [11, 6, 6, 6, 1, 1, 11, 11, 1, 6]
Minimum Icom Achieved: 0.1415246720938096
A file APs_Canais_Configuracao.csv was created with the final configuration.
```

- **After several executions, the result remained unchanged.**
- **Indicates a high probability of convergence to the global optimum.**
- **A detailed analysis is recommended for further confirmation.**

Results and Parametric Analyses

Analysis Case:

Without modifying the RSSI measurements of the APs.
Only adjusting the parameters.

Conclusion

Larger population sizes and mutation rates improved exploration but required more generations.

Smaller population sizes converged faster but risked suboptimal solution

POP_SIZE = 100
MAX_GENERATIONS = 1000
STAGNATION_LIMIT * = 200
MUTATION_RATE = 0.02

[11, 6, 6, 6, 1, 1, 11, 11, 1, 6]
Finished at Generation = 366
Icom = 0.1415246720938096

A: Case: Increasing Parameters

POP_SIZE = 1000
MAX_GENERATIONS = 10000
STAGNATION_LIMIT = 2000
MUTATION_RATE = 0.05

[11, 1, 1, 1, 6, 6, 11, 11, 6, 1] ← Change
Finished at Generation = 2011
Icom = 0.1415246720938096 ← No Change

B: Case: Decreasing Parameters

POP_SIZE = 10
MAX_GENERATIONS = 100
STAGNATION_LIMIT = 20
MUTATION_RATE = 0.01

[6, 6, 6, 1, 11, 1, 11, 11, 1, 6] ← Change
Finished at Generation = 30
Icom = 0.1450859700168667 ← Worsened

**Generations Without Improvement*

Results and Parametric Analyses

Analysis Case:

Modifying the RSSI measurements of the APs while keeping the parameter values unchanged.

POP_SIZE = 100
MAX_GENERATIONS = 1000
STAGNATION_LIMIT = 200
MUTATION_RATE = 0.02

Results:

With different RSSI inputs, a combination is always found that reduces the interference within the AP community.

A

Icom with all APs on channel 6 :**0.6147880783328228**
[1, 1, 11, 11, 11, 6, 6, 1, 6, 6]
Finished at Generation = 202
Icom = 0.140213132170341

B

Icom with all APs on channel 6: **0.631830973993903**
[1, 11, 6, 11, 1, 6, 1, 11, 6, 6]
Finished at Generation = 209
Icom = 0.14782913060766906

C

Icom with all APs on channel 6 :**0.5949152827056094**
[1, 6, 11, 1, 11, 6, 6, 1, 1, 11]
Finished at Generation = 213
Icom = 0.12801122157911723

Results and Parametric Analyses

Validation: Genetic Algorithm vs. Brute Force

To confirm the global optimum

Brute Force Algorithm: To address doubts about obtaining the global optimum, a brute force algorithm was added to the code for calculating and generating channel configurations.

- Results matched the genetic algorithm's output, verifying its effectiveness.
- Note: The channel configuration is different, possibly due to symmetry issues.

```
Icom com todos os APs no canal 6: 0.6060524313335425

Algoritmo genético:
Estagnação alcançada. Terminando na geração: 203
Melhor solução encontrada: [11, 6, 1, 1, 6, 11, 6, 1, 11, 1]
Icom mínimo alcançado: 0.13570233092722067

Forca Bruta:
Configuración óptima por fuerza bruta: (1, 6, 11, 11, 6, 1, 6, 11, 1, 11)
Icom óptimo por fuerza bruta: 0.13570233092722067
```

Results and Parametric Analyses

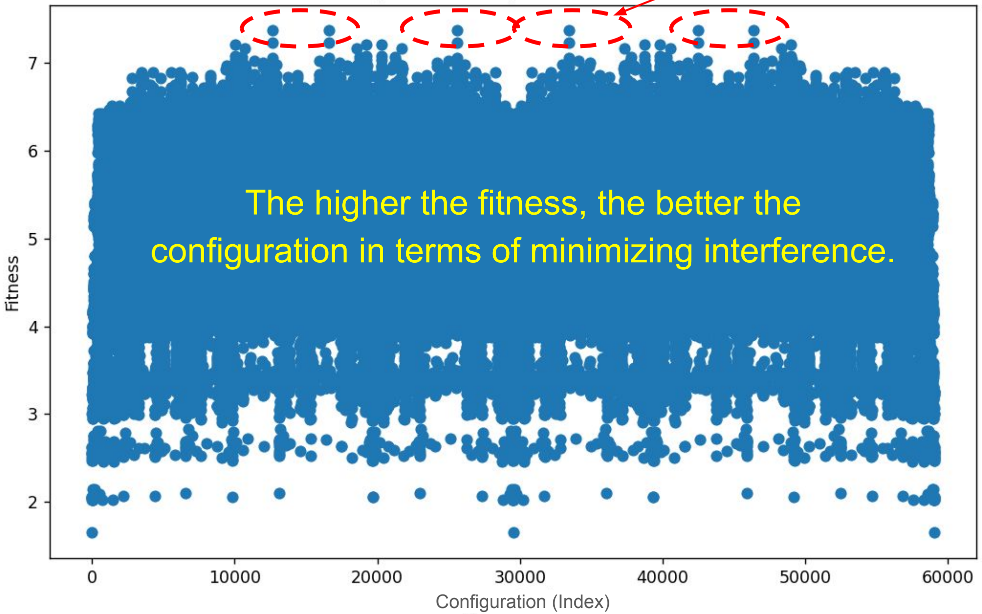
Exploration of the Search Space: Fitness vs. Channel Configurations

The graph confirms that the **search space contains multiple suboptimal configurations** but also shows identifiable optimal configurations with high fitness values.

This reinforces the **effectiveness of the genetic algorithm**, which **focuses** on exploring this space **to find the highest-quality configurations** without the need to evaluate each point exhaustively (brute force).

The highest points in the graph represent configurations that minimize interference (global or local optimal).

Figure : Fitness Search Space -Illustrates the distribution of fitness values across configurations



Each point on the X-axis corresponds to a specific combination of channels assigned to the APs.

Conclusions and Future Directions

General Conclusions

- The use of genetic algorithms proved effective in optimizing channel allocations in Wi-Fi networks, reducing co-channel interference without relying on brute force, which is computationally infeasible for large networks.
- The methodology efficiently explores the solution space, using RSSI measurements to identify channel configurations that minimize global interference.

Proposed Future Direction

- Incorporate additional parameters such as adjacent channel interference, connected devices, and Quality of Service (QoS).
- Explore the integration of neural networks to predict optimal configurations, reducing reliance on iterative optimization.
- Evaluate real-world implementation feasibility, focusing on processing time constraints for large-scale deployments.

Thank you!
Muito Obrigado!
Muchas Gracias!