Lagrangian-Relaxation-Based Self-Repairing Mechanism for Wi-Fi Networks

Optimization Algorithms and Techniques (CS-357)
Project Proposal

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Introduction

Wi-Fi networks have become essential for seamless data transmission and connectivity in today's rapidly evolving communication landscape. They serve as the backbone for various applications and devices, enabling work, entertainment, and communication. However, despite technological advancements, Wi-Fi networks face challenges that can impact their effectiveness.

In Wi-Fi networks, two main problems are:

- When Wi-Fi stops working (Access Point failures)
- When signals get mixed up (interference) because of other devices.

Access Point (AP) failures come from hardware or setup issues, leading to weak or no Wi-Fi in some places. Interference is when other Wi-Fi or gadgets confuse signals, making Wi-Fi slow and things delayed.

In Wi-Fi networks, achieving optimal load distribution among Access Points (APs) is essential for maintaining network efficiency and user experience. This is a big deal, especially in places like hospitals or businesses where good Wi-Fi is crucial. So, finding solutions to these issues is important for dependable Wi-Fi.

Objective

The objective of this research paper is to develop a Lagrangian-Relaxation-Based Self-Repairing Mechanism for Wi-Fi Networks.

The key goals include:

1. Modeling the self-repairing problem using linear and nonlinear integer programming.
2. Proposing a Lagrangian-Relaxation-based algorithm to bridge the gap between upper and lower bounds of delay differences.

3. Demonstrating the effectiveness of the proposed Multiple-level load-balancing traffic adjustment (MLTA) algorithm through experimental cases.

The primary focus is on enhancing overall network performance by mitigating the impact of AP failures and interference, thus maintaining a high quality of service for users.

Problem Formulation

The objective function aims to maximize the minimal delay difference, defined as the tolerable delay minus the transmission delay. This captures the essence of service quality and fairness among served MDs.

$$\max \min_{v \in V_{MD}} (T_v - d_v)$$

where, T_v = Tolerable Delay,

d_v = Transmission Delay,

V_{MD} = Set of all mobile devices in the network,

v = A specific mobile device(MD) that is part of the network

The formulation involves various constraints to ensure optimal network performance:

1. **Channel Assignment**: APs are assigned binary variables to indicate their operational status. An AP must be assigned a channel when switched on, ensuring that each AP is assigned only one channel.

$$\alpha_u \leq \sum_{h \in H} n_{hu}, \quad \forall u \in V_{AP}$$

$$\sum_{h \in H} n_{hu} \leq \alpha_u, \quad \forall u \in V_{AP}$$

Here,

$\propto_u$= binary decision variable to determine whether an AP is switched on or not.

n_{hu} = binary decision variable for channel h

2. **SINR Threshold**: Signal-to-Interference-plus-Noise Ratio (SINR) thresholds are used to determine AP and MD associations. MDs within the SINR range of an AP are considered associated.

$$\frac{\beta_{uv}}{\kappa_{th}} \geq \eta_{uv}, \quad \forall u \in V_{AP},\ v \in V_{MD}$$
$$\frac{\beta_{uv} - \kappa_{th}}{M_1} \leq \eta_{uv}, \quad \forall u \in V_{AP},\ v \in V_{MD}$$

Where,

k_{th} = signal threshold

η_{uv} = Decision variable, used to indicate whether the MD v is in the service area of the AP

β_{uv} = SINR value

u = Access Point (AP) within the network

V_{AP} = wireless service areas that are covered by a set of APs

3. **Cell Breathing**: APs' transmission power ranges are constrained within minimum and maximum values.

$$\alpha_u p_{\min} \leq p_u$$
$$p_u \leq \alpha_u p_{\max}$$
$$0 \leq p_u \leq p_{\max}$$

Where,

$\boldsymbol{p}_u$ = transmission power range of the AP u in the range ($\boldsymbol{p}_{min}$, $\boldsymbol{p}_{max}$)

$\boldsymbol{p}_{min}$ = minimum power range

$\boldsymbol{p}_{\max}$ = maximum power range

4. **Association Management**: MDs are associated with APs, subject to constraints to ensure proper connection management.

$$\delta_{uv} \leq \eta_{uv}, \quad \forall u \in V_{AP},\ v \in V_{MD}$$
$$\sum_{u \in V_{AP}} \delta_{uv} \leq 1, \quad \forall v \in V_{MD}$$

$$\delta_{uv} \leq \alpha_{uv}, \quad \forall u \in V_{AP},\ v \in V_{MD}$$
$$\alpha_u \leq \sum_{v \in V_{MD}} \delta_{uv}, \quad \forall u \in V_{AP}$$

Where,

δ_{uv} = Binary decision variable

5. **Capacity**: The capacity of an MD's connection is calculated based on SINR values and mapped to available channels.

$$\beta_{uv} = SINR(p_u, dis_{uv}, p_{u'}, dis_{u'v'}) = \frac{p_u / (dis_{uv})^2}{\sum_{u' \in V_{AP}} p_{u'} / (dis_{u'v'})^2},$$
$$\forall v \in V_{MD}, \quad u \in V_{AP},\ u' \in V_{AP},$$
$$v' \in V_{MD}, \quad u \neq u',\ v \neq v' \quad (13)$$

$$c_v = f(\beta_{uv}), \quad \forall v \in V_{MD},\ u \in V_{AP}$$
$$0 \leq c_v, \quad \forall v \in V_{MD}$$

Where,

c_v = Capacity

dis_{uv} = Distance between u and v

$f(\beta_{uv})$ = stepped function that maps the SINR value to the capacity

6. **Delay**: The delay is the combination of transmission time and queuing time. It is calculated based on traffic requirements, data capacity, and other factors.

$$\left(\frac{\gamma_v}{c_v} + \omega\right) - (1 - \delta_{uv}) N_1 \le d_{uv}, \quad \forall v \in V_{MD},\ u \in V_{AP} \tag{16}$$

$$0 \le d_{uv} \le T_v, \quad \forall v \in V_{MD},\ \forall u \in V_{AP} \tag{17}$$

$$\sum_{k \in V_{MD}} d_{uk} - (1 - \delta_{uv}) N_2 \le d_v, \quad \forall u \in V_{AP},\ v \in V_{MD}$$

$$t_v \le d_v \le T_v, \quad \forall u \in V_{AP},\ v \in V_{MD}$$

Where,

γ_v = data traffic requirements of MD v

ω = Queuing time

t_v = Propagation time

Algorithms

1. Lagrangian relaxation
2. Multiple-level load-balancing traffic adjustment (MLTA) algorithm
3. Minimum Delay Neighboring AP (MDNA) algorithm

Further Scope

Our primary goal is optimizing Wi-Fi networks using Lagrangian Relaxation. As an expanded scope, we will include "Multiple-level load-balancing traffic adjustment", intelligently distributing network traffic among different Access Points. This helps prevent congestion and makes the best use of the network's resources. The goal is to have a well-balanced and efficient distribution of network traffic all over the Wi-Fi network.

Our next goal is to explore how self-repairing can work with both wifi and 5G mobile networks.

References

Lagrangian-Relaxation-Based Self-Repairing Mechanism for Wi-Fi Networks Ming-Chi Tsai; Frank Yeong-Sung Lin; Yean-Fu Wen

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