Priority-Aware Genetic Algorithm for Multi-Constraint Dynamic Spectrum Allocation in Logistic Centers

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Abstract: With the growing technology in the field of IoT (Internet of Things), the study aims to improve the technology related to spectrum and channel allocation. Dynamic spectrum allocation is pivotal and useful in logistics centers, where the IoT device provides real-time tracking, monitoring, and data exchange. This study presents various models and algorithms that are implemented in MATLAB for dynamic spectrum allocation tailored to logistic environments, addressing challenges to spectrum allocation. The proposed solution to the problem improves the bandwidth and channel allocation and reduces conflicts between different IoT devices. The results demonstrate the efficiency of the proposed models, which paves the way for improvement in advanced spectrum management in IoT-based logistics.

1 INTRODUCTION

In the growing world of technology, the Internet of Things (IoT) has revolutionized industries worldwide, including logistics, where data exchange in real time is crucial for efficient operations. IoT devices deployed in logistics centers are used for communication between the inventory management system, device tracking, and other operational equipment. But with increasing number of these IoT devices, the conflicts between them also increase, which demands more spectrum allocation. This poses a challenge to ensuring communication between all IoT devices and optimal resource allocation in logistic networks.

This study aims to abolish this complication by modeling various models for the optimal bandwidth allocation. Usage of genetic algorithms can be effectively applied to various such problems, including the 0/1 knapsack problem. This problem, which is solved in exponential time, can also be done in linear time using genetic algorithms. The analysis later on of various crossover functions and mutation operations throws more light on the enhanced way of allocating our IoT devices (Ramana, Shilpa, et al. 2023). Another study also highlights the optimization in applications of the genetic algorithms. The study solves the 0/1 knapsack problem using a multi-objective algorithm. This highlights the effectiveness of genetic algorithms (Ramana, Shilpa, et al. 2023). Another study also illustrates the evolution of help desk systems and the integration of advanced techniques like genetic algorithms. The literature also points out the limitations of genetic algorithms and how to deal with them (Lekshmy, Anusree, et al. 2018).

Resource allocation is also a critical aspect of network management, particularly in environments such as a logistic center. It involves the efficient distribution of resources, i.e., bandwidth, here to respected IoT devices to ensure reliable and efficient communication. A similar study emphasizes the usage of bipartite graph matching techniques to enhance the system capacity in device-to-device communication. Two primary algorithms have been discussed: the Hopcroft-Karp (HK) algorithm and the Kuhn-Munkres (KM) algorithm. The study also identifies challenges such as deep fading and outage conditions affecting the 10-15% of overall resource (Vaishnav and Panda, 2017). These IoT devices can also be

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RFID (Radio Frequency Identification); similarly, in a study, supply chain management using RFID tags was discussed. The study provides an overview of SCM, discussing the main factors that govern the product cycle (Ravi, 2010). This article aims to study the chromatic polynomial of some families of graphs and to describe the properties of the chromatic polynomial of some graph operations (Sony and Manjusha, 2023). Our study aims to work on the limitations of all the above literature and to build an optimized model for bandwidth allocation.

2 EXISTING SYSTEMS

Dynamic allocation of spectrum being an emerging topic in the networking phase, there is minute implementation of these models in real time. A study proposed a working real-life model that is based on the idea of WSN's (wireless sensor networks). WSN's are distributed networks with flexible wireless communication. The limitation of this research is that the limited spectrum of resources poses challenges for WSN development. With an increase in the resources, the more the chances of collision of bandwidth between two devices (Xiaomo, Cai, et al. 2022).

3 RELATED WORKS

The authors propose a novel channel allocation algorithm designed to maximize both frequency and time continuity in spectrum sharing between mobile network operators (MNOs) and incumbent radio systems. Unlike traditional methods that only focus on meeting MNO demand, this approach considers continuity across time and frequency to boost spectrum efficiency by up to 6 percent and channel continuity by 23 percent (Ikami, Hayashi et al. 2020). The authors present an advanced dynamic spectrum allocation algorithm that uses multiple fairness indicators to allocate spectrum equitably among mobile network operators (MNOs) sharing resources with incumbents. This approach improves fairness by 16 percent and satisfaction by 44 percent, addressing the limitations of previous single-indicator models (Ikami, Hayashi et al. 2020). The authors of this paper address spectrum sharing issues among multiple network operators. It proposes a spectrum allocation algorithm incorporating priority-based sharing and negotiation to dynamically manage spectrum resources. Key innovations include using a Spectrum Sharing Metric (SSM) to account for class service priorities, urgent bandwidth requests, and long-term spectrum occupation ratios among operators (Kim, Lee et al. 2005). This research develops a game-theoretic model for dynamic spectrum allocation, allowing secondary users (SUs) to adjust spectrum requests based on primary user (PU) pricing and SU competition. The model achieves faster convergence to Nash equilibrium and offers improved allocation stability, simulating real-world competitive conditions among SU's (Zhao, Liu et al. 2018). The authors identify the key factors affecting inventory management in Thailand's construction industry using exploratory factor analysis (EFA). Four main factors were extracted: performance, cost, strategy, and inventory policy, with a total of 15 associated items. The findings aim to provide insights for Thai construction companies on improving inventory-related financial performance and project cost management (Jakkraphobyothin, Srifa, et al. 2018). This research describes how 5G base stations provide multiple services in various scenarios, which provides the authors an opportunity to enhance spectrum efficiency. Base stations can flexibly utilize the idle frequency band for spatiotemporal low-demand services and guarantee services with high priority. We use the Lyapunov optimization method to solve the problem (Zhang, He, et al. 2020). This research study presents a review on signal processing techniques used for performing spectrum detection in CR networks Cognitive Radio helps to allocate the available radio frequency spectrum of an essential client and an auxiliary client. In the cognitive radio technology also known as Dynamic Spectrum Access (DSA), secondary clients may take advantage of the numerous spectrum gaps in allowed spectrum groups (Poonguzhali, Rekha, et al. 2023). The authors explore game theory models and graph-coloring models, which can improve spectrum efficiency and solve the deficiency of spectrum resources (Yan, Song, et al. 2009). Game theory-based cognitive radio dynamic spectrum allocation is one of the hot researches of the field of cognitive radio. Taking into account the differences in the spectrum, using a Cournot game model, and adding the spectral similarity matrix to the original pricing function, a new utility function that makes the spectrum allocation more close to the actual network (Zhang, He, et al. 2020).

4 METHODOLOGY

Fig. 1 explains how the workflow of the code goes. First, initialize the specific IoT devices, channels, and time slots. Next, initialize the population of random channel allocation. Calculate the penalties for interference and priority mismatch. Select top solutions

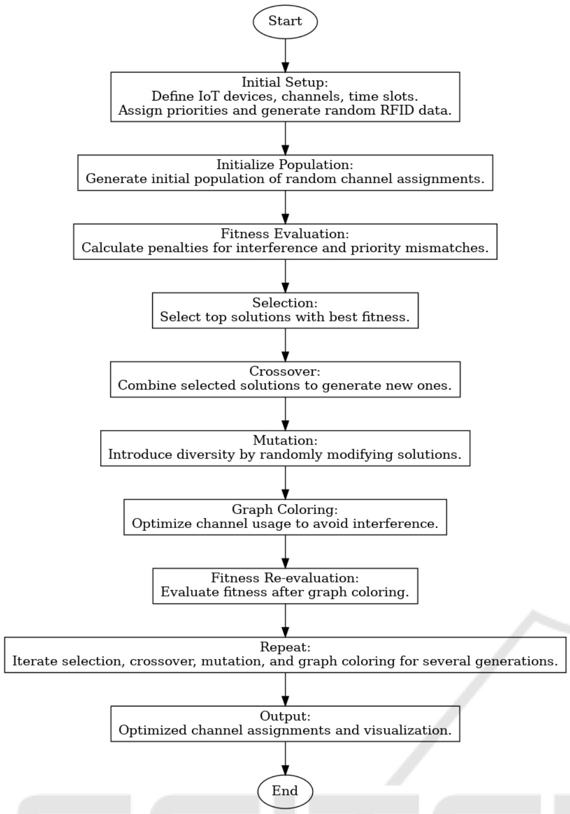

Figure 1: Workflow Diagram

with the best fitness, combine the solutions to generate new ones, and introduce diversity by modifying solutions. Optimize channel usage to avoid interference. We then evaluate fitness after graph coloring. We repeat the above steps until the output is achieved. The priority-based approach in the dynamic spectrum allocation helps in ensuring optimal channel usage for efficient bandwidth utilization and reliable data transmission to the cloud. The initial attempt at understanding how this spectrum allocation is done can be simulated using the help of MATLAB Simulink. The authorized devices in the context of the IoT devices dealing with the RFID scanners would be those devices that deal with the

- **Dock Door RFID scanners**: Track items during loading and unloading.
- **Conveyor belt RFID scanner**s: Scan items on the conveyor for automated sorting.
- **Handheld RFID scanners (critical areas)**: used to check high-value or time-sensitive shipments.
- **Checkpoint RFID scanners**: Monitor movement of priority goods like fragile or perishable items.

These devices hold a great significance in the delivery and smooth functioning of the process conducted at the logistic centers. Hence, these devices have the channel allocated to them at the first. A signal strength threshold of greater than 0.7 ensures that only these critical devices get the spectrum and have uninterrupted communication.
However, there are also unauthorized devices and low-priority devices that handle less important data. In relation to the designated area, these devices could be

- **Backup Dock Door Scanners**: Used for redundancy or in low-traffic areas.
- **Inventory Shelf RFID Scanners**: Periodically scans shelves to ensure stock is correctly placed.
- **Secondary Checkpoint RFID Scanners**: Used to validate movement of non-priority goods within the facility.

Although the devices that take care of these also help in the logistic center's orderly operation, they are not crucial during situations. Although this data may contribute to the center's greater functionality, it is only somewhat significant. Only when the primary users or authorized devices are served are these devices assigned to a channel for communication. It is also possible to use the idea of spectrum holes to facilitate data sharing for secondary users. In order to accommodate non-critical devices and maintain optimal channel use, a lower threshold of 0.3 or less is used.
The output of the following methodology is a binary vector, indicating whether each device is allocated a channel. But nonetheless, the output shows an equal share of the channel to all the devices while maintaining priority for critical devices.
Fig. 2 explains how the channel is allocated to the

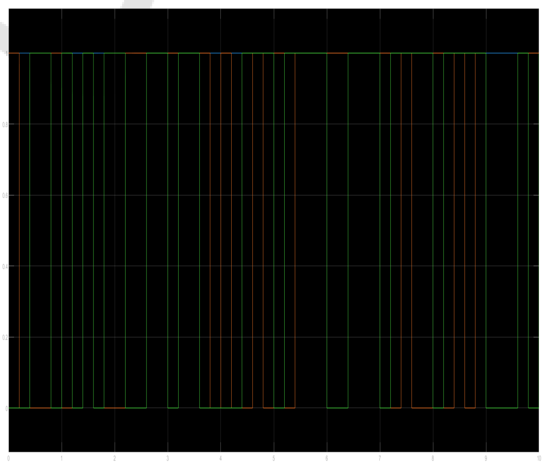

Figure 2: The graph of allocation

devices based on the priority levels.
The graph here displays the dynamic spectrum allocation for IoT devices with different priority levels. Time or device IDs are displayed continuously on the

X-axis, while the spectrum allocation status is shown on the Y-axis. Devices with different priorities are represented by different colored lines on the graph; high-priority devices are shown as green, low-priority devices are shown as orange or red, and secondary or waiting-for-allocation devices are shown as blue. The splitting of spectrum resources among devices according to their priority levels is shown in the allocation pattern. While low-priority devices only receive spectrum when resources are available or on an as-needed basis, high-priority devices receive spectrum more regularly or continuously.

While secondary devices are given spectrum according to availability, this priority-based method guarantees those devices essential to fast operations and correct shipments receive bandwidth first.

The previous methods must have introduced the concepts of how the primary users are preferred and their data to be sent is vital. But these assign the channels based on some round-robin fashion where devices are given the channels one by one in a repeating order based on their priority. This method is simple and straightforward and ensures that all devices get a chance to use the channels, but this doesn't handle the conditions of interference between the channels. For example, two devices assigned to the same channel at the same time can cause interference, which lowers performance.

This problem is more critical in logistic centers, where devices need to communicate over a limited number of channels. The devices with high priority need reliable and hassle-free channels for data transmission, while the secondary devices should still be assigned channels that don't disrupt the high-priority ones.

To solve these issues, we use a more advanced method, a genetic algorithm (GA) combined with a graph coloring model. The GA helps us optimize to the best channel assignments by evolving solutions over time. The graph coloring model ensures that devices that might interfere with each other are not assigned the same channel. This combined approach also provides better performance as it considers both device priority and the need to minimize interference.

The genetic algorithm is a search heuristic inspired by the method of natural selection, where the best traits are passed on to future generations. It is a method used to find approximate solutions for optimization and search problems. It works by imitating how natural evolution happens. The algorithm runs over a population of possible solutions, applying selection, crossover, and mutation to evolve solutions toward better ones. Fig. 3 displays the ideal genetic algorithm flowchart and illustrates the iterative process of evolving solutions through selection, crossover, and mutation to optimize complex problems.

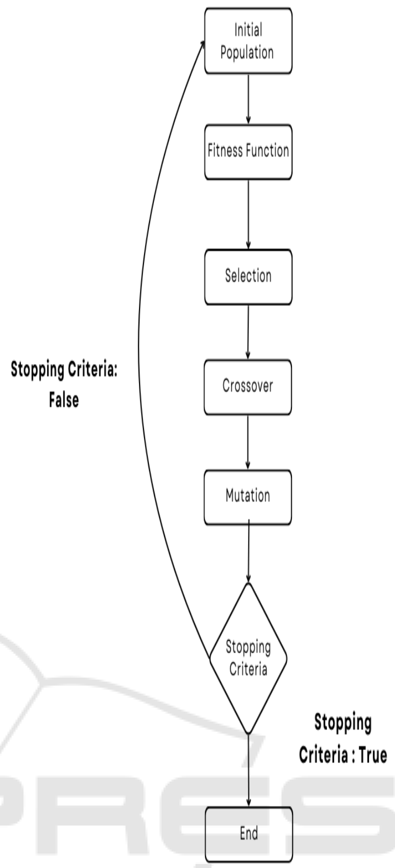

Figure 3: Flowchart of a Genetic Algorithm

- **Population Initialization**: Random channel assignments are created for all IoT devices, where each channel assignment represents a possible solution
- **Fitness Function**: This is used to evaluate how good each solution is by calculating the interference between devices. Devices assigned to the same channel at the same time step cause interference, which is penalized in the fitness function. The function also ensures that high-priority devices are given better channel assignments.
- **Selection**: The best solutions, based on the least interference and highest priority, are chosen for the next generation
- **Crossover and Mutation**: New solutions are created by combining parts of selected solutions (crossover) and introducing random changes (mutation). This keeps the population diverse and prevents the algorithm from getting stuck in suboptimal solutions.

To further reduce interference and optimize channel assignment, a graph coloring model is integrated into the genetic algorithm. This model ensures that devices likely to cause interference are not assigned to the same channel. Using graph coloring as a pre-optimization step reduces the likelihood of starting with high-penalty solutions.

- **Graph Representation**: Each IoT device is represented as a node. An edge is drawn between the two nodes if they could interfere with each other.
- **Graph Coloring**: A unique color is assigned to each device so that no two devices that interfere share the same channel. This helps reduce interference, especially for high-priority devices.
- **Integration with GA**: The graph coloring model is used for each generation before evaluating the fitness function. It ensures that devices with possible conflicts are allocated distinct channels.

It can be highlighted that the genetic algorithms might be able to offer a novel approach for dynamic spectrum allocation within the logistic centers. This variant of genetic algorithms uses priority-based optimization, ensuring critical devices are assigned optimal channels with minimum interference. A fitness function that focuses on interference reduction is emphasized to support efficient spectrum usage in resource-constrained IoT settings. Genetic algorithms are potential candidates to be applied to large logistic centers with thousands of simultaneously operating devices.
In fact, the integration of graph coloring into the framework of the genetic algorithm is a ground-breaking hybrid strategy. It derives all the benefits from the adaptive exploration by genetic algorithms combined with organized conflict resolution through graph coloring. It actually enhances the overall efficiency of spectrum allocation with this minimum interference and observation of priority of various devices.

To summarize what has been discussed so far, the first approach to allocating channels to devices was based on the devices' priorities and significance in the logistics environment. Then it was discovered that the method of assigning channels to higher priority devices first and then lower priority devices was very similar to round-robin. This method could not handle the situation of interference, which occurs when two devices compete for a single channel to send data. As a result, a newer algorithm, known as the genetic algorithm, was developed with some modifications in order to handle the interference situation smoothly while providing the least-interference combination and a low penalty score situation. The above technique is combined with a graph-coloring model, in which no two devices are assigned to the same channel. The optimized channel assignment is the result of multiple checks and runs of the genetic algorithm, and the graphs displayed in the results section represent the best channel assignment for that specific scenario.

5 RESULTS AND OUTPUT

The genetic algorithm optimizes channel assignments for devices, reducing interference by prioritizing high-priority devices for the best channels and assigning remaining channels to lower-priority devices to minimize conflicts. Interference is measured by penalties added when devices share the same channel at the same time, with high-priority devices receiving less penalty. An interference graph identifies potential conflicts between devices, and graph coloring ensures connected devices use different channels, improving efficiency and reducing interference.
We take in a hypothetical scenario of having 25 IoT devices with a total of 10 channels present, and they compete for the spectrums based on their priorities over a time step of 20 units of duration.
Fig. 4 depicts the scenario of interference among devices and allocates channels based on priority levels.

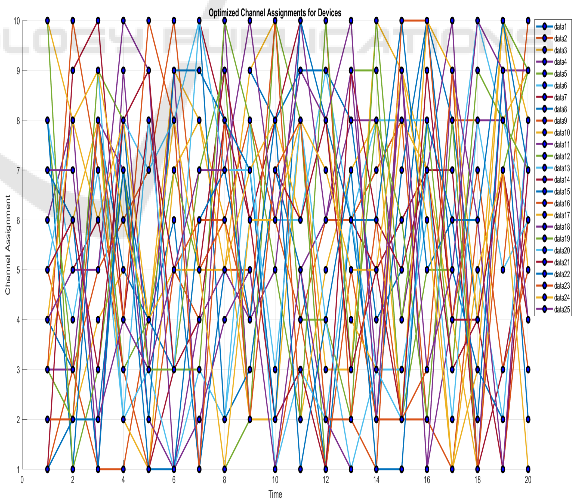

Figure 4: Interference Graph

The graph displayed gives an idea of how channels are allocated to devices over time. The x-axis represents the time steps, whereas the y-axis indicates the channel numbers assigned to them. We move forward with the assumption that a channel is allocated to one device for performance reasons. Each line corresponds to a specific device, and the points along the lines show the channel assigned to that device at a given step. The different patterns of the lines show dynamic channel allocation, ensuring devices use different channels over time to minimize interference and optimize spectrum usage. Fig. 5 depicts the inter-

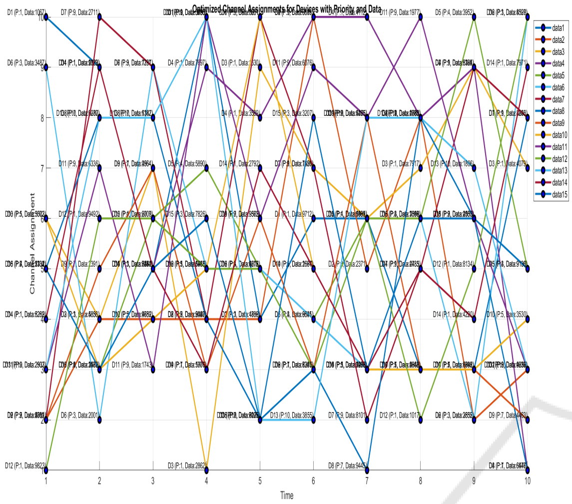

Figure 5: Interference graph with data

ference scenario among devices and shows their priorities and the data they carry.
The graph above depicts the scenario of having 10 channels and 15 devices over a 10-unit time period. Each device's priority and RFID tag data are displayed, and if there is interference, the devices are assigned different channels based on their priorities and fitness score evaluation.
The graph depicts the best-case scenario of low interference and a lower penalty score among all combinations of assigning 15 devices to 10 channels in a time frame of 10 units. This could be achieved through optimal channel assignments and the evolution of solutions over time.

Realistic application of the proposed Genetic Algorithm (GA) with Graph Coloring can be implemented by developing an IoT central controller. Several IoT devices, for instance, sensors and communication nodes, are connected to a central server to develop an interference graph in a conflict discovery process. The GA assigns channel priority to critical devices and reduces channel interference, while graph coloring makes sure that two interference devices will not be assigned the same channel. These optimal channel allocations are therefore transmitted to the devices through wireless communications. A performance monitoring system is implemented, and the algorithm can dynamically adjust the channel if devices are added or change the interference pattern to guarantee effective and stable communications.

6 CONCLUSION AND FUTURE SCOPE

This study presents us with a MATLAB-based framework for dynamic spectrum allocation to meet the demands of logistic centers. Our study addressed many challenges, such as spectrum scarcity, resource allocation, bandwidth allocation, and reliable communication between IoT devices. The integration of algorithms like Round Robin, priority-based algorithms, Genetic Algorithms with graph coloring ensures all the challenges are tackled, even in high-density IoT environments. This work highlights the importance of dynamic and adaptive spectrum management techniques in overcoming the limitations of existing systems.
Future scope of the study would be

- Increasing the scale of the IoT devices, extending our framework to accommodate a large number of IoT devices.
- Incorporating machine learning techniques and algorithms to predict the spectrum usage patterns.
- Utilizing energy-harvesting techniques to support sustainable IoT devices.
- Integrating the spectrum with security systems to safeguard against unauthorized access and interference in logistic networks.

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