Rapid Optimisation For Frequency Deconfliction

1. Introduction

Radio networks require careful frequency planning to ensure that assets can operate together without mutual interference. This planning typically involves assigning the appropriate frequencies to the various assets in a way that do not cause mutual interference. The problem of allocating frequencies to the assets is called the frequency assignment problem (FAP) which can be difficult to solve in the instance when there are many assets and only limited number of frequency available to assign.

This white paper explores using constraint programming (CP) to tackle the frequency assignment problem. Constraint programming is a framework to solve combinatorial problems which declares constraints on the feasible solutions for a set of decision variables. The FAP is the problem of assigning a limited number of frequencies to a given number of sites in such a way that the sites do not interfere with each other. Constraint programming is just one of the many possible techniques that can be used to solve the FAP and it is a technique that Nova has used to successfully frequency plan major radio networks.

2. Overview

The problem starts off with a number of fixed base stations in various geographic locations, and the stations are required to provide communication service to their respective service region. In order to provide a communication service a frequency is assigned to each base station in such a way that minimises interference with their adjacent base stations. Finding an acceptable frequency to base station assignment is called the frequency assignment problem (FAP).

When there is only a small number of frequencies to be assigned to a relatively large number of base stations then the FAP may be difficult to solve or even intractable. Nova has developed an efficient process to tackle the frequency assignment problem and has successfully used it to perform large scale frequency planning.

The high level process is summarised in the flow chart in Figure 1.

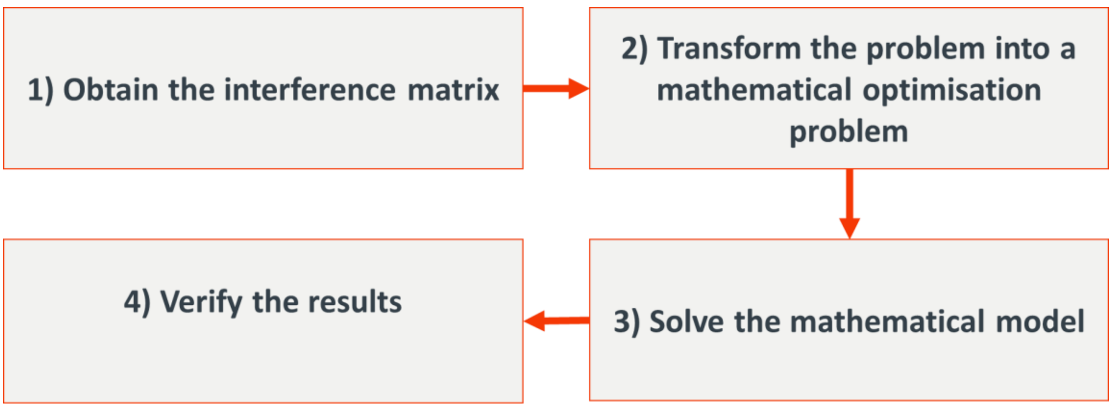

Figure 1 – High level flowchart of the process

In the first step, an interference matrix is required as a prerequisite to perform frequency planning. The interference matrix is a metric to measure the interference levels experienced by each site with respect to the other sites.

If there are m sites then the interference matrix, Q will be m x m square matrix.

$$Q = \begin{pmatrix} q_{11} & \cdots & q_{1m} \\ \vdots & \ddots & \vdots \\ q_{m1} & \cdots & q_{mm} \end{pmatrix}$$

Where $q_{i,j} \in \{0,1\}$ and,

$$q_{ij} = \begin{cases} 1, & if\ site\ i\ interferes\ with\ j \\ 0, & otherwise \end{cases}$$

Notice that Q is a symmetric matrix because of the symmetric relation: if site i interferes with site j then vice versa, site j also interferes with site i.

As an example if there are 3 sites then an example interference matrix can be the following:

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

The above matrix depicts the following situation:

1) Theres an interference between site 1 and 2.
2) There's an interference between site 2 and 3.

What this amount to is that site 1 cannot share the same frequency as site 2. Site 2 and site 3 cannot share the same frequency.

For the second step, the frequency assignment problem is formulated into a constraint satisfaction problem (CSP). A CSP consists of a set of decision variables where every variable has an associated domain of possible values, and there are a set of constraints that restrict the values that the variables can take simultaneously. Formally a CSP is defined as a triple: $< \boldsymbol{X}, \boldsymbol{D}, \boldsymbol{C} >$, where,

$\boldsymbol{X} = \{X_1, \dots, X_n\}$ is a set of decision variables,

$\boldsymbol{D} = \{D_1, \dots, D_n\}$ is a set of their respective domains of values, and

$\boldsymbol{C} = \{C_1, \dots, C_m\}$ is a set of m constraint, where each C_i restricts the values that some subset of $\boldsymbol{X}$ may take simultaneously.

With respect to the frequency assignment problem the decision variables can be the site to frequency mapping and the constraints be derived from the interference matrix which ultimately determines which sites can share the same frequency.

For the third step, the FAP model is then fed into an appropriate solver. The solver does most of the heavy lifting and implements a variety of algorithms to prune the search space. There is a range of solvers available on the market ranging from open-source software to paid commercial ones.

The speed at which feasible CSP models can be solved (or verified to have no solution if the model is infeasible) depends on a variety of factors including the size and the number of parameters in the model, the way the constraints are defined and finally the speed of the solver.

For the fourth and final step the frequency assignment results are verified using radio simulation tools to ensure no unacceptable interference.

With this process, Nova Systems has found success in solving complex frequency assignment problems at a reasonably large scale of ~200 sites with a run time of under 10 seconds. As an illustration, Figure 2 and Figure 3 respectively depict the interference scenario before performing frequency planning and after the planning. Areas shaded in purple are interfered due to frequency overlap. It's evident that prior to frequency planning there is a large amount of interference and after the planning there is minimal interference.

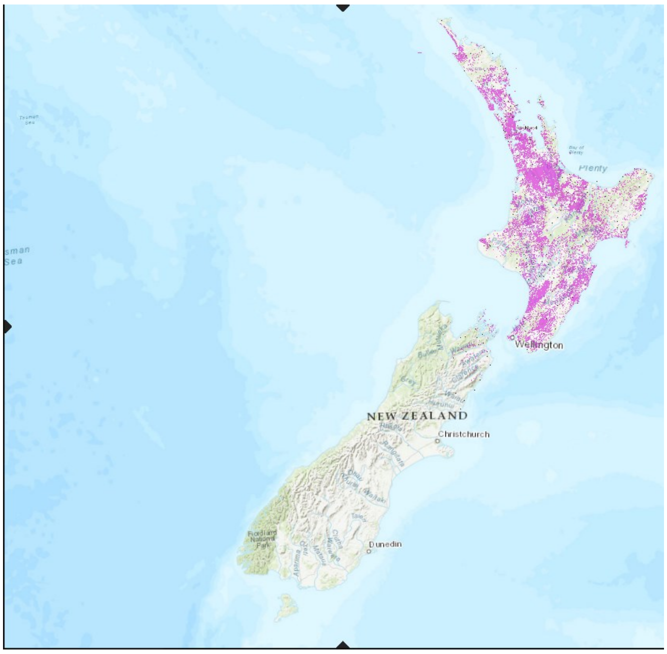

Figure 2: Before performing the frequency optimisation planning. Purple areas indicate interference due to frequency overlap.

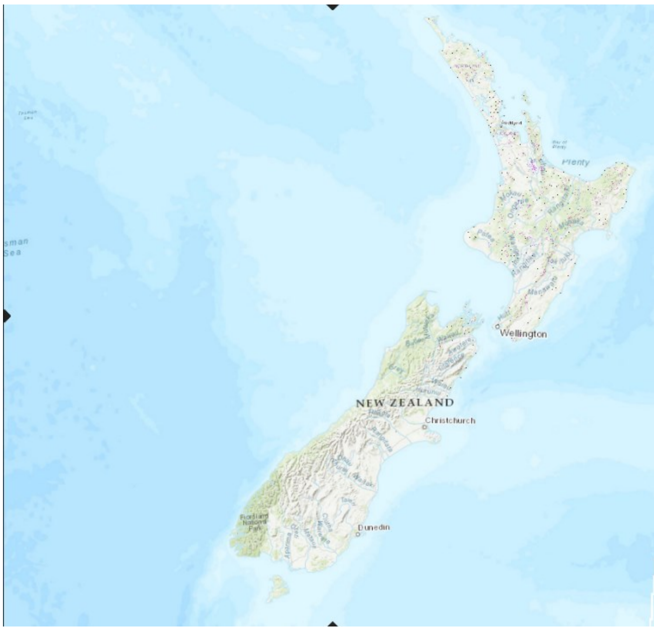

Figure 3: After performing frequency optimisation planning. Purple areas indicate interference due to frequency overlap.