Conference Paper:

A Genetic Algorithm Approach for Approximating Resource Allocation in Virtualized Wireless Networks with Log-Normal Distributed Traffic Demand

The concept of a virtualized wireless network involves being able to take a set of available resources and virtualize them, allocating slices or whole resources into a single or set of virtual networks which are obfuscated form the original resources. In this paper, I simplify the problem by seeking an optimal solution by allocating the set of available resources into a single network which provides the maximal demand satisfaction with the minimal possible cost.

This problem is presented as a two-stage stochastic optimization model in the form of a capacitated set cover problem; that is, what is the minimum (in terms of cheapest cost) two-dimensional set of polygons with associated weights that fully covers the area and its desired capacity. Each resource is assumed to lossless within a given range, able to cover all demand equally within its range, and with a given total capacity. The demand is assumed to be a stochastic variable distributed following a continuous-space log-normal density model which has been shown to closely model urban traffic demand in cellular wireless networks.

The problem is first approximated as a deterministic equivalent program (DEP) of the stochastic optimization problem, which realizes the stochastic demand variable (the continuous demand field) as a set of discrete scenarios, each with an equal probability and as a single realization of the log-normal distribution as a non-stationary Poisson point process. With infinite scenarios, the DEP converges to the original stochastic program. Thusly, with sufficient scenarios, the DEP solution can provide a sufficiently tight solution. However, as the number of scenarios, resources, or demand points increases, the DEP becomes increasingly intractable.

As a contrast to the DEP, the original problem is secondarily approximated using a genetic algorithm (GA) to estimate the first stage to determine a specific set of resources to allocate to the network. Here it is assumed that demand field is left as a continuous distribution and that demand is allocated to the closest available active resource. When evaluating each stage of the GA, demand allocated to each active resource can be easily found by integrating the distribution over the region dictated by that resource's cell in the Voronoi tessellation of the active resources. Through this method, the first stage can be solved without involving any scenarios or demand points, and the only complexity is introduced via the resolution of the field (currently it's solved by summing over pixels of the region, not a true integral) and the number of resources, the latter of which also scales the DEP. Once the first stage solution is found, the second stage of the original problem can be solved assuming a specified approximately optimal set of resources, a far more tractable solution than the original.

It is expected that the GA can provide a solution in much less time than the DEP assuming the model exceeds a certain amount of complexity. To test this, the DEP and second stage were implemented using CPLEX and the GA was implemented using MATLAB. Testing shows the expectation is true; the GA will converge to a solution in less time than the DEP assuming the model is sufficiently complex. The GA currently invokes 20% more cost than the DEP. However, I believe that this is because the model is sufficiently simple so the DEP converges in a timely manner that any error – one or two resources – invokes a 10%-20% cost increase.

Thesis/Journal Extension Work:

Thesis working title: An Analysis of Approximating Resource Allocation in Virtualized Wireless Networks using Genetic Algorithms

The thesis work will continue on the work done for the earlier conference paper (last page). In that work I implemented a linear discrete optimization problem (DEP) in CPLEX and a genetic algorithm (GA) to approximate an exact solution to allocating a set of resources to subnetwork. These simplifications effectively remove any possible notion of virtualization – for instance, only a single network is considered and resources are allocated as a whole to the network, which removes any potential for "slicing" physical resources into multiple virtual resources, each allocated to a different virtual network – and instead investigate a genetic algorithm approach to a solution of a capacitated set cover problem in the context of a simplified wireless network.

Extensions building upon this work within a thesis or journal extension will involve adding additional complexity to the model and further investigation. That is:

- Doing a Sample Average Approximation (SAA) analysis, which involves understanding the question of "how many scenarios (samples) are needed for the DEP to provide a sufficiently tight solution (average approximation) to the original problem?" If the number of scenarios are low, then the DEP can solve more complicated problems than it is currently expected. If the number is high, then other approximation approaches become more interesting.
- Solving for multiple built networks.
- Allowing for partial resources to be allocated rather than whole. This is only interesting for potential cost savings (i.e. "buying" half a base station rather than a whole) and for splitting resources among several built networks (see previous bullet).
- Heterogeneous Networks (HetNets) where the resources being investigated are not homogenous.
- In extension to HetNets, allow for weighted preferences in the voronoi partition of the GA
- Add pathloss and other realities of wireless networks currently ignored
- Investigate a compromise between the two approximations, where a GA (or other metaheuristic) solves or simplifies a sub-problem of the optimization model, causing the overall model to be simplified and far more tractable, but still using the brute-force power of software like CPLEX to solve the problem. That is, if the resource space is sufficiently large to render the DEP intractable, use a GA to trim the overall resource space to a smaller set that more closely aligns to the demand model being investigated.
- Investigate another approximation tool, such as particle swarm optimization. (Pipedream)

Several of these are likely over reaching in terms of complexity, but several of these avenues have already been partially investigated. The first would provide additional mathematical rigor to my thesis, and I have some papers available in this vein. My current implementation is already built to allow for HetNets, I just need to specify the correct data. Multiple networks and partial resources would require tweaking of the original optimization model, but I have some considerations for how to approach this in a GA. Implementing pathloss would likely defunct the voronoi tessellation of the GA, but would also be covered by the second stage. Weighting the voronoi partition would allow for some resources to naturally cover more demand, as would be expected in a HetNet.