Some Thoughts on Adaptive Grid-Enabled Optimisation Algorithms for Wireless Network Simulation and Planning

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Abstract

Planning and optimizing 3G networks (e.g. Wideband Code Division Multiple Access, WCDMA) needs large amounts of data modelling, parameters adjusting until satisfied conditions are found. It often needs significant computation resources since the problem becomes unmanagedly large if the network size is large (non-polynomial hard). Grid is one of the established technologies that can speed up complex algorithms and increase their accuracy by allowing individual PCs to work together in centralised and distributed clusters. Dynamic Simulators (DS) can be employed to evaluate Radio Resource Management (RRM) algorithms, such as Soft Hand Over (SHO) by employing grid-enabled and adaptive optimisation algorithms.

Keywords: adaptive, grid-enabled, optimization algorithms, network planning, wireless simulator, 3G, WCDMA, dynamic simulator.

1. Introduction

CDMA is the core technology used [1] in WCDMA networks. To fully explore the potential of WCDMA networks, planning and optimizing processes are necessarily.

A typical WCDMA network planning and optimizing process consists of three phases:

- PHASE 1 --- Base Station (BS, or Node-B in WCDMA) selection: System dimensioning [2, p.95] approximately provides the number of BSs that are planned, desired capacity and coverage, required Quality of Service (QoS), among other specifications. The sets of candidate sites can be determined within a territory specified for coverage.

- PHASE 2 --- Simulation with random test points (wireless terminals, or User Equipment (UE)) allocated to BSs in phase 1: Test points are used to simulate the Mobile Stations(MS) within the wireless network. These MSs can be either static or dynamic (moving from time to time). Static MSs gives a static snapshot-based model, which is simpler than a dynamic model. However, MSs moving in successive time steps can be simulated using DS, which also evaluates Radio Resource Management(RRM) [3, pp.231-268] but needs much greater computational power.

- PHASE 3 --- Network parameter adjustment in order to maximise performance: A simulator, either static or dynamic, evaluates the performance in terms of different objective functions (e.g. Maximise Coverage). Often, some of these objective functions contradict one to each other. For example, bigger coverage will cause smaller capacity and vice versa. So, a trade-of between these factors must be decided. Since all MSs share the same air interface in WCDMA, any single MS's change of emission power will influence other MSs to change too. The changes iterate until the power stabilises [4, p.10]. So, MSs can not be analyzed independently. Parameters are next adjusted and the process iterates to approach a good solution.

Existing literature has presented interesting mathematical models to simplify planning issues. The models given [5] [25] are mostly Integer Linear Programming (ILP), which may be very advantageous in practice. However, accuracy remains to be improved due to the many link-level factors [1] in WCDMA. It is expected that as more parameters are considered, better accuracy can be obtained although this needs much greater computational power. To solve the problem in reasonable time will benefit the construction and improvement of wireless networks.

2. Problems

Many important parameters in WCDMA contribute to an extremely-data-intensive problem [24]. Parallelization can be used to speed up processing but a good strategy to parallelise algorithms is not easy to find. Physical transmission layer parameters are difficult to include in the model (e.g. configurations of antenna tilt) so approximation is normally considered. A static simulator takes a couple of parameters as inputs, models the data and generates an output. There will be tens of Test Points(TP) allocated in order to improve accuracy, which contributes to a NP-hard problem. A dynamic simulator, which takes consideration of the TPs in the movement from time to time and contributes to a even complex problem. To find an optimisation algorithm that can filter some data will accelerate the processing to a extent.

In [6], running time of the set-covering algorithm on an "The Hague" problem instance with 912 installations and 76 sites on a 1GHz Pentium III are 73s, 1435s, and 4283s when 5, 10, and 20 snapshots are taken respectively. In [7], a total computation time of 48h on a 400-MHz computer with 512MB RAM running C++ code is required to run from 5000 to 20,000 iterations. Industry requires at least 1000 snapshots to obtain accurate results, which obviously is beyond a single processor's capability because the computation time does not grow linearly with the number of snapshots. A 3G dynamic simulator considers time variant effects for precise simulators of 3G networks. Compared to static simulators, they are more time-consuming. So, it is very unlikely that a single processor can be used to successfully plan and optimise a 3G network. Parallel processing is desirable and feasible since more than one computer can work simultaneously, which makes it possible to obtain more accurate results of those large-scale computation problems within the required time period by allowing parallel computation. This is the ideal situation when algorithms are applied without consideration of the communication overhead between processors because distributed processing would suffer from network latencies.

3. A Mathematic Model

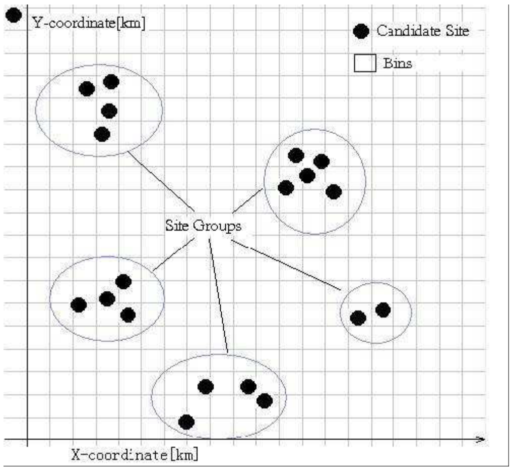

Figure 1 – Candidate Site Groups & Bins

In System Dimensioning, engineers collect data and a set of candidate sites will be roughly known. These sites can be grouped as seen in Figure 1 (i.e. some candidate sites are very close to each other and must not be constructed together). Let K denote the site groups (the number of groups is k), and each group K_i $(i \in [1,k])$ contains n_i sites, from which only one site is chosen. Assume s_{ij} represents sets of location orthogonal coordinates for site j in group i. Assume S_{ij} denotes the jth site within group i. S_{ij} is a binary decision variable which is in {0, 1} such that:

$$S_{ij} = \begin{cases} 1 & \text{site } j \text{ in group } i \text{ is chosen} \\ 0 & \text{site } j \text{ in group } i \text{ is not chosen} \end{cases} \tag{1}$$

The following equation exists to ensure the total number of sites selected is exactly g:

$$\sum_{i=1}^{k} \sum_{j=1}^{n_i} S_{ij} = k \tag{2}$$

The following constraint prevents more than one site being selected from the same group:

$$\sum_{j=1}^{n_i} S_{ij} = 1, i \in [1,k] \tag{3}$$

The installation costs associated with the candidate site j in group i is known as c_{ij} $(1 \leq \ i \leq g, 1 \leq j \leq n_i)$. Since the overall candidate sites are chosen from site groups and the number of total sites planned is fixed (Equation 2), the total costs of sites installations are comparatively at a fixed level. The cost of any single site is expensive and it is assumed that the cost difference between any two sites is neglected compared to a cost of a site. Hence, the cost objective function usually is given less priority than the others, e.g. capacity.

In order to perform simulations, either static or dynamic, of the MSs within a configured WCDMA network, TPs, which represent MSs, are needed. Assume TPs within a specified large area (bin) [8] are the same, in other words, each TP is considered as a bin, in which any MSs are assumed to have the same wireless environment (signal prorogation, fading, etc.). The smaller a bin is, the more accuracy of simulation (higher resolution) can be achieved. In Figure 1, squares are bins to simulate MSs in the area covered. Assume TP_{ij} is the test point (bin) assigned to the coverage area and located *i* units horizontally and *j* units vertically. The Resolution is defined as the area of an actual bin. Let $x_{(S_{ij},\mathrm{TP}_{kw})}$ be the binary variable in {0, 1} to represent whether TP_{kw} is served by S_{ij}

$$x_{(S_{ij},\mathrm{TP}_{kw})} = \begin{cases} 1 & \mathrm{TP}_{kw} \text{ is served by } \mathrm{S}_{ij} \\ 0 & \mathrm{TP}_{kw} \text{ is NOT served by } \mathrm{S}_{ij} \end{cases} \quad (4)$$

WCDMA is an inference-limited system [9], in which traffic distribution largely determines the interference. Transmission power varies by the MSs' position, i.e. MSs nearby BSs need less power while the ones far from BSs may not reach minimal Signal-Interference-Ratio (SIR) threshold. Interference comes from other MSs' signals (filtered by BSs as noise, due to orthogonal spreading code) and thermal noise (which can be neglected because it is much smaller than the former one). In order to improve quality, MSs must increase their transmission power to increase SIR, which can in turn increase other MSs' interference [3, p.208]. As the available power transmission is limited, the capacity is heavily affected by power and so is coverage (known as cell breathing effect). Hence, in the model, power control must be investigated. Assume available emission power for *BSj* in site group *i* in time *t* is denoted as P_{ijt} and the MSs' receiving power P_{ijt} represent the signal strength at bin (*i*, *j*). Then P_{uwt} is based on P_{ijt}:

$$p_{uwt} = h(t) \star P_{ijt} \quad (5)$$

h(t) is the wave propagation model, which is complex in real world wave propagation (due to Line-Of-Sight (LOS), ground-wave, fading and other phenomena). Thus appropriate propagation models such as those proposed by Hata [10, p.88] should be used. Propagation Gain Matrix $\mathrm{G}=\{g(S_{ij},\mathrm{TP}_{kw})\}$ can be estimated, in which, *g* is the propagation factor of the radio link between site S_{ij} and TP_{kw}. The SIR can then be obtained by equation [11]:

$$SIR = SF\frac{p_{ijt}}{\alpha I_{in} + I_{out} + \eta}, \alpha \in [0,1] \quad (6)$$

I_{in} is the total intra-cell interference due to the signals emitted by the same BS while I_{out} is the total inter-cell interference by other BSs. α is the orthogonality loss factor and η is the thermal noise. Multipath propagation causes unavoidable interference from other orthogonal signals.

MSs adjust their transmission power to approach $P_{\min}$ or $SIR_{\min}$ [12]. $P_{\min}$ is an average minimal transmission power value determined by experiments while $SIR_{\min}$ is the minimal SIR value that is acceptable and is calculated by Equation 6, which is largely associated with the rest of the MSs in the wireless environment and is much more accurate.

When a MS initialises a call, it searches for the Common Pilot Channel (CPICH, 10-15% of available transmission of a BS) [3, p.127], which carries information about available BSs, etc. A ratio E_c/I_0 (carrier-to-interference) [2] is calculated. When the ratio is below a threshold γ , handover procedures are initialised (at least two active connections). Let $E_{(S_{ij},\mathrm{TP}_{kw})}$ be the ratio, measured at the radio link between S_{ij} and TP_{kw} . The variable $\delta_{(S_{ij},\mathrm{TP}_{kw})}$ denotes the CPICH signal detection:

$$\delta_{(S_{ij},\mathrm{TP}_{kw})} = E_{(S_{ij},\mathrm{TP}_{kw})} - \gamma \quad (7)$$

The best server [13] can be chosen as TP by sorting δ :

$$b_{(S_{ij},\mathrm{TP}_{kw})} = \begin{cases} 1 & \mathrm{TP}_{kw} \text{ is best served by } \mathrm{S}_{ij} \\ 0 & \mathrm{TP}_{kw} \text{ is not the best served by } \mathrm{S}_{ij} \end{cases} \quad (8)$$

Evaluation function can consist of the following objective values.

- BSs' Costs $C = \sum_{i=1}^{k}\sum_{j=1}^{n_i} S_{ij}c_{ij}$
- BSs' Coverage Area (QoS)
- BSs' Soft Capacity [14]. (see e.g. Erlang)
- Blocking Probability (QoS)

One or more objectives can be combined as a single objective by applying different weights to them.

$$O = \lambda_1 O_1 + \lambda_2 O_2 + \ldots + \lambda_n O_n \quad (9)$$

4. Why Grid?

It is known that in fact many other well-defined technologies and standards for distributed computing have been developed. Those technologies, such as cluster computing, can also employ parallelism, then why use grid?

Simply improving equipment will not result in too much speed-up, even if algorithms are split into multi-threads in parallel because it is known that the capability of a single computing resource is limited. Putting more investment into computers to form a cluster may bring significant speed-up of the processing, but it also has a major drawback. A cluster is a group of loosely-coupled computers that are localised. So if the problem size becomes even larger, which is possible if indefinite TPs are considered, more computers should be required. That is to say, one cluster alone would not be sufficient enough to tackle the problem. It may be required to combine distributed clusters working together towards goal achievement. More importantly, clusters are limited in scope with dedicated functionality and local to the domain, and are not suitable for resource sharing from different domains [15].

Distributed technologies (e.g. .NET, CORBA, and J2EE) lack interoperability among technology protocols, resource discovery across virtual participants, and dynamic construction of a virtual organization [16, p.55]. Compared to grid, it also lacks a suitable platform for sharing of resources [16, p.55]. Grid Computing is an emerging technique, which can aggregate world-wide un-used computing resources that are geographically dispersed (within different control domains) [17] [18]. For radio network simulation, planning and optimisation, it is very likely that the radio network system modelling, simulation engine (e.g., using Monte Carlo, dynamic or discrete event simulation methods), and optimisation engine are in geographically dispersed areas. The use of grid middleware [17] [18] would allow individual PCs, centralised and distributed clusters working on a demand basis to implement the optimization algorithm. The scalability and flexibility are guaranteed. Besides, the grid technology can be easily merged with Web Services [16, pp.91-127], which can be very advantageous to make the planning tool developed a web service for commercial use. As described above, the simulation of a 3G network takes too much time for a single processor. It will be advantageous if a grid is employed to solve the problem, because a grid allows the use of a vast number of idle CPUs, which is the major advantage over a computer cluster. As more heterogeneous collections than clusters can exist in a grid, a huge number of computers can participate in computation.

Grid technology differs from cluster computing in one major performance aspect. In a cluster the number of PCs is fixed. They are connected by high speed LAN, working simultaneously. Compared to a cluster, grid involves computers over a much larger network. These computers work dynamicly together, and on a demand basis. The connections among computers in a grid are usually unpredictable, i.e. some clients use dial-up and some others may abruptly terminate connections.

Globus Toolkit 4.0 (GT4) [19] was released recently, which is known as the best version of grid tools that can be used in various application. Job Submission Description Language (JSDL) [20] is used as a protocol to distribute sub-tasks to computing resources within different control domains all over the internet. Condor [21] can act as a grid tasks scheduler, which makes use of unused processing power and can be easily used together with GT4. It may be possible to develop a planning tool which can be submitted to grid environment and merged with a web service. The outcome may be inspiring. For example, if the time needed to plan a particular wireless network is fifty minutes, and a grid-enabled algorithm is developed with the factor f (*0.1*), which is the fraction of operations that must be done sequentially, then the possible time, needed to obtain the same result by applying the algorithms to grid resources will be reduced to five minutes. The users access the web service on demand and this will bring significant profit.

5. Grid-Enabled 3G Network Planning Tool Schema

The end-users obtain a copy of the client software, install it and log in to the grid environment. They next submit a wireless network model to a nearby agent, which will look up all available resources from the pool of users logged in. The agent will send specific computation tasks to each available PC and collect the result from them. The agent then sends the final result to the requester.

The agent will act as the "master" node which will schedule and distribute computation tasks to processors in the "grid pool", which act as "worker" nodes. A "master-worker" schema has been generally defined in [22] and a particularly known model "farming model" has been presented in [23]. In this section, the model presented is based on rule of thumb.

1. The master node estimates the task and divides the task into sub-tasks for workers. In this stage, the master node takes into account the processing power of each individual processor, because the grid environment contains heterogeneous PCs. In this case, each processor obtains different amount of works according to capability, as shown in (10). w_i is the work amount distributed to processor i. w_{total} is the total work remaining and p_i is the processing power of processor i (e.g. how many add calculations the processor can finish in unit time).

$$w_i = w_{total} \frac{p_i}{\sum p_i} \quad (10)$$

2. The workers divide the sub-tasks received into two buffers, the second buffer is estimated to finish within average communication time. The worker finishes the first buffer, sends partial results along with a request to the master, and immediately continues with the second buffer.
3. The master receives the partial results from workers, stores them and sends new sub-tasks back. Meantime, the worker is supposed to finish the second buffer and to pick up the new sub-task.
4. The master collects all the partial results and determines the final results.

In the paradigm described above, on average a more powerful processor will receive more computation sub-tasks than the rest and most of the time, all processors are expected to be usefully busy.

6. Proposed Research Methodology

This research aims to investigate the performance impact of a grid-enabled planning tool for wireless networks when parallelised optimization algorithms are adopted. After the completion of the planned research, a grid-enabled planning tool will improve the process of wireless network planning.

The specific research objectives are:

1. apply optimization algorithms in WCDMA network model;
2. develop a good parallel scheme for the optimization algorithm;
3. test and compare their efficiency with other existing parallel strategies;
4. develop a grid-enabled WCMDA network planning tool which adopts parallel optimization algorithms;
5. test and improve the tool in a grid environment;

These research objectives are important to the future planning of wireless networks. The achievement of greater accuracy will benefit wireless network vendors.

The project will follow a systematic approach as follows:

1. state-of-the-art review. Optimization algorithms within wireless networks are studied. The first step of the project aims at verifying existing methods.
2. pilot scenarios development. WCDMA planning models are established and optimization algorithms are applied.
3. grid-enabled planning tool modelling. The grid-enabled tool will be modelled as a network of computing resources distributed geographically, each comprising a number of processors and a limited amount of storage. Each grid user submits a job and the nearby agent deals with other request simultaneously. Grid-enabled tools have to deal with abrupt termination, maximum utilisation of grid resources and other specific problems associated with a grid environment.
4. development of parallel optimization algorithms for use in WCDMA networks. Algorithms are developed, parallelised and made adaptive in this stage. Efficiency will be analysed.
5. grid-enabled planning tool development. A grid-enabled planning tool including client, agent, and grid user program are developed at the stage.
6. testing and refinement: Simulators are used to test the algorithms. Based on the results, modifications are made. This procedure is iterative, until sound results are obtained. Additionally, an appropriate approach to make the algorithms adaptive will be done.

7. Conclusion

The paper has reviewed the complexity of planning 3G networks in section 2 and has given a mathematic model in section 3. The justification of using grid is discussed in section 4, followed by a schema for using grid technology to plan and optimise 3G networks, which is described in section 5. Section 6 gives the proposed research methodology.

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