ENHANCED DYNAMIC RADIO RESOURCE ALLOCATION PERFORMANCE USING A GRADIENT DESCENT ALGORITHM

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ABSTRACT

Mobility of the wireless user creates uncertainty in demand and non-optimum use of radio resources. Current wireless networks are periodically re-configured manually to improve network performance. Dynamic Channel Assignment (DCA) methods can be used to reconfigure radio channels automatically. But many of these DCA techniques use "parochial" allocation schemes which consider only the received interference levels and do not consider the impact of the new interference generated by a particular channel assignment on other cells. These DCA algorithms typically allocate channels on an instantaneous need basis so there is little computation time to consider the impact of network wide interference. This paper will propose a new DCA approach which uses time intervals to estimate traffic trends. These traffic trends will be used to estimate radio requirements for each period. All investigated DCA algorithms will consider network wide interference impact and select radio configurations which minimize overall interference. This paper will examine the performance of two different DCA approaches, the Gradient Descent Algorithm (GDA) and Cell Level Radio Tuning Algorithm (CLRTA) methods. The different DCA algorithms will also be compared to static allocation algorithms. The GDA is shown to have superior performance to that of the CLRTA by approximately 2-4 dB depending on the number of available radio channels. The DCA approach is approximately 3-5dB better than conventional Fixed Channel Allocation (FCA) scheme.

I. INTRODUCTION AND DCA BACKGROUND

In the 1970s D.C. Cox and D.O. Reudink proposed [1] and analyzed Dynamic Channel Assignment (DCA) algorithms as a way to increase channel utilization. The algorithms attempted to maximize channel utilization under the radio channel reuse constraint by a fixed D/R. These algorithms assumed no relationship existed between cells and channel numbers and that the channels were assigned based on demand. Other DCA approaches assume there is a nominal relationship between cell and channel numbers but channels can be temporarily assigned to neighboring cells. This DCA technique is often called channel borrowing. L.G. Anderson explored several different channel borrowing strategies[2]. Most of these early approaches basically attempt to dynamically reuse channels within a cell cluster, and therefore the objective was a localized channel use optimization.

In the 1980s and early 1990s D. Everitt published many articles[3] on the performance of various DCA approaches. These analyses do not consider the network-wide interference impact of assigning radio channels. Later P.T.H. Chan, and D. Everitt [4] proposed several algorithms using neural networks. Still other researchers believed that a centralized approach to DCA is extremely complex and difficult to undertake in real time [5]. This research employed a Least Interference Algorithm (LIA) to select radio channels based on local interference measurements.

Unlike other DCA algorithms, this research will use a centralized channel allocation scheme. But due to the complexity in dynamic frequency planning, we propose a slow-DCA algorithm which uses interval traffic measurements and an interference matrix to periodically define an optimum frequency plan. This approach will maximize system resource utilization and minimize the overall interference to carrier ratio. This objective is similar to some of the DCA approaches but is applied on a network-wide basis. This network-wide approach has the benefit of analyzing the impact of two-way interference. The new algorithm evaluates the impact of co-channel interference on the new channel assignment, and the impact of the newly assigned channel on the surrounding co-channel cells. It is our belief that this global view of interference method will improve the system wide frequency assignment scheme.

II. RADIO NETWORK DEPLOYMENT MODELING

The deployment model considers the geographic locations of the different power sources. The power source model does not assume a uniform spacing for cells but instead uses actual cell position data. All mature networks will have non-homogeneous deployed cells and frequencies which reflect the non-uniformity in the network demand [6]. These networks cannot be modeled using homogenous clusters. The details of the deployment model are covered extensively in a previous paper [7].

III. DEMAND MODELING BASED ON ALLOCATION TYPE

This section covers the method used to generate radio channel requirements based on allocation type. These channel requirements for both the dynamic and static allocation methods will be processed by the interference minimizing algorithm which will be discussed later.

Fixed Channel Allocation (FCA)

In a FCA scheme, radio channels are allocated to cells based on individual busy hour data. The static radio resource are computed using the following equation,

\[ N_r = \sum_{i=1}^{k} \text{ErlangB} \left[ \text{Max}(A_i), GOS \right] \]  

where \( N_r \) represents the number of radio traffic channels required.
for static allocation, \( A_{i,t} \) represents offered traffic at cell \( i \) at time \( t \), and \( K \) is number of cells in the network. The \( \text{Max} \) function is used to find the peak traffic for each cell. Note that the peak offered traffic at cell \( i \) during the day is used to engineer the radio channel requirements.

**Dynamic Radio Allocation (DCA)**

In DCA approach, each cell allocates radio resources based on the traffic demand for the current period. Sector traffic prediction will be based on recent historical data for that period of time. Fig. 1 shows spatial distribution of traffic for a 5 kilometer by 9 kilometer section of an operational network during the busy hour. Position and pointed angle of each sector is represented by a pie wedge. Sectors are shaded based on its corresponding Erlang traffic.

![Fig. 1 - Example Interval Demand in Erlangs](image)

DCA radio requirements are defined on a per period basis. The computation uses the following equation,

\[
N_d = \sum_{i=1}^{K} \text{Erlang}B[A_{i,p}, GOS]
\]

where \( N_d \) represents the number of radio traffic channels required for cell \( i \) at time \( t \). Dynamic radio allocation will achieve significant savings over static radio assignments. This method improves voice quality by decreasing interference from radio channels which will not be needed during a particular period. This analysis will use GSM 200kHz TDMA radio channel modulation scheme. Each channel will have 8 time slots. The analysis will assume one time slot is reserved for signalling and 7 time slots are available for traffic.

**IV. OBJECTIVE FUNCTIONS**

The dynamic frequency planner uses both deployment information and traffic measurements to maximize network voice quality. This section defines the objective criteria for optimizing the radio frequency plan. Automatic frequency planning systems attempt to maximize the voice quality in a cellular network by maximizing the C/I under limited system bandwidths.

**I/C Ratio per Erlang in the Network,**

\[
\frac{i/C_{\text{System}}}{N_d} = \frac{\sum_{i} \sum_{k} A_{i,k} (i/C_{i,k})}{\sum_{j} \sum_{k} A_{j,k}}
\]

where \( A_{i,k} \) is the offered traffic generated on frequency \( k \) in cell \( i \).

**Minimum Carrier to Interference Level**

The objective will have the following constraints associated with each element in the \( i/c \) matrix,

\[
\frac{i/C_{i,k}}{c/I_{\text{Min}}} < \forall \text{Cell}_i
\]

This constraint is imposed to guarantee a minimum grade of service in voice, typically quantified by a bit error rate (BER) < 0.001. The minimum C/I varies for different access technologies.

**Adjacent Channel Interference Constraints**

A channel exclusion constraint is used by the automatic frequency planning algorithm to minimize adjacent channel interference. This test prevents the assignment of adjacent channels within a BTS. For example, if channel 5 is assigned to a BTS, then channels 4 and 6 will be excluded from site assignment. Equation (5) shows an exclusion matrix for a two site network with seven radio channels. Each column is a cell index and each row is a frequency index. Columns 1-3 refer to BTS 1 and columns 4-6 refer to BTS 2. For example, the 1 entered at \( E_{11} \) indicates radio channel 1 is assigned to cell 1 in BTS 1, and the 3 's entered in \( E_{21}, E_{22}, E_{23} \) indicate radio frequency 2 is excluded from use in all cells of BTS 1.

\[
E = \begin{bmatrix}
1 & x & x & x & x & x & x \\
x & x & x & 1 & x & x & x \\
x & 1 & x & x & 1 & x & x \\
x & x & 1 & x & x & x & 1 \\
x & x & x & x & x & x & x \\
x & x & x & x & x & x & x
\end{bmatrix}
\]

**Formulating the Percentile Network Level C/I Metric**

Order statistics have been proven to be extremely useful as estimators for data analysis. These statistics have been successfully applied in controls systems and signal processing fields. Corrupted data can skew a conventional statistical moment estimator, while an estimator based on order statistic, have shown an immunity under these conditions. Rank statistics have the ability to suppress outliers.

Individual cell level C/I's are computed for the cell area based on both the power of the received carrier signal and the interfering levels. The individual cell performance is based on the estimate of the C/I at the cell’s perimeter. Each cell’s performance is collected to form the C/I distribution for the entire network. We will use order statistics to identify the C/I level at which 90 percent of channel C/I's is greater than that point or 10% of the channels have C/I that are lower. The cell level distribution for an example time period is shown in Fig. 2.
Although order statistics will be used for the final benchmarking of all future algorithms, the linear properties of the average i/c metric will continue to be the basis for the tuning of the algorithm, due to its computational ease and accurate reflection of overall interference. For example, if a rank metric were used, a radio configuration that improves overall interference may not be detected since the order statistics has not improved.

V. DEFINING THE INTERFERENCE GRADIENT

This section defines the interference gradient equation based on localized interferers. This new gradient equation will be used to define a new tuning algorithm. This process will be modeled as a linear equation and will be used to compute the gradient.

Fig. 3. Evaluating the Impact of a Potential Channel Reassignment

When testing a potential channel reassignment during the tuning process, the algorithm attempts to minimize total interference. But before the re-assignment is done, a test must be done to ensure that the interference level in the potential co-channel does not exceed the maximum allowable level. The parameter $I_{pot,j,Q}$ will be defined as the normalized potential interference experienced by sector $j$ in channel $Q$, if sector $X$ is assigned channel $Q$.

$$I_{pot,j,Q} = I_{j,Q} + I_{j,x,Q}$$

Equation (6) will be subjected to the constraint, $I_{pot,j,Q} \leq I_{MAX}$, for all potential co-channel interferers. The index $j$ represents the array of all $Q$ co-channel cells. The term $I_{j,Q}$ is the total interference before the addition of interference from sector $X$. The term, $I_{j,x,Q}$, is the incremental interference due to the assignment of channel $Q$ in sector $X$. Similarly, we compute the reduction in interference by indexing through the k sector group.

$$I_{pot,k,R} = I_{k,R} - I_{k,x,R}$$

If all constraints are satisfied we compute the relative benefit of the move using a derivative of the average i/c metric,

$$\Delta I_{p,R,Q} = \frac{(I_{pot,j,Q} - I_{j,x,Q})E_j + \left( \sum_{k} I_{j,k,R} - \sum_{k} I_{k,x,R} \right)}{R_j} < 0$$

where $E_j$ is the Erlangs in sector $j$ experienced for a specific period, and $R_j$ is the number of radio channels required for a particular time interval.

VI. CHANNEL ASSIGNMENT ALGORITHMS

A. Intelligent Initial Channel Assignment

The first pass algorithm selects radio channels for each cell based on localized interferers and radio channel requirements. At this point channel assignment does not consider the interference impact to other cells. This algorithm computes potential i/c for each radio channel and selects the $N$ lowest potential i/c. The $N$ required radio channel is based on the estimate of cell traffic for that period.

B. Radio Tuning Algorithms

Cell Level Radio Tuning Algorithm (CLRTA)

The second pass algorithm validates that the selected channels during the first pass actually reduced the overall network interference per erlang. If the newly assigned radio channels do not reduce the overall interferences, the radio channels will be reset to prior assignments and the algorithm will move on to the next cells to refine its frequency plan [7]. The algorithm terminates when there is virtually no reduction in the overall i/c for two consecutive passes.

Fig. 4 shows an example of overall network i/c per Erlang for each pass of the algorithm. This example tuning curve uses the CLRTA approach for a 25 channel radio system. Each pass represents a complete cycle through each cell’s channel assignments in the network. Based on simulation experiments, most periods converge before the sixth iteration. The algorithm tends to take a greater number of iterations to converge when there is more traffic on the network. Currently the dynamic radio
algorithm starts with no prior radio channel assignment knowledge for each period. In future simulation runs there will be an opportunity to evaluate the algorithm’s performance using prior period radio channel assignment information. This should allow the algorithm to converge much faster and also allow more channel assignment continuity between periods.

In this section, the gradient descent algorithm will be used in place of the previously defined second-pass tuning algorithm. This algorithm will evaluate re-assignment of individual radio channels to other feasible radio channels. GDA computes the interference gradient for candidate radio reassignments and selects a configuration change which maximizes the reduction in interference. Unlike the CLTRA, GDA can tune individual radio channels. First, GDA computes the gradient for all candidate radio channels. A candidate radio channel must pass the adjacent channel assignment rule and must not create interference in the local network which exceeds the maximum interference limit constraints. DCA selects the radio channel which maximize the reduction in interference. If no candidate channel move reduces the interference than no reassignment occurs. After all allocated channels have been evaluated for reassignment, the algorithm moves on to consider the next cell. The algorithm cycles through all cell sites until a complete network pass yields no further radio channel changes. Fig. 5. shows the flow diagram for the channel reassignment algorithm based on the gradient equation.

Fig. 4 shows the performance convergence for the static radio requirements. The static radio assignment problem is the most challenging case due to the fact that more radio channels are required to be assigned. The x-axis indicates the number of passes through the entire set of cells. The y-axis indicates the average I/C metric in linear units.

Another important consideration when using the gradient algorithm is to evaluate the impact of the starting radio channel assignment on the performance of the algorithm. The performance evaluation method uses a randomly assigned radio channel combined with GDA to test if any of the random initial conditions yield better results. The baseline algorithm will use the previously defined intelligent selection method to define initial channel assignments and the GDA for radio assignment tuning. The randomized runs will use a uniform random number generator algorithm called RAN1[8] and then perform tuning using the GDA.

We compare the gradient transition curves for 30 randomly initialized channel assignments to the baseline gradient algorithm. Although the gradient algorithm found several local minima for randomized initial conditions, none of the random runs performed significantly better than the intelligently initialized radio channels combined with the gradient algorithm. These results confirm that this gradient algorithm is highly susceptible to finding local minima and not the global minimum. GDA performance is significantly improved when the initial radio assignment scheme starts near the global minimum. Therefore, the intelligent initial radio assignments increase the probability that the GDA finds a near optimum solution.

VII. PERFORMANCE WITH GRADIENT DESCENT ALGORITHM

This section compares the Cell Level Radio Tuning Algorithm (CLRTA) to the newly defined Gradient Descent Algorithm (GDA). A direct comparison of the performance of the CLRTA and the more complex but more efficient GDA is shown in Fig. 7. The gradient algorithm resulted in a temporal average 90th percentile C/I which was 1.9 dB greater than the more simplistic CLRTA. The static GDA in the 1:30 PM time frame performs better than the dynamic CLRTA. Fig. 8 shows a performance comparison for a 37 Channel radio system. In this case the DCA algorithm performed an average of 4.3 dB better than CLRTA algorithm.

GDA’s superior performance is due to the fact that the GDA allows for one to N radio channels to be reassigned while the CLRTA attempts to pick all N radio channels at once. If these N
channels do not reduce the overall interference, the CLTRA will reject all potential reassignments. Therefore, the GDA's higher resolution tuning capabilities results in radio configurations with lower overall interference.

VIII. CONCLUSION AND FUTURE WORK

This investigation has yielded several important results. The most important is that the initial conditions near the final global minimum are extremely important when using a GDA. We have demonstrated that when an intelligent initialization algorithm is used, the GDA algorithm will yield acceptable results very near the global minimum for average CA. The GDA performed approximately 2-4 dB better than the CLRTA. The actual performance depends on the number of radio channels available in the system. The dynamic radio allocation scheme proved to be approximately 3-5 dB better than the static radio allocation scheme, which requires more radio channels to maintain the same Grade of Service. Future work will explore the effects of spatial traffic correlation on these dynamic allocation algorithms. We also will monitor the churn in radio channel assignment between allocation periods and attempt to define new algorithms which minimize this churn.

REFERENCES


