Investigation on Channel Borrowing in Channel Assignment Problem

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Abstract – *Mobile Communication is the use of technology that allows us to communicate with others in various locations without the use of any physical connection. The mobile communication system involves a large coverage area that serves a large geographical area. Due to the enormous growth of mobile telephone users, the limited number of channels available in the regions is unable to fulfill the user demand calls and this leads to the channel assignment problem. To solve this problem, efficient channels reuse or allocation policy is needed to optimize the uses of channels with low channels interference in the regions. In order to have an efficient channel allocation, one of the solution is to fully optimize utilization of all channels. This work introduces channel assignment with Channel Borrowing Scheme. This scheme allows borrowing of free or unused channels from neighbouring or adjacent cells to fulfil the demand calls. Next, the interference occurs in the cells is optimized as the objective function since quality of calls is important in mobile communication. The result of the experiment shows that this proposed scheme has better result in terms of number of rejected calls compared to non-channel borrowing scheme.*

Keywords:*Channel Borrowing Assignment, Fixed Channel Borrowing, Simple Channel Borrowing*

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I. Introduction

In today's era, communication became a crucial part of human live. Although human has taken an advanced step in communication, there are many more improvements that need to be done. For a communication network system, mobile devices are widely used. Communication process transverse through the medium of radio frequency. The channel allocation schemes can be divided into three types which are fixed channel assignment (FCA) [1], dynamic channel assignment (DCA) [2], and hybrid channel assignment (HCA) [3]-[4]. In FCA, a set of nominal channels is permanently allocated to each region which represented by cell for its exclusive use. However, it is unable to adjust to the changing conditions of traffic and consumer demand. On the other hand, for DCA, all channels are accessible by every cell and it depends on demand. DCA scheme has lower efficiency than FCA when high demand user is involved [5]. HCA is the mixture of FCA and DCA techniques. In HCA, the total number of channels can be divided into two; a set of channels which is assigned as fixed set and another set is being kept in a central pool for dynamic use [6]-[7]. In order to further utilize the channel use in mobile communication, channel borrowing can be applied through different techniques. As in fixed allocation systems, channels are allocated to cells. If a cell needs an extra channel to meet the demand calls, the cell will borrow a channel from one of its adjacent cells given that the adjacent cell has extra available channel [8]. However, channel borrowing may lead to an increment in interference. To minimize the number of rejected calls, algorithms are needed to make sure idle channels are borrowed from the adjacent cells in such a way the interference is being minimized.

II. Channel Borrowing Assignment

A call can only be connected when a channel is assigned to the caller and receiver pair. A region is divided into a number of cells and the channels are assigned into the cells to serve the maximum area coverage. If all the channels are occupied, then the new call will be blocked in this system. Most of the time, there are some cells out of available channels while some of them have idle channels since the incoming demand calls are dynamic all the time. Hence, channel borrowing can be applied to reduce the calls from being blocked due to lack of channels.

In the Fixed Channel Assignment, a fixed set number of channels is assigned to each of the cells for exclusive user only. This can be described by following the principle of co-channel reuse constraints [9]. FCA requires manual frequency planning. Due to the fixed number of channels assigned, this disadvantage can lead to traffic overcrowding and some calls will be rejected due to heavy traffic or there is not enough channel to fulfil the demand [10].

There are two types of channel borrowing schemes, which are Simple Channel Borrowing and Hybrid Channel Borrowing. In Simple Channel Borrowing scheme, any channel in a cell may be borrowed by the neighbouring cells for temporary used. For Hybrid Channel Borrowing Scheme, the channel set is divided into two subsets where one subset is for own cell use only and another subset is borrowable.

In channel borrowing, cells are allocated with channels in the same way as in FCA. If a cell needs to borrow a channel from one of its neighboring cells due to no available channels in its own cell, it may borrow a free channel based on different techniques in channel borrowing scheme. One of the drawbacks when a cell borrows a channel from a neighboring cell is, due to co-channel interference, other neighboring cells are not permitted to use the borrowed channel. This can lead to more increased number of call blocking over time.

In order to minimize this rejected call problem, algorithms are needed to ensure the most suitable available channels from neighboring cells are being chose to be borrowed. Some popular hybrid channel borrowing schemes are Borrowing with Directional Channel Locking (BDCL) and Borrowing with Channel Ordering (BCO), where both are the variations from channel borrowing scheme. In BDCL scheme, channels that are borrowed are only locked to the nearby call that are affected by the borrowing. It also depends on the type of cell layout. For example, in Fig. 1, it shows a hexagonal planar layout. The distance that reuse of one cell is locked in three additional neighboring cells from the borrowed channel.

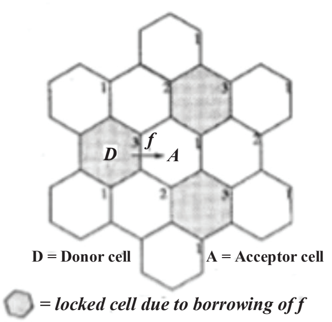

Fig. 1. Channel locking in hexagon planar [11].

The BDCL's advantage is that in the presence of borrowing, more channels are available and subsequent call blocking is reduced [11]. The disadvantage of BDCL is that the borrowed channel is locked within the reuse distance in each cell. Unlike the BCO, a channel can only be borrowed if it is free in the adjacent co-channel cells.

For simple channel borrowing schemes, there are some popular schemes named Borrow from the Richest (SBR), Basic Algorithm (BA), Borrow First Available (BFA) and others. These schemes are compared in [12] in terms of complexity, flexibility, and performance on number of tests to locate borrowable channel. The results are shown in Table I as follows.

TABLE I
COMPARISON BETWEEN BFA, SBR AND BA [13]

Scheme	Complexity	Flexibility	Performance # of tests to locate borrowable channel
SBR	Moderate	Moderate	Few
BA	High	Moderate	A lot
BFA	Low	Low	Very Few

In this paper, the scheme of SBR is used due to the moderate complexity with moderate flexibility in the process. BFA has lower complexity compared to SBR but the flexibility is also lower. We proposed a complete channel assignment scheme with channel borrowing which started from zero interference assignment.

For SBR, channel candidates for channel borrowing are available from an adjacent cell of the acceptor cell which has the largest number of free or available channels. If there are more than one channel available to be borrowed, a channel will be borrowed from the cell with the highest number of available channels. A channel borrowing may result in a channel locking scheme from the early discussion. When choosing a borrowing candidate channel, SBR does not consider of channel locking [13].

For an illustrative example, the allocation channels in five cells is shown in Figure 2 as follows.

CC $[i]$ denotes channels allocation to cell i

CC [1] = 2,4,7

CC [2] = 1,8

CC [3] = 3,6

CC [4] = 1,5,9

CC [5] = 3,7

The demand calls D = [1 2 3 3 1]

Channel number

	0	1	2	3	4	5	6	7	8	9	Demand
cell #	1		■		■			■			1
	2	■							■		2
	3			■			■				3
	4	■				■				■	3
	5			■				■			1

Fig. 2. Illustrative example of allocation channel in 5 cells.

From the example above, cell 3 is unable to fulfil the 3 demand calls since it has only 2 allocated channels. So, cell 3 must borrow one channel from another cell that contains free channel(s). Cell 1 and cell 5 have 2 and 1 free channels, respectively. According to SBR scheme, channel that will be chosen to be borrowed comes from cell 1 since it has the highest number of available channels among the cells with unused channels.

III. Methodology

There are 4 steps involved in developing the proposed channel borrowing scheme in channel assignment problem. In the first step, minimum span with zero interference assignment is computed, which is the minimum number of channels to have zero interference channel assingment. Step 2, the channels are assigned to cells by using Tabu search algorithm based on a partially total number of channels from the first stage which is determined by a parameter in percentage, *P*. This *P* value is varied from 60% - 90%. Step 3, the demand calls will be generated randomly. And lastly, step 4, there are two branches at this stage: Non-Channel Borrowing and Channel Borrowing will be applied in assigning the channels.

A. Stage 1 (Obtaining minimum span)

This first stage was developed in [14]. The purpose of using local search is to find the minimum span of channel from a given data set. Minimum span refers to the minimum number of channels needed for a zero-interference assignment. From the minimum span, the number of channels is limited or reduced to a percentage, *P* and it is varied from 50% to 80% of minimum span. The step to limit the number of channels is to reduce the number of channels since it is limited resource but this step leads to some degree of interference.

Given number of *N* cells and the total number of channels available is denoted by *M*. The demand of channels in each of the cells is represented by *D*. Separation of matrix *C* shows the minimal separation of channels between cells.

For illustrative purpose, the parameter used in this project is given as follows.

Given number of cells, $N = 5$, separation of matrix,

$$C = \begin{pmatrix} 6 & 5 & 1 & 0 & 0 \\ 5 & 6 & 4 & 2 & 0 \\ 1 & 4 & 6 & 3 & 1 \\ 0 & 2 & 3 & 6 & 2 \\ 0 & 0 & 1 & 2 & 6 \end{pmatrix},$$

and the demand of the calls in each of the cells,

$$D = [2 \quad 1 \quad 2 \quad 3 \quad 2]$$

with a total number of 10 demand calls. From this data set, local search gives the result of min-span as 15 channels.

B. Stage 2 (Channel assignment using Tabu search)

From stage 1, total number of channels used is limited to a percentage of *P* on the minimum span value. The limitation of *P* varied from 60% to 90%. Hence, total number of channels used is calculated as follows.

Total number of channels = $P\%$ × minimum span

For example, from stage 1 for the case of $P = 60\%$:

Total number of channels = 60/100 × 15

= 9 channels

Next, the total number of channels are assigned to cells by using Tabu Search.

From the illustrative example, the result obtained from Tabu Search is as follows.

CC [i] = Channels assigned in cell i

CC [1] = 4,7

CC [2] = 1

CC [3] = 3,6

CC [4] = 1,5,9

CC [5] = 3,7

Notice that channels 2 and 8 are not assigned to any cells. Hence, they will be assigned into the cells equally.

Channel number

	0	1	2	3	4	5	6	7	8	9
cell number	1		■		■			■		
	2	■							■	
	3			■			■			
	4	■				■				■
	5			■				■		

Fig. 3. FCA based on initial setup P (60% from minimum span).

The shaded boxes show the channels assigned based on the demand calls, $D = [2 \quad 1 \quad 2 \quad 3 \quad 2]$. This demand calls data is treated as the demand of calls from experience or history of the five regions (cells). Hence, Fig. 3 shows the fixed channels assigned to each of the cells based on the demand from history.

C. Stage 3 (Generating new channel set)

Simulated demand calls are generated by using a developed coding based on the demand calls that represents the usual demand calls in each of the cells. For example, the demand calls from the past is given $D = [2\ 1\ 2\ 3\ 2]$. The new demand is then generated from it with the deviation of ± 0.05.

D. Stage 4 (Channel assignment for generated demand)

To achieve interference free assignment, the constraint of $C_{i,j}$ must be satisfied. Matrix $C_{i,j}$ is defined as minimal separation of channels in cells i and j. However, a slight interference is allowed to increase the availability of channels. If the minimum separation constraint is violated, an interference will occur and a penalty value will be imposed by cost tensor, $P_{j,i,m}$ where m is the distance between channels assigned to cells i and j. The penalty cost function shows the degree of interference occurred among the assigned channels. In this project, the penalty cost function is called cost value. The problem formulation for the channel assignment is stated as follow [15].

Minimize

$$F(X) = \sum_{j=1}^{N}\sum_{k=1}^{M} X_{j,k} \sum_{i=j}^{N}\sum_{l=k+1}^{M} P_{j,i,(|k-l|+1)} X_{i,l} \quad (1)$$

where $m = |k-l|$ $j = 1,2,3\ldots., N$; $k = 1,2,3\ldots., M$

and

$$P_{j,i,m} = \max\{(C_{j,i} - m, 0)\} \quad (2)$$

Subject to a set of binary variable:

$$X_{j,k} = \begin{cases} 1\text{, if cell } k \text{ is assign to channel } j \\ 0\text{, otherwise} \end{cases} \quad (3)$$

where

$$\sum_{k=1}^{M} X_{j,k} = D_j \ , \ j = 1,2,3,\ldots.,N\ ; \ k = 1,2,3,\ldots.,M \quad (4)$$

E. Channel Assignment Method Without Channel Borrowing

In this stage, channels will be assigned to the demand calls. If the demand of calls in a cell exceeds the number of available channels which are assigned in stage 2, the extra calls will be rejected. This happen due to number of channels is not enough to fulfil the demand. From that, number of rejected calls will be recorded. The cost value will be computed and the result will be recorded and analyzed.

A cost value exists due to the interference of the channel occurred among the cells. It can be calculated based on the cost value function above. The higher amount of cost value shows the more severe is the interference occurred between the channels in the cells. The cost value will decrease when the channels k and l from equation (2) are far enough from each other.

For example, given a generated demand, D = [(1 2 3 1 1)] and the assigned channels are shown as in Fig. 3. Cell 1 has three assigned channels which are 2, 4 and 7. From the generated demand, there is only one demand call, hence channel 2 is assigned to the call. Cell 3 has two assigned channels which are channels 3 and 6, respectively. From the generated demand, there are three demand calls, hence channels number 3 and 6 are assigned to the first two calls while one call will be rejected due to cell 3 has only two channels which is unable to fulfil the demand of three calls. The number of rejected calls will be recorded and cost value will be computed.

F. Channel Assignment with Channel Borrowing

The channel assignment is carried out as in previous section E. When there is a rejected call, the rejected call will be assigned a borrowed channel under channel borrowing SBR scheme. The idea of SBR is to borrow a channel from the cell with the highest number of idle channels. If there is no more available channel to be borrowed from other cells, that call will be rejected eventually.

From the above example in Section E, cells 1, 4 and 5 have extra unused channels. But under SBR algorithm, channel in cell 1 is chosen to be borrowed because cell 1 has the highest number of idle channels which are two unused channels i.e. channels number 4 and 7. With the use of channel borrowing, it may reduce the number of the rejected calls but at the same time, it may increase the cost value since it may lead to a higher degree of interference. Hence, analysis will be carried out based on the results collected from sections E and F.

IV. Results

Simulation data are run by using Phyton software. The simulation was run with values of P=(60%,70%,80%,90%), with two different demand sets D in order to get an accurate results. Table II shows the result of channel borrowing for the demand, D = [2,1,2,3,2].

TABLE II
RESULTS OF CHANNEL BORROWING WITH D = [2,1,2,3,2]

P	Reduction in rejected calls	Increment in cost value
60%	48 (65.8%)	472 (35.5%)
70%	40 (52.6%)	423 (43.1%)
80%	41 (53.9%)	412 (38.1%)
90%	41 (53.9%)	321 (34.7%)

From the above table, for P = 60% (M = 9), there is a significant decrease in number of rejected calls between Non-Channel Borrowing scheme (73 rejected call) and Channel Borrowing scheme (25 rejected calls). The total difference between both schemes is around 65.8% (48 rejected calls). The result of reduction in number of rejected calls affects the cost value. The difference in cost value between Non-Channel Borrowing scheme (cost value = 857) and Channel Borrowing scheme (cost value = 1329) increases for 35.5% (cost value = 472). The increment in the cost value reveals that the number of free channels in the cells are fully utilized. The reason why there is huge difference in number of rejected calls and cost value for P = 60% is because the interference occurs in the cell is still low.

For *P* = 70% (*M* = 11), the different in number of rejected calls between Non-Channel Borrowing scheme (76 rejected calls) and Channel Borrowing (36 rejected calls) is about 52.6% (40 rejected calls). The difference in cost value between Non-Channel Borrowing and Channel Borrowing is 43.1% (cost value = 423). The average rejected call between *P* = 60% and *P* = 70% is the same because the interference between channels in the cells is still low.

For *P* = 80% (*M* = 12), it has not much difference between previous case *P* = 70 %. The total reduction of rejected call is 53.9% or 41 rejected calls. The total cost value for Channel Borrowing increased for 38.1%.

Lastly, for *P* = 90% (*M* = 14), it has the same result as *P* = 80% in terms of reduction in number of rejected calls which is 53.95% or 41 rejected calls while it has the least increment in cost value compare to *P* = 60%, 70%, and 80%. This can be concluded that *P* = 60% gives the highest percentage of reduction in number of rejected calls and the relatively low increment in interference.

Table III shows the result of channel borrowing for the demand, *D* = [1,1,2,3,1].

TABLE III
RESULTS OF CHANNEL BORROWING WITH *D* = [1,1,2,3,1]

P	Reduction in rejected calls	Increment in cost value
60%	35 (68.2%)	372 (33.9%)
70%	33 (78.6%)	340 (29.0%)
80%	35 (68.6%)	374 (27.9%)
90%	35 (68.2%)	363 (32.0%)

From the table above, it is notice that case *P* = 70% gives the highest reduction in number of rejected calls with a relatively low increment in interference. Hence, from the data of both tables shown above, we can conclude that for the first demand (*D* = [2,1,2,3,2]) the best value of *P* is 60%. While for the second demand (*D* = [1,1,2,3,1]), the best value of *P* is 70% (*M* = 11). This is due to both cases have the highest percentage in reduction of rejected calls and the lowest percentage of cost value for Channel Borrowing compared to Non-Channel Borrowing schemes.

The lower percentage of cost value indicates the lower interference occurs in the cells. The highest percentage of reduction in rejected calls shows that the number of free channels in the cells have been fully utilized to reduce the number of rejected calls in the cells to fulfil the demand calls. Hence, the optimal setting of parameter *P* is between 60% to 70%.

V. Conclusion

Due to the enormous growth of mobile telephone users, along with the limited number of channels available in the cells cannot fulfill the user demand calls, lead to the channel assignment problem. In order to overcome this problem, one of the solutions is to fully utilize all the available channels. This project proposed a method of Channel Borrowing in the Channel Assignment Problem. It starts with finding minimum span of channels and from the limitation of the minimum span, channels are assigned using the Tabu Search method. The proposed channel borrowing method scheme will borrow any free or unused channels from neighbouring or adjacent cells when the demand of calls exceeds the number of channels available in that cell. This helps to reduce the number of rejected calls in the cells and fulfil the demand calls. From the channel borrowing scheme, the number of rejected calls is reduced with some increment of interference. The result of the proposed scheme is compared to non-channel borrowing scheme. The simulation study shows that channel borrowing scheme gives an optimal solution at the parameter setting of 60%-70% in the limitation of available channels from the interference free assignment.

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