THE SWARM EFFECT MINIMIZATION ALGORITHM
Utilized to Optimise the Frequency Assignment Problem

Grant Blaise O'Reilly and Elizabeth Ehlers
Academy for Information Technology, University of Johannnesburg,Auckland Park, Johannesburg, South Africa

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Abstract: The swarm effect minimization algorithm (SEMA) is presented in this paper. The SEMA was used to produce improved solutions for the minimum interference frequency assignment problem (MI-FAP) in mobile telecommunications networks. The SEMA is a multi-agent orientated design. The SEMA is based on the stigmergy concept. The stigmergy concept allows the actual changes in the environment made by entities in a swarm to act as a source of information that aids the swarm entities when making further changes in the environment. The entities do not blindly control the changes in the environment the actual changes guide the entities. The SwarmAFP is tested against the COST 259 Siemens bench marks as well as tested in a commercial mobile telecommunications network and the results are presented in this paper.

1 INTRODUCTION

The frequency assignment problem (FAP) is a daily occurrence in second generation (2G) mobile telecommunications networks. A large saving in revenue could be made by mobile network operators if a model were presented that could improve optimization of the FAP more efficiently and in less time. The FAP focused on in this paper is the minimum interference frequency assignment problem (MI-FAP) with a fixed spectrum. The FAP is a NP-complete problem (Grotschel 2000, Eisenblätter 2000). There are a number of techniques that have been used to try and optimize a solution in an NP-complete problem to a level that is acceptable (Eberhart *et al*., 2001, Bonabeau *et al*., 1999, Dorigo *et al*., 1999). The success of these techniques is measured by the time it took to reach an acceptable solution as well as the efficiency of the acceptable solution. The FAP is practically unsolvable for real mobile telephone networks and approximate algorithmic methods that obtain solutions close the absolute minimum in a reasonable time frame need to be used. It is beyond the scope of this paper to give a detailed discussion on all the proposed optimization algorithms for FAP. However, a survey of all the optimization algorithms and additional references can be found (Aardal *et al*., 2001, Eisenblatter and Koster, 2007).

In this paper the swarm effect minimization algorithm (SEMA) will be presented and discussed. SEMA is an algorithm based on stigmergy. The SEMA is a multi-agent orientated application design. The SEMA was utilized to try and improve the optimization of the minimum interference frequency assignment problem (MI-FAP). The results produced by the SEMA were compared to the COST 259 Siemens bench marks (Eisenblatter and Koster, 2007). The SEMA was also applied to a commercial, operational mobile telephone network and the results are presented in this paper.

2 STIGMERGY

Stigmergy is the coordination of tasks and regulation of constructions (e.g. a termite mound in a termite colony) in an environment that depends not on the entities, but on the constructions themselves (Kristensen 2000, Valckenaers *et al*., 2001). The entities do not direct the work but are guided by it. In the swarm effect, stigmergy is defined as the influence the changing environment has on the entities in the environment. The constructions created by the entities in the environment are assumed to form part of the environment. These constructions change the environment and the changing environment stimulates a certain response in the agents. In stigmergy the fundamental mechanism is the ability to use the environment as a

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shared medium for storing information so that other individuals can interpret it (Heylighen, 1999).

3 THE SWARM EFFECT MINIMIZATION ALGORITHM

The swarm effect minimization algorithm (SEMA) is based on a swarm of agents making changes in the environment in which they exist. The continual changes induced in the environment act as a growing information base which the agents utilize to make further more informed changes. When applying the SEMA to the FAP, in particular the MI-FAP, the environment will represent the mobile telephone network. The cells in the network will represent the swarm agents and will be referred to as cell agents. Each cell agent will contain a list of its channels and each channel will require a carrier i.e. frequency. The environment will be represented by the collective memory map. The collective memory map is a data structure containing information on all the cell agents. The cell agents in the cellular network make localized changes that result in a globalized effect.

The algorithm utilizes a heuristic cost function to determine the minimum interference or network quality due to interference (NQI) (see equation 1 (Eisenblätter 2000)). The first step in the algorithm is to load the interference matrix. An interference matrix (IM) is a model of all the interference in the network, i.e. it describes how the cell's frequencies are interfering with the neighbouring cell's frequencies. Each row in the IM represents a cell in the cellular network while each column represents an interfering cellular network cell.

Mobile measurement reports (MMRs) are used to generate an interference matrix (Eisenblätter 2000). MMR data can be extracted from the base station controller (BSC) in the network. This data is utilized to build up the cell agents. From this data each cell agent is able to build up a list of interferers, neighbours and transceivers (TRX). Interference between two cells in the IM is measured by the frame erasure rate (FER). To calculate the FER the frame erasure probability (FEP) is needed. The FEP is calculated for all the measurements collected on the specific cell and its interferers. These measurements are summed and then divided by the total number of MMRs as in equation 2 (Kuurne, 2001). The FEP is defined in equation 4. The constants *a* and *b* are used to fit the curve to actual broad casting control channel (BCCH) FEP and traffic channel (TCH) FEP measurements in the network. To calculate the FEP the carrier to interference ratio (CIR) is needed. The CIR is defined in equation 3. The CIR is calculated using the data in the MMR, namely the BSPower, rxlevelsub for the serving cell (i.e cell agent) and the rxlevel for all the potential interferers. The BSPower indicates the reduction from nominal power in steps of 2dB emitted by the channel used by the call that originated the MMR. To eliminate the effect of power control the BSPower*2 needs to be added to the carrier power level in an MMR. The rxlevelsub is actually the carrier power level measured on the slow associated control channel (SACCH). The rxlevel reports the average signal strength during a measurement period.

$$NQI_{\substack{\min \\ y \ \ feasible}} = \sum_{\substack{y(v)=y(w) \\ vw\in E}} c^{co}(vw) + \sum_{\substack{|y(v)-y(w)|=1 \\ vw\in E}} c^{adj}(vw) \qquad (1)$$

where

- *v,w* are carriers and represent transceivers (TRX).
- $c^{co}(vw)$ and $c^{ad}(vw)$ denote the co-channel and adjacent channel respectively, which may occur between *v* and *w*
- $y(v)$ Є C where C= all available channels at carrier *v*\
- $|y(v) - y(w)| \geq d(vw)$ where $d(vw)$ gives the separation necessary between channels assigned to *v* and *w*

$$\text{FER} = \textstyle\sum_{i,j}\text{FEP}/\ (\text{Total number of MMRs}) \qquad (2)$$

$$\text{CIR}_{i,j} = \text{C} - \text{I}_{i,j} \qquad (3)$$

where

- **C**=BSPower*2 + rxlevelSubservercell.
- **I*i,j***=Potential interferer's rxlevel (dBm).
- Each MMR contains up to six I-values.

$$FEP = \frac{1}{1+e^{a+bCIRij}} \qquad (4)$$

All the cell agents are referenced from the collective memory map. Once all the cell agents have been created the process begins. The swarm of agents is created by iterating through the collective memory map and spawning each cell agent. Each cell agent then determines its interference. An important rule is that a cell agent is only allowed to adjust its own channels. The cell agent cannot adjust its interferer's or neighbour's channels. A cell agent will adjust its own channels depending on how the channels interferer with other cell agents' channels (i.e. the cell agent's interferers and neighbours channels). Weights are assigned to each channel depending on the amount of interference that channel is experiencing. Thus a channel with a large amount of interference will have a large weighting. If a certain channel of the cell agent interferes with a channel from one of the cell agent's interferers or neighbours then that specific channel is weighted accordingly.

If the interference is co-channel i.e. the channels have the same frequency values then the channel is weighted for co-channel interference. Similarly, if the interference is adjacent channel interference i.e. the channels are adjacent to each other (separated by one) then the channel is weighted for adjacent channel interference. The weightings are found in the interference matrix. Channels are also checked against locally blocked channels, handovers, co-site and co-cell separation. Channels violating these checks are weighted heavily i.e. a large value typically 1000. Thus channels with the lowest weighting are queued to the front of the selection queue while the highest weighted channels are queued at the back. Once the cell agent has picked the channels with the least interference from the selection queue (i.e. the best channels) it will update its channels with these selections.

If the cost value or NQI (defined in equation 1 (Eisenblätter 2000)) is greater than the previous cost value then the localized adjustments made by the cell agent are not beneficial to the collective. Non beneficial adjustments are dropped and the old channels of the cell agent are reloaded. The cost value is then assigned to the previous cost value. In the case where the cost value is equal to the previous cost then no adjustment has been made i.e. the cell agent is content with its current channel settings.

If the cost is less than the lowest cost then the cell entities have made a localized adjustment to their channels that have benefited the collective. In this scenario the global interference is lower than it was previously and the adjustment is accepted. The lowest cost is then set to the current cost and the collective memory map is update with the recent changes. The process is terminated by the user once a satisfactory cost value is achieved.

Predators are introduced into the system when trying to break a local minimum. A local minimum can be defined as a minimum found by the system but that minimum is not a global minimum. Predators are used to cause perturbations in the collective by randomly selecting a cell agent and then randomly changing the cell agent's channels. If the cell agents are randomly changed this will cause a major perturbation in the interference resulting in a change in the cost value or NQI. If the change caused by the predators is within a certain threshold value then the change is allowed otherwise the change is dropped and another attack by the predators is allowed. Each predator will only select and attack a single cell agent out of the collective. A beta parameter is used to reduce the number of predators every time a new lowest cost is found. An alpha parameter is used to reduce the threshold value as time progresses.

At startup the threshold value will be set large enough so that the system will accept many of the changes made by the predators i.e. the system is very volatile allowing a greater search space. However, as the process matures the selection on changes caused by the predators will become more conservative. Thus, allowing the process to be less volatile as it matures. As the process matures the threshold value will grow smaller allowing the process to settle into a more stable state.

4 COST 259 BENCHMARK

The effectiveness of the swarm effect algorithm is demonstrated by applying the algorithm to the COST 259 benchmarks (Eisenblatter and Koster, 2007). These instances are widely used in the mobile telephone industry. The best cost values found by the SEMA for the Siemens instances were compared to the following: DTS (Glamorgan) a dynamic tabu search method (Eisenblatter and Koster, 2007), KTHIN a simulated annealing combined with dynamic programming to compute local optima method (Mannino *et al*., 2002),, TUHH a simulated annealing (Beckmann and Killat, 1999). RWTH a threshold accepting method (Hellebrandt and Heller, 2000) TA a threshold accepting method (Hellebrandt and Heller, 2000) and U(Siemens) an unknown method (Eisenblatter and Koster, 2007). The COST 259 scenarios used are described in Table 1.

The results from these methods were obtained from the FAP website (Eisenblatter and Koster, 2007) and are presented in Table1. The comparison of these results and the results obtained with the SEMA are also presented in Table 1. The columns described in table 1 are the total cost, the maximum co-channel, adjacent channel and TRX values as well as the total number TRX pairs exceeding an interference of x where $x€(0.01, 0.02, 0.03, 0.04)$. The emphasis was on the ultimate quality of the solution so the SEMA solutions did not take time into consideration i.e. the application was run until an acceptable solution was found. However, it should be emphasized that the SEMA can produce satisfactory results in times that range from 45 minutes to several hours. These times are acceptable in a commercial environment. For example a cost minimization value of 3.21 was achieved in 45 minutes for the Siemens 1 scenario utilizing ten predators, alpha = 0.95 and beta = 0.99. Best results were found when using less than twenty predators, 0.9≤alpha≤0.99 and 0.9≤beta≤0.999 in all the COST 259 scenarios.

Table 1: COST 259 Siemens scenarios.

App	Cost	Co	Adj	TRX	TRX pairs exceeding			
Siemens 1: GSM 900 network with 179 active sites, 506 cells, and an average of 1.84 TRXs per cell. The available spectrum consists of two blocks containing 20 and 23 frequencies, respectively								
App	Cost	Co	Adj	TRX	TRX pairs exceeding			
					.01	.02	.03	.04
K-THIN	2.20	0.03	0.03	0.05	33	4	1	0
TUHH	2.78	0.04	0.04	0.08	60	14	6	0
RWTH	2.53	0.03	0.03	0.06	48	11	3	0
TA	2.30	0.03	0.03	0.05	43	7	2	0
U	3.36	0.05	0.04	0.12	78	25	10	3
SEMA	2.35	0.03	0.03	0.06	44	9	2	0
Siemens 2: GSM 900 network with 86 active sites, 254 cells, and an average of 3.85 TRXs per cell. The available spectrum consists of two blocks containing 4 and 72 frequencies, respectively								
App	Cost	Co	Adj	TRX	TRX pairs exceeding			
					.01	.02	.03	.04
DTS	14.28	0.11	0.02	0.20	343	89	24	18
K-THIN	14.27	0.07	0.02	0.16	359	71	27	17
TUHH	15.46	0.07	0.02	0.18	404	109	42	20
RWTH	14.75	0.06	0.02	0.17	268	91	34	13
TA	15.05	0.11	0.02	0.20	381	92	37	15
U	17.33	0.08	0.02	0.20	462	148	47	18
SEMA	14.86	0.08	0.02	0.17	364	87	41	14
Siemens 3: GSM 900 network with 366 active sites, 894 cells, and an average of 1.82 TRXs per cell. The available spectrum comprises 55 contiguous frequencies.								
App	Cost	Co	Adj	TRX	TRX pairs exceeding			
					.01	.02	.03	.04
DTS	5.19	0.04	0.03	0.07	88	14	3	0
K-THIN	4.73	0.03	0.02	0.08	80	6	0	0
TUHH	6.75	0.05	0.03	0.11	137	31	9	2
RWTH	5.63	0.03	0.03	0.07	103	15	3	0
TA	5.26	0.04	0.03	0.07	87	10	3	0
U	8.42	0.05	0.04	0.12	188	47	18	6
SEMA	5.76	0.03	0.03	0.08	101	28	3	0
Siemens 4: GSM 900 network with 276 active sites, 760 cells, and an average of 3.66 TRXs per cell. The available spectrum comprises 39 contiguous frequencies								
App	Cost	Co	Adj	TRX	TRX pairs exceeding			
					.01	.02	.03	.04
DTS	81.88	0.20	0.05	0.43	2161	971	547	344
K-THIN	77.25	0.19	0.05	0.36	2053	871	445	282
TUHH	89.15	0.24	0.03	0.53	2350	1056	591	368
RWTH	83.57	0.18	0.04	0.35	2251	1006	540	343
TA	80.97	0.17	0.03	0.36	2143	933	502	328
U	105.82	0.27	0.04	0.53	2644	1286	798	562
SEMA	81.96	0.21	0.05	0.48	2181	991	549	353

5 RESULTS OF IMPLEMENTATION

The SEMA was tested on a commercial mobile telecommunications network in South Africa, namely MTN. The SEMA was applied to one operational base station controller (BSC). There were 349 cells with an average of 3 transmitters per cell in the BSC. The available spectrum consisted of two blocks containing 24 and 31 frequencies, respectively. The frequency plan produced by the SEMA took on average several days to produce. The frequency plan produced by the SEMA was also implemented into the mobile telephone network. The %DROP (percent drop) parameter represents the percentage of abnormal disconnections (drop calls) on the BSC in a mobile cellular network. From figure 1 it is clear that there was a decrease in the %DROP on the BSC after the SEMA frequency plan was implemented. This can be seen by studying the %DROP before and after the vertical yellow broken line. The vertical yellow broken line depicts the point at which the SEMA was implemented into the BSC (see the label “Swarm AFP run in”). Swarm AFP stands for the Swarm automatic frequency planner that implements SEMA. The measurement before this mark depicts the initial network measurements while all measurements after the mark depict the network after the SEMA frequency plan was implemented. The decrease in the %DROP was a substantial 0.4 on the %DROP scale. This may not seem significant, but in terms of the %DROP on a cellular network that prides itself on its low %DROP, a decrease of 0.4 is amazing. An improvement of 0.4 on the %DROP scale on a BSC carrying a large amount of traffic can equate to a large addition in revenue. To substantiate the actual decrease of a 0.4% on the %DROP scale, the traffic (erlang rate) would have to have remained constant, since a decrease in the erlang rate would also cause a decrease in the %DROP. However, by studying figure 1 it can be seen that the erlang rate remained constant (see the horizontal black broken line which represents the erlang gradient), while there was a distinct decrease in the %DROP after the SEMA was implemented. Usually when a frequency plan is implemented an increase in the %CFAIL is experienced. The %CFAIL (percent channel failure) parameter represents the percentage failure rate in the ability to seize a traffic channel. The reason for this is that most frequency plans relax the adjacent channel rule for the traffic channels, as the major concern is to minimize co-channel interference on the TCHs and to ensure that there is absolutely no co-channel or adjacent channel interference between the BCCH and TCHs. Again, an encouraging feature noted in figure 1 is that the BSC did not suffer from an increase in the %CFAIL. The %CFAIL remained fairly constant after the SEMA implementation. This indicates that the actual frequency planning that was taking place by the SEMA was of good quality. Overall the SEMA frequency plan performed fairly well by decreasing the %DROP by 0.4% on the %DROP scale and did not cause the %CFAIL to fluctuate in an increasing way after the frequency plan was implemented.

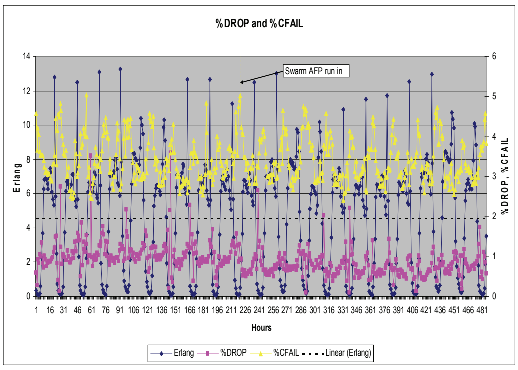

Figure 1: %DROP and %CFAIL for the operational BSC before and after the Swarm AFP run.

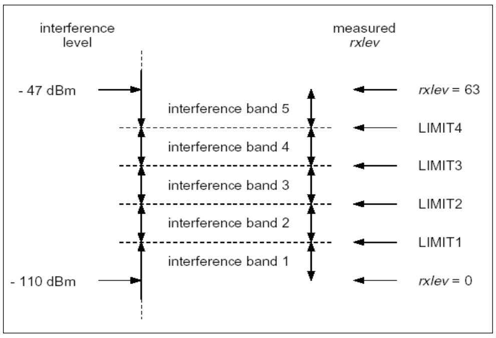

Figure 2: Interference bands 1 to 5.

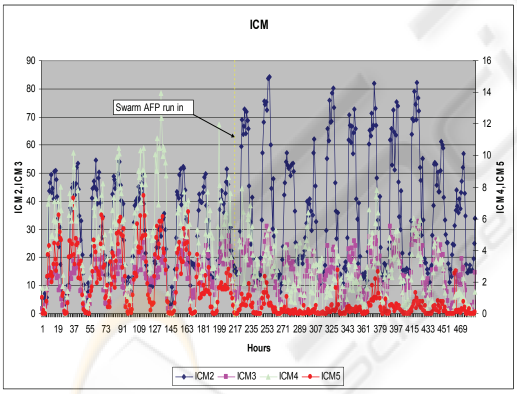

Figure 3: ICMs for operational BSC.

The idle channel measurement (ICM) parameter is explained with the use of figure 2. There are five interference bands, each marked by a limit. For example, interference band 1 ends at limit 1 and interference band 2 ends at limit 2. This continues up to interference band 5, which is the last interference band. The limits 1 to 5 are represented by the ICM parameters, namely ICM1 to ICM5, respectively. The ICM band parameters provide an indication of the level of interference in the cell.

A large number of points in the ICM4 and ICM5 bands indicates a large amount of interference in the BSC and is a very unfavourable situation. From figure 3, it can be seen that the more points in band 5, the more the interference (~-47dBm), while interference band 1 has much less interference (~110dBm). Thus ICM5 is worse than ICM4 and similarly ICM4 is worse than ICM3 and so on. The ideal situation in a mobile cellular network BSC is to have all points located in ICM1 and ICM2, a smaller number of points in ICM3 and virtually no points in ICM4 and ICM5.

Figure 3 depicts the actual idle channel measurements for the BSC before and after the SEMA frequency plan was implemented. Remember that the vertical yellow broken line represents the point at which the frequency plan was implemented into the BSC. It is apparent from the measurements in figure 3 that there was a drastic drop in ICM5 and ICM4 parameter values after the SEMA was implemented into the BSC. There was also an extensive improvement in ICM2 after the implementation of the SEMA frequency plan. This again proves that the SEMA frequency plan has made considerable improvements to the BSC. The BSC was optimized to the ideal situation with regard to the ideal channel measurements. The number of points has decreased in the ICM4 and ICM5 bands, while the ICM2 band has increased considerably.

6 CONCLUSIONS

In this paper an engineering problem of high practical relevance has been addressed, a relatively simple optimization approached based on a particular search scheme, namely the swarm effect minimization algorithm (SEMA) has been designed and implemented using a multi-agent model. The SEMA was benchmarked against the COST 259 benchmarks, in particular the Siemens set of problems. The SEMA was then implemented into a commercial mobile telephone network in South Africa, namely MTN. It was shown that the SEMA produced encouraging results when applied to the COST 259 Siemen's problems. The results were compared to the current results published on the FAP website (Eisenblatter and Koster, 2007) and the SEMA closely match some of the best results. One of the most important characterizing aspects produced in the swarm effect minimization algorithm is the use of the stigmergetic model of communication. This allows the cell agents to be directed by the formation of the ever changing assignments of frequencies in the network. The cell agents form the swarm. This novel approach of allowing the changes in the structure of the network frequencies (i.e. the environment) to guide the actual selection and determination of assigned frequencies is the main reason for the improvements displayed by the SEMA.

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