Channel Allocation for Third-generation Mobile Radio Systems

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A range of Dynamic Channel Allocation (DCA) techniques are studied comparatively in the context of the GSM-like system, with the aim of increasing the system's carried traffic performance. The locally optimised least interference algorithms (LOLIA) emerges, as the best overall candidate, potentially increasing the teletraffic capacity of fixed channel allocation schemes by up to 80 %.

1 Dynamic Channel Allocation

Dynamic channel allocation (DCA) techniques have been discussed in detail in the excellent overview paper of Katzela and Naghshineh[1]. Zander [2] investigated the limitations of radio resource management in future wireless networks, while Peha et al [3] discussed the practical problems that may be encountered in designing a DCA based mobile radio system.

In dynamic channel allocation all sufficiently high-quality, un-interfered channels can be allocated to users becoming active. DCA algorithms have to balance the increased teletraffic capacity gain upon allocating unused channels to users against the potential co-channel interference inflicted to users already in the system. Due to lack of space here no formal classification of the various DCA techniques can be considered. Instead, we focussed our attention on the comparative study of the family of distributed DCA techniques, which exhibit typically lower complexity and slightly reduced performance in comparison to centralised DCA algorithms. A range distributed DCA algorithms were investigated by Chuang et al [4]. As compromise schemes, locally optimised distributed DCA algorithms were proposed for example by Delli Priscoli et al [5, 6].

2 Distributed Dynamic Channel Allocation Algorithms

In this contribution we have comparatively studied four DCA algorithms. In the so-called Least Interference Algorithm (LIA) an unused channel exhibiting the least interference is allocated to a new call, hence this technique attempts to minimize the total interference within the system. This algorithm ensures low interference load at low traffic loads, but increases the interference inflicted at high traffic loads.

The second DCA algorithm we consider is the so-called Least interference below Threshold Algorithm (LTA), attempting to reduce the interference caused by the LIA algorithm at high traffic loads, by blocking calls on channels, which are excessively interfered. Explicitly, the algorithm allocates the least interfered unused channel to new calls, provided that their interference is below the interference threshold required by the transceiver employed. Therefore the LTA algorithm attempts to minimize the overall interference in the system, while maintaining the quality of each call above the minimum acceptable level, which is a transceiver-dependent parameter.

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Parameter	**Value**	**Parameter**	**Value**
Noisefloor	-104dB	Pathloss Exponent	3.5
Multiple Access	TDMA	No. of timeslots	8
Frame length	0.004615s	No. of carriers	7
BS max TX power	10dBm	MS max TX power	10dBm
Average call-length	60s	Average inter-call-time	300s
MS speed (uniform traffic)	13.4m/s (30mph)	MS speed (nonuniform traffic)	$\leq$13.4m/s ($\leq$30mph)
No. of Basestations simulated	49	Max new-call queue-time	5s
Handover hysteresis	2dB	Cell radius	218m

Table 1: GSM-like system parameters

The third DCA technique we investigated attempts to utilise the frequency spectrum more efficiently, while maintaining an acceptable signal quality. This algorithm operates similarly to the LTA technique and it is referred to as the Highest (or Most) interference below Threshold Algorithm (HTA or MTA), where the latter terminology was advocated by Bernhardt [7, 8]. Since its goal is to maximise the carried traffic, upon serving a new call it opts for the most interfered channel, whose interference is below the maximum tolerable interference threshold determined by the call quality required. Again, this is a transceiver-dependent threshold.

The final distributed DCA algorithm we investigated is the so-called Lowest Frequency below Threshold Algorithm (LFA). This algorithm is a derivative of the LTA algorithm, the difference being that it attempts to reduce the number of carrier frequencies used concurrently. This has the advantage that on average less transceivers are required at each base station (BS). The algorithm allocates the least interfered channel, which has to satisfy the maximum tolerable interference criterion, while also attempting to reduce the number of carrier frequencies used. Therefore a new carrier frequency is not invoked, unless all the available channels on the currently used carrier frequencies are considered excessively interfered.

3 Locally Distributed Dynamic Channel Allocation Algorithm

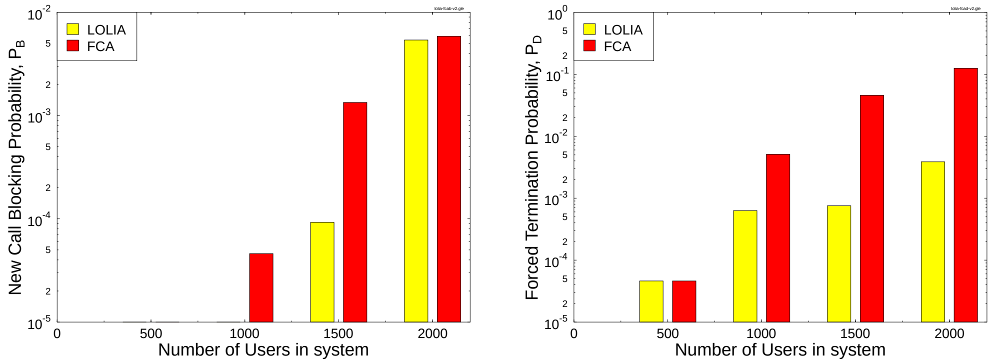
Locally distributed DCA algorithms are a hybrid of distributed and centrally controlled channel allocation decision making. They use information provided by neighbouring BSs, in order to improve the channel allocation decisions. Their complexity is therefore between that required for central and distributed control algorithms.

The first locally distributed DCA algorithm we investigated is the so-called Locally Optimised Least Interference Algorithm (LOLIA). Its makes its channel allocation decisions in the same way as the distributed LIA algorithm, however it will not allocate an otherwise adequate quality channel, if it is used in the nearest "n" neighbouring cells. Therefore the nearby BSs exchange information about channels that are currently being used. This requires a fast backbone network, but it is not reliant on central control. The overall level of interference in the system can be reduced by increasing the number of cells, which are classed as neighbouring cells. However, the larger "n", the more calls are blocked, since there will be less available channels, which are not used by the nearest "n" BSs.

The second locally distributed DCA algorithm we consider is similar to the LOLIA, but it is based on the HTA philosophy, and not on the LIA distributed algorithm. This technique is referred to as the Locally Optimised Most Interference Algorithm (LOMIA). This algorithm picks the most interfered channel, provided that the channel is not used in the nearest "n" neighbouring cells. Let us now focus our attention on the performance comparison of these techniques.

4 Performance Comparisons

In order to compare the performance of the various DCA algorithms, the algorithms were simulated in the context of a GSM-like system, the parameters of which are defined in Table 1. We investigated the algorithms under uniform and non-uniform traffic distributions, and under a variety of traffic loads.



(a) Blocking Probability (b) Forced Termination Probability

Figure 1: Blocking and Forced termination performance versus number of users comparison of the Locally Optimized Least Interference Algorithm with 7 “local” BSs and of fixed channel allocation (FCA) using a 7-cell reuse cluster under uniform traffic.

4.1 Performance Metrics

There are several performance metrics that can be used to quantify the performance or quality of service provided by a particular channel allocation algorithm. The four performance metrics defined below have been widely used in similar performance studies.

- Call Blocking probability, P_B = probability that a new call is denied access to the network.
- Call Dropping or Forced Termination probability, P_D = probability that a call in progress is forced to terminate early.
- Probability of low quality connection, P_{low} = probability that the uplink or downlink signal quality is below the transceiver-specific level required to maintain a good quality connection. This could be due to low signal strength or high interference. Hence it is defined as:

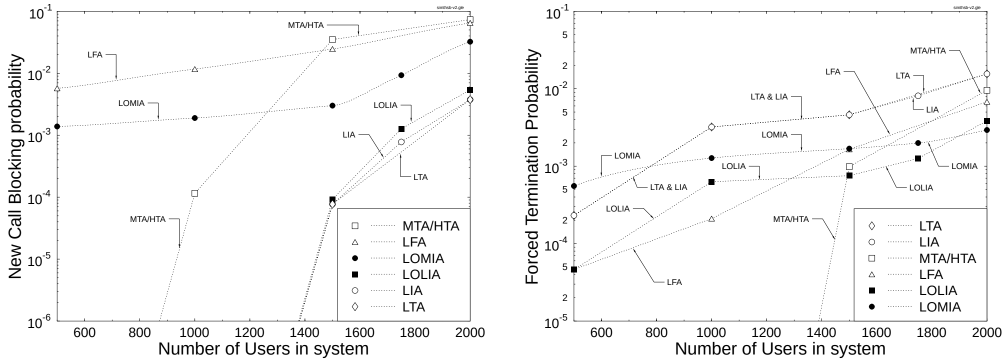
$$\begin{aligned} P_{low} &= P\{SINR_{uplink} < SINR_{req} \text{ or } SINR_{downlink} < SINR_{req}\} \\ &= P\{min(SINR_{uplink}, SINR_{downlink}) < SINR_{req}\} \qquad (1) \end{aligned}$$

- Grade of Service, GOS = probability of unsuccessful or low quality network access, defined as:

$$\begin{aligned} GOS &= P\{\text{unsuccessful or low-quality call accesses}\} \\ &= P\{\text{call is blocked}\} + P\{\text{call is admitted}\} \times \\ &\quad P\{\text{low signal quality and call is admitted}\} \\ &= P_B + (1 - P_B)P_{low} \qquad (2) \end{aligned}$$

4.2 Comparing the LOLIA (DCA) Algorithm with fixed channel allocation (FCA) algorithm

Firstly we compared the fixed channel allocation (FCA) and the locally optimised least interference DCA algorithm (LOLIA) under uniform traffic conditions. The fixed channel allocation used a seven cell reuse cluster, corresponding to one carrier frequency per BS. The LOLIA algorithm imposed the constraint of seven nearest BSs, ie $n = 7$. Figure 1 shows the call blocking and call dropping probability for different uniform traffic loads, measured in terms of the total number of users in the system. The Figure shows that LOLIA has lower blocking and lower forced termination probabilities than FCA. LOLIA also outperforms the FCA algorithm in terms of better (lower) grade of service and less low quality accesses. This is due to its adaptive nature, and due to the higher number of potential channels available at each BS.



(a) Blocking Probability (b) Forced Termination Probability

Figure 2: Comparison of distributed DCA algorithms (LIA, LTA, MTA, LFA) with locally distributed DCA algorithms (LOLIA, LOMIA) using an uniform traffic distribution.

4.3 Comparing distributed and locally distributed DCA algorithms

Again, the interference threshold based DCA algorithms limit the maximum tolerable interference, in order to maintain a transceiver-specific minimum required signal quality. Generally a channel allocation algorithm will not allocate a channel, if the interference in that channel is higher than the interference threshold. Therefore relaxing the interference threshold allows more interfered channels to be allocated to new calls. The effective reuse distance in an interference threshold based DCA algorithms is dependent on the interference threshold. As the interference threshold is relaxed, for example due to using a more interference-resilient transceiver, the effective reuse distance is decreased, allowing more calls to be handled at the expense of higher interference.

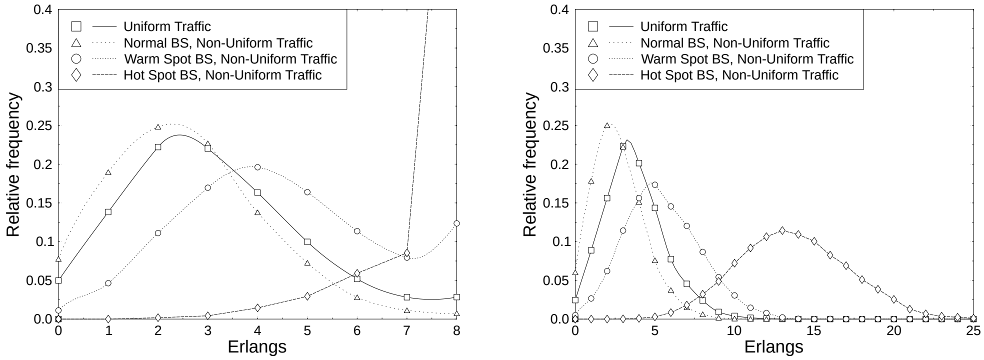
During our performance studies we found that the optimal interference threshold for the LTA, MTA, and LFA was extremely sensitive to traffic loads and propagation conditions. This meant that the interference threshold has to be adapted to time-variant conditions. This would render the interference threshold based distributed DCA algorithms more complex, and difficult to implement. The optimal interference thresholds were found by simulation, for the range of traffic loads investigated in the context of the three interference threshold based algorithms, namely LTA, MTA, and LFA.

Figure 2 shows the call blocking and dropping probabilities versus traffic loads measured in terms of the number of users within the system. The Figure shows results for four distributed DCA algorithms and for the locally distributed algorithms, LOLIA and LOMIA. It can been seen that the LTA algorithm has similar call blocking performance to LOLIA, however it is worse in terms of call termination probability due to the increased co-channel interference in the system. The locally distributed LOLIA and LOMIA algorithms outperform the distributed algorithms at high traffic loads in terms of call dropping, and only the LTA has lower blocking at high loads.

4.4 Performance comparison using non-uniform traffic distributions

Generally investigations using fixed channel allocation assume a uniform traffic distribution, and therefore a uniform carrier frequency allocation per BS. In practice some BSs have more channels, where the demand is expected to be higher. However, fixed channel allocation cannot cope with unexpected traffic demand peaks, which are sometimes referred to as traffic "hot-spots". DCA algorithms can cope with these unexpected traffic demands, since a DCA system is effectively a self-adapting system. Furthermore, DCA schemes typically have more potential channels available at each BS. This is an area in which DCA algorithms have a clear advantage over FCA.

In order to show the performance benefits of DCA under non-uniform traffic conditions, we simulated the performance of FCA and some DCA algorithms using a non-uniform traffic model. We decided to have a "hot-spot" cell, surrounded by less heavily loaded cells for our non-uniform traffic distribution scenario. In the cell exhibiting the heaviest traffic the mobile stations (MS) are limited to a maximum speed of



(a) FCA

(b) LOLIA

Figure 3: PDF of the number of instantaneous calls at a BS in terms of Erlang, for uniform traffic and the three possible cells types in non-uniform traffic. Results are shown for the Fixed Channel Assignment Algorithm (FCA) and for the Locally Optimized Least Interference Algorithm Dynamic Channel Assignment (DCA) Algorithm (LOLIA).

4m/s (9mph). This "hot-spot" cell is surrounded by six reduced-traffic cells, in which the maximum speed is limited to 9m/s (20mph). In the remaining cells the MSs move with a constant velocity of 13.4m/s (30mph). The effect of these reduced-velocity "hot-spot" cells is that the MSs stay longer in these cells, increasing the terminal density and the associated teletraffic density.

Figure 3 shows the PDF of instantaneous traffic measured in Erlang at a range of BSs using uniform and non-uniform traffic distributions for both fixed and dynamic channel allocation algorithms. The Figure shows the traffic PDF at each of the three types of BSs in the non-uniform traffic distribution scenario. It can be seen that with FCA the maximum carried traffic is limited to 8 Erlang, as clearly shown by the PDF for the 4 m/s 'hot-spot' and for the 9 m/s cells. It can be seen that the DCA algorithm can cope with traffic demands in excess of 20 Erlang in the "hot-spot" cell under non-uniform traffic. Clearly, these results have shown the benefits of DCA in terms of being able to cope with unexpected peaks of demand in traffic.

4.5 Overview of Results

In order to compare our results from fixed and various dynamic channel allocation algorithms, it is necessary to consider more than one performance metric. Sometimes an algorithm may provide excellent performance in terms of one metric, but poor performance in another. Therefore we decided to invoke two different scenarios, in order to compare our results:

- A *conservative scenario*, where the maximum acceptable value for the blocking probability P_B is 3%, for the dropping probability P_D is 1%, for P_{low} is 1%, and for the GOS is 4%
- A *lenient scenario*, in which the dropping probability P_D still must be less than 1%, but the maximum tolerable blocking probability P_B is 5%, P_{low} is 2%, and the GOS is 6%.

The maximum traffic load, measured in terms of the number of users in the system, that could be served, while maintaining the constraints imposed by the above two scenarios is shown in Table 2. The Table shows results for uniform and non-uniform traffic distributions. The user population of the Table is distributed over the 49 cell simulation area, which is $6km^2$, therefore 1200 users represent a user density of 198 users/Km^2. However, the users in our investigation generate a high traffic, making on average a 1 minute call every 6 minutes. If the users were less active, a higher user density may be supported. Notice that the LOLIA algorithm can support the highest traffic under the constraints imposed.

Algorithm	UT		NUT	
	Con.	Len.	Con.	Len.
FCA	≈1200	≈1200	≈1000	≈1000
LOLIA	≈1900	> 2000	≈1550	> 1750
LOMIA	≈1500	> 2000	≈1450	≈1600
LIA	≈1800	≈1800	≈1350	≈1350
LFA	≈1600	≈1850	—	—
LTA	≈1800	≈1800	—	—
MTA	≈1400	≈1400	—	—

Table 2: Maximum number of users supported by the system using the algorithms investigated and considering conservative constraints (Con.) and lenient constraints (Len.), under uniform traffic load with a 4QAM modem (UT) and nonuniform traffic (NUT).

5 Conclusions

In this paper we have compared fixed and dynamic channel allocation algorithms. We have shown the potential benefits of dynamic channel allocation, which can cope with exceptionally high, non-uniformly distributed traffic demands. DCA also simplifies the the frequency planning. There are several disadvantages, however, which have to be overcome, in order to use DCA in practical high capacity systems. The disadvantages are longer call setup delays, complex call control, the requirement of a fast backbone network, and more frequency agile transceivers. Best overall performance was offered by the LOLIA algorithm. However, this is essentially based on the simple distributed LIA algorithm, and hence slightly more complex algorithms based on LOLIA may give even better performance and increased capacity, an issue, which is the subject of our future work.

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