ADAPTIVE BEAMFORMING ASSISTED DYNAMIC CHANNEL ALLOCATION

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ABSTRACT

This paper is concerned with the comparative study of fixed channel allocation (FCA) and dynamic channel allocation (DCA) algorithms [1–3], many of which were proposed and studied, in terms of the achievable Grade-of-service (GOS), by Chuang et al throughout the past few years. The performance gains that may be obtained using adaptive antenna arrays at the basestation are also determined, along with a range of further performance measures, such as carried traffic, call blocking, call dropping, the probability of low quality access and outage. The comparisons are carried out for a range of channel allocation techniques under identical uniform traffic conditions, where all users seemlessly roam across the simulation area, rather than simply assigning them to arbitrary, uncorrelated, but essentially stationary random positions.

1. INTRODUCTION

The recently emerging micro/picocellular frequency reuse structures increase the user capacity and area spectral efficiency of the system, although often at the cost of reduced frequency reuse distance and hence increased co-channel interference. Sectorisation techniques, interference cancellation or adaptive antennas [4] have been proposed to mitigate the co-channel interference inflicted.

The physical layer is simply modelled using two parameters, namely the 'Outage SINR' and 'Reallocation SINR'. When the signal quality, or signal-to-interference+noise ratio (SINR), drops below the reallocation SINR, then the mobile requests a new physical channel to handover to, initiating an intra-cell or inter-cell handover. If, while waiting for a reallocation handover, the signal quality drops further, below the so-called 'Outage SINR', then outage is encountered, a prolonged outage leads to call dropping or forced termination. The values used in the simulations are contained in Table 1.

We investigated FCA and locally distributed DCA algorithms, with and without adaptive antenna arrays at the basestations. Dynamic Channel Allocation (DCA) techniques offer substantially improved call-blocking, packet dropping, and grade-of-service performance, in comparison to Fixed Channel Allocation (FCA), at the cost of increased infrastructure complexity. A range of so-called distributed DCA algorithms were investigated by Chuang et al [3]. As compromise schemes, locally optimised distributed DCA algorithms were proposed, for example by Delli Priscoli et al [5]. In our previous work we conducted a comparative study of a range of DCA algorithms and found that the best overall compromise was constituted by the so-called Locally Optimised Least Interference Algorithm (LOLIA).

The reduction of frequency reuse distance motivated by achieving increased area spectral efficiency results in increased levels of co-channel interference. Adaptive antennas can be used to mitigate these problems [4,6], since they may exploit the spatial dimension, i.e, the physical separation between co-channel users, in order to increase the network capacity. Since an adaptive antenna may receive signals strongly from one direction, whilst nulling signals arriving from other directions, it is inherently suited to an interference limited cellular network. Thus a beam may be formed to communicate with the desired mobile, whilst nulling interfering mobiles [4]. Assuming that each mobile station is uniquely identifiable, it is a relatively simple task to calculate the antenna array receiver weights so as to maximize the received SINR. However, due to the generally uncorrelated up- and down-link channels of Frequency Division Duplexing (FDD), the weights used for the down-link are not suitable for the up-link. Hence, it has been proposed to use a feedback loop from the mobile to the base station, thus allowing the transmitter weights to be adjusted [7]. Alternatively, using Time Division Duplexing (TDD) with a suitably small dwell time allows the complex conjugate of the receive antenna weights to be used as the transmit weights [4].

2. SYSTEM PARAMETERS

The performance of the various channel allocation algorithms was investigated in a GSM-like microcellular system, the parameters of which are defined in Table 1. The number of carrier frequencies in the whole system was limited to seven, each with eight timeslots, in order to accelerate our simulations. Thus, a DCA system could theoretically handle a maximum of $7 \times 8 = 56$ simultaneous calls at one basestation. Power control was not used. If a channel allocation request for a new call could not be satisfied immediately, it was queued for up to 5s, after which time, if not serviced, it was classed as blocked. The mobiles moved freely, in random directions, at a speed of 30mph within the simulation area, which comprised a regular hexagonal 49-cell grid, with a cell radius of 218m. The call length and

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inter-call periods were Poisson distributed with the mean values shown in the Table.

The reference signal length of eight bits was a compromise between complexity, the number of uncorrelated reference signals for assignment to the interfering mobiles, and the quality of estimation of the co-variance matrix. One of the eight reference signals was assigned to the desired mobile and the remaining seven were allocated to interfering mobiles.

Line-Of-Sight (LOS) and multipath environments were considered, for both of which the transmit/receive channel was assumed to be identical, thus allowing the same antenna pattern to be used in both the up- and the down-links, as in a TDD system. The multipath environment consisted of the direct ray and two additional rays, each having a third of the direct ray power. The Geometrically Based Single-Bounce Elliptical Model (GBSBEM) of [8] was used to generate the angles of arrival of these multipath rays. It was assumed that these rays arrived with no time delay. In a real system, the multipath rays would have an associated time delay, causing them to be nulled, unless a space-time equalizer [9], was employed.

3. PERFORMANCE STUDY

The results presented here are the combination of adaptive beamforming at the basestation and fixed and dynamic channel allocation algorithms.

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 following performance metrics have been widely used in the literature and were also advocated by Chuang [3]:

- New Call Blocking probability, P_B
- Call Dropping or Forced Termination probability, P_D or P_{FT}
- Probability of low quality connection, P_{low}, quantifying the chances that either the uplink or downlink signal quality is below the level required by the specific transceiver to maintain a given target performance.
- Probability of Outage, P_{out} is defined as the probability that the SINR value is below the minimum SINR to maintain a call.
- Grade of Service, GOS was defined by Cheng and Chuang [3] as:

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

3.1. Comparing the LOLIA with FCA for LOS

Firstly we compared the FCA and the LOLIA DCA (7 and 19 cell exclusion zones) algorithms using both a single antenna element, as well as two and four element adaptive antenna arrays in a LOS propagation environment.

Figure 1 shows the Grade-Of-Service (GOS) versus the mean normalized carried traffic, expressed in terms of Erlangs/ km^2/MHz. The LOLIA algorithm, with an exclusion zone of 19 cells, offers a good GOS performance measure for lower traffic levels. However, for high user loads, the GOS deteriorates very rapidly, with little increase in the teletraffic carried above 140 Erlangs/km^2/MHz, corresponding to 1600 users. This is mainly attributable to the large exclusion zone, in which the same channel may not reallocated, thus leading to a high call blocking probability. The LOLIA 7 algorithm does not suffer from this constraint and continues to offer good performance for high user loads, with the adaptive antennas improving the GOS, whilst enabling additional traffic to be carried.

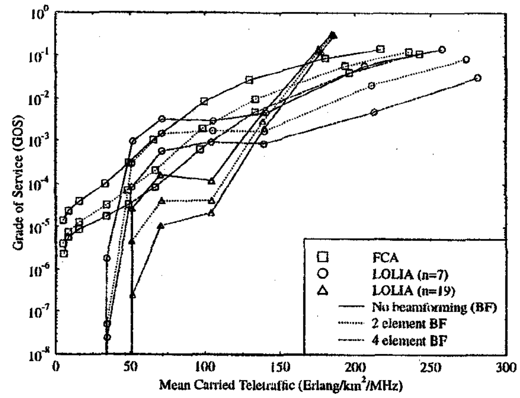

Figure 1: Grade-Of-Service performance versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for a single antenna element as well as 2 and 4 element antenna arrays with beamforming in a **LOS environment.**

From Figure 2 it can be seen that the LOLIA 19 algorithm performs the lowest number of handovers, with beamforming barely altering the results. In contrast, the number of handovers performed, when using the FCA algorithm, is reduced significantly when using adaptive antennas, with a maximum reduction of 81% for two elements, and of 92% for four elements. This results in a significantly reduced network load, therefore reducing the network infrastructure cost and complexity. The LOLIA 7 algorithm also benefitted, but to a much lesser extent, with a maximum reduction of only 12%, in terms of the number of handovers.

3.2. Comparing the LOLIA with FCA over multipath channels

The FCA and LOLIA channel allocation schemes were then examined in a multipath environment in conjunction with two, four and eight element adaptive antennas.

For a given number of antenna elements in the adaptive array the GOS of the FCA algorithm in the multipath scenario was half as good as that for the LOS situation, as illustrated by Figures 1 and 3. However, the GOS of the LOLIA 7 algorithm was improved over the multipath environment for user loads of less than 172 Erlangs/km^2/MHz. A similar situation is observed for LOLIA 19, where superior GOS was obtained for lower traffic levels, but as the traffic increased, the GOS approached that of the LOS situation. The probability of low quality access occurring was

Parameter	Value	Parameter	Value
Noisefloor	-104dBm	Multiple Access	TDMA
Frame length	0.4615ms	Cell radius	218m
BS transmit power	10dBm	MS transmit power	10dBm
BS power control	No	MS power control	No
Number of basestations	49	Handover hysteresis	2dB
Outage SINR threshold	17dB	Re-allocation SINR threshold	21dB
Modulation scheme	4QAM	Pathloss exponent	-3.5
Number of timeslots	8	Number of carriers	7
Average inter-call-time	300s	Max new-call queue-time	5s
Average call length	60s	Reference signal modulation	BPSK
Beamforming algorithm	SMI	Reference signal length	8 bits
MS speed	30mph	Number of antenna elements	2, 4 & 8

Table 1: GSM-like simulation parameters.

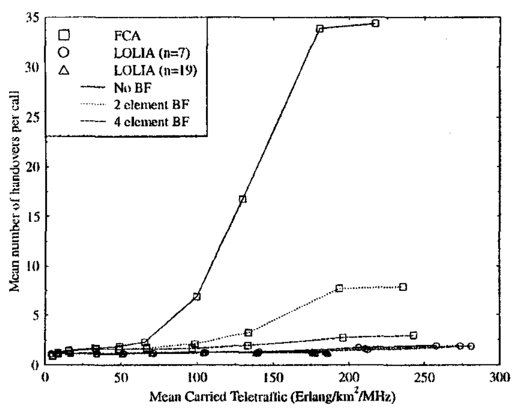

Figure 2: Mean number of handovers per call versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for a single antenna element as well as 2 and 4 element antenna arrays with beamforming in a **LOS environment**.

strongly related to the GOS by Equation 1 and thus the simulation results obtained bore a close resemblance to those of the GOS.

Figure 4 shows the mean number of handovers per call in a multipath environment. The LOLIA 19 algorithm offered the same low number of handovers for both propagation environments and no improvement by increasing the number of antenna elements was observed. The LOLIA 7 scheme was amenable to the multipath environment with less than 3.5 handovers per call required, when the network was loaded with 270 Erlangs/km^2/MHz. However, the FCA algorithm requested many more handovers than the LOLIA techniques, and its performance degraded in the multipath scenario with almost four times as many handovers per call being performed in the worst cases.

The blocking probabilities shown in Figure 5 illustrate the superior blocking performance of the LOLIA 7 algorithm, and the benefits of using it in conjunction with larger antenna array sizes. The probability of blocked calls using the FCA scheme gently increased, with the adaptive antenna offering a slight performance gain, as the number of elements increased. However, the LOLIA 19 algorithm did not appear to benefit significantly from the adaptive antenna arrays and its performance saturated as the large exclusion zone quickly limits the number of calls that may be made.

From Figure 6 it was noted that the call dropping probability of the FCA algorithm in the multipath environment, was the same as that for the LOS scenario, with each increase in the number of the antenna elements reducing the dropping probability by an order of magnitude. The LOLIA 19 algorithm exhibited a low blocking probability up to a certain traffic load, followed by a marked increase in the probability of a dropped call. The LOLIA 7 scheme offered the lowest probability of dropped calls for more than 140 Erlangs/km^2/MHz.

The amount of teletraffic carried by the channel allocation algorithms did not increase markedly when using adaptive antenna arrays, but for a given traffic load the call quality was improved signicantly. The teletraffic carried by the LOLIA 19 networks only increased by 5%, when doubling the number of mobiles using the system to 3200, therefore suggesting that the network has reached its capacity limit imposed by the large exclusion zone restriction. Both FCA and LOLIA 7 carried more traffic at higher user loads, with LOLIA 7 offering the highest teletraffic capacity.

3.3. Overview of Results

Above, we have investigated FCA and LOLIA DCA in conjunction with adaptive antenna arrays at the basestations for both Line-Of-Sight and multipath propagation environments. However, no single algorithm performs best in terms of every performance metric. Therefore, in order to compare fairly our results for the various channel allocation schemes, it was necessary to consider a combination of performance metrics. Sometimes an algorithm may provide excellent performance in terms of one metric, but poor performance in another. Therefore, we defined a conservative and a lenient scenario, as follows:

- *Conservative scenario*:
  $P_B \leq 3\%$, $P_{FT} \leq 1\%$, $P_{low} \leq 1\%$ and $GOS \leq 4\%$.
- *Lenient scenario*:
  $P_B \leq 5\%$, $P_{FT} \leq 1\%$, $P_{low} \leq 2\%$ and $GOS \leq 6\%$.

Algorithm	Conservative $P_{FT} = 1\%$, $P_{low} = 1\%$ $GOS = 4\%$, $P_B = 3\%$				Lenient $P_{FT} = 1\%$, $P_{low} = 2\%$ $GOS = 6\%$, $P_B = 5\%$			
	LOS		Multipath		LOS		Multipath	
	Users	Traffic	Users	Traffic	Users	Traffic	Users	Traffic
FCA, 1 element	1150	95	-	-	1150	95	-	-
FCA, 2 elements	1750	145	1520	126	1750	145	1670	139
FCA, 4 elements	2500	185	1940	160	2500	185	2250	184
FCA, 8 elements	-	-	2730	209	-	-	2940	223
LOLIA (n=7), 1 element	1900	165	-	-	2150	187	-	-
LOLIA (n=7), 2 elements	2220	195	2250	198	2500	220	2500	219
LOLIA (n=7), 4 elements	2750	242	2650	230	3070	270	2930	255
LOLIA (n=7), 8 elements	-	-	3025	260	-	-	>3200	>280
LOLIA (n=19), 1 element	2025	160	-	-	2190	166	-	-
LOLIA (n=19), 2 elements	2100	162	2170	165	2200	167	2250	169
LOLIA (n=19), 4 elements	2140	164	2165	166	2230	170	2280	172
LOLIA (n=19), 8 elements	-	-	2175	166	-	-	2290	172

Table 2: Maximum mean carried traffic, and maximum number of mobile users that can be supported by each configuration whilst meeting the preset quality constraints. The Carried Traffic is expressed in terms of Normalized Erlangs (Erlang/km^2/MHz), for the network described in Table 1 in **LOS and multipath environments**.

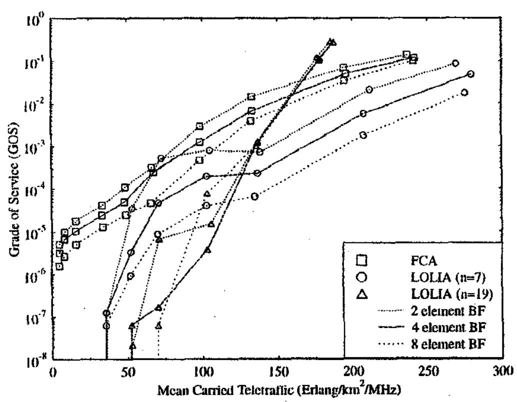

Figure 3: Grade-Of-Service performance versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for 2, 4 and 8 element antenna arrays with beamforming in **a multipath environment.**

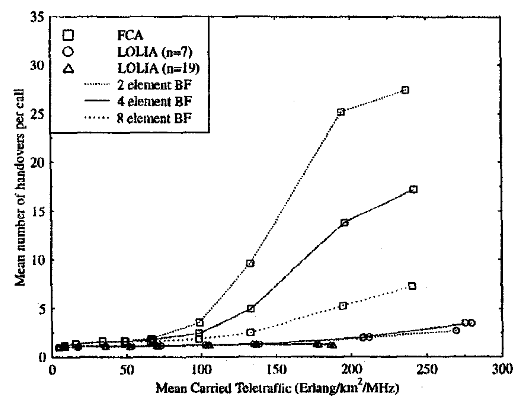

Figure 4: Mean number of handovers per call versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for 2, 4 and 8 element antenna arrays with beamforming in **a multipath environment.**

It can be seen from Table 2 that the employment of adaptive antenna arrays increased the number of users supported by the network for all the channel allocation algorithms under the LOS conditions. The FCA scheme exhibited the greatest gains in the number of users carried by network, with a 52% increase using two element arrays, and 117% through the use of four element arrays, in a LOS environment. In the multipath scenario the performance advantages were still attractive, with capacity improvements of 28% obtained in moving from a two element array to an array of four elements, and a gain of 80% achieved, when replacing a two element array with an eight element array. The LOLIA 7 algorithm consistently carried more traffic than the FCA algorithm, and for almost all situations, the LOLIA 19 scheme. For the LOS propagation environment user capacity gains of 17% and 45% were observed for two and four element antenna, respectively, over a single antenna element. For the multipath simulations the improvements were 18% and 34% for four and eight element antenna arrays, in comparison to a two element array. The performance of the LOLIA 19 algorithm was barely affected by the use of the adaptive antenna arrays as a result of the low levels of interference incident upon the antenna arrays. Unlike FCA, which did not perform as well under multipath conditions as in a LOS environment, LOLIA 19 actually benefitted from the multipaths. This was due to the large reuse distance of such a system, where the three desired multipath signals were received at a significantly higher

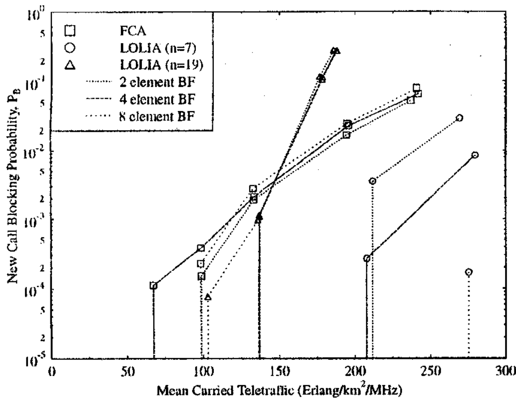

Figure 5: Blocking probability performance versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for 2, 4 and 8 element antenna arrays with beamforming in a **multipath environment**.

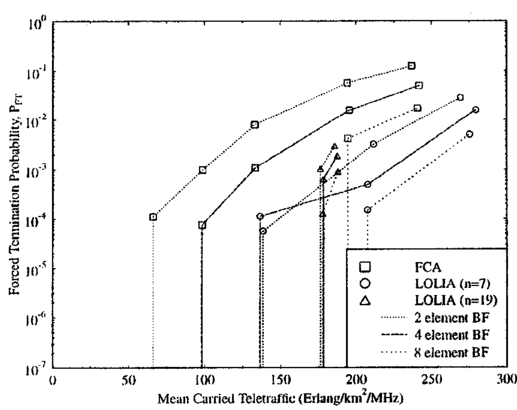

Figure 6: Call dropping probability performance versus mean carried traffic, for comparison of the LOLIA, with 7 and 19 'local' basestations, and FCA using a 7-cell reuse cluster, for 2, 4 and 8 element antenna arrays with beamforming in a **multipath environment**.

level, than the three interfering signals from each source of interference, resulting in an improved SINR. The LOLIA 7 algorithm benefitted slightly for smaller array sizes from the multipaths, but for four elements suffered a decrease in terms of user capacity.

4. CONCLUSIONS

In this contribution we have examined the FCA and LOLIA channel allocation schemes in conjunction with adaptive antenna arrays, used at the basestation for the up- and the down-link, and compared their performance in Line-Of-Sight and multipath propagation environments, using the performance metrics of Section 3. The LOLIA 19 algorithm offered the best network capacity without the use of adaptive antenna arrays, but with their implementation its capacity barely increased whilst the FCA and LOLIA 7 capacities benefitted significantly. Although benefitting most from the adaptive antenna arrays, the FCA algorithm was unable to support as many users with a given quality criteria as the LOLIA 7 algorithm using adaptive beamforming. In fact, for the 'Lenient' scenario the LOLIA 7 algorithm using a four element array supported the same number of users as an FCA based network using an eight element antenna.

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