DYNAMIC CHANNEL ALLOCATION USING ADAPTIVE ANTENNAS AND POWER CONTROL

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ABSTRACT

This papers investigates the performance of adaptive antenna arrays at the basestation in conjunction with Dynamic Channel Allocation (DCA) and power control. Results are also presented for a Fixed Channel Allocation (FCA) network, using adaptive antennas without power control, for the purposes of comparison. A variety of different performance metrics, and the number of users supported for a given network quality, were determined for the different networks examined. The comparisons were carried out under identical uniform traffic conditions, with the users roaming across the simulation area, rather than simply assigning them to arbitrary, uncorrelated, but essentially stationary random positions.

1. BACKGROUND

The user capacity and area spectral efficiency of wireless systems can be increased upon employing micro- and pico-cellular frequency reuse structures, often at the cost of reduced frequency reuse distance and hence increased co-channel interference. However, adaptive antenna arrays may be employed to mitigate the increased co-channel interference, since they can exploit the angular separation between co-channel users, in order to increase the network capacity [1, 2]. The ability of an adaptive antenna array to form a beam in one direction, from which signals can be received strongly, such as from a desired mobile, whilst nulling signals arriving from other directions, e.g. from interfering mobiles, makes it inherently suited to use in an interference limited cellular network.

Given that that each mobile station is assigned a unique reference signal, the adaptive antenna array receiver can relatively simply calculate the antenna weights required to receive this signal with the maximum SINR. However, when using Frequency Division Duplexing (FDD), with its non-reciprocal up- and down-links, the weights used for the up-link are typically unsuitable for the down-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 [3]. 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 [1].

In general, Dynamic Channel Allocation (DCA) techniques offer substantially improved call-blocking, packet dropping, and grade-of-service performance in comparison to Fixed Channel Allocation (FCA) [4–6]. A range of so-called distributed DCA algorithms were investigated by Chuang et al [4–6]. As compromise schemes, locally optimised distributed DCA algorithms were proposed, for example, by Delli Priscoli et al [7], and it was shown [8] that the Locally Optimised Least Interference Algorithm (LOLIA) provided the best overall compromise in terms of network performance.

The physical layer is simply modelled using three parameters, namely 'Outage SINR', 'Reallocation SINR' and 'Target SINR'. When the signal-to-interference+noise ratio, drops below the reallocation SINR, defined as the average SINR required by a QPSK/4QAM transceiver for a 5% FER over a channel with narrowband Rayleigh fading, 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 below the so-called 'Outage SINR', define as the average SINR required in order to maintain a 10% transmission FER, then an outage is encountered. A prolonged outage leads to call dropping or forced termination. The 'Target SINR' is used in our power control investigations and the target SINR has to be maintained by controlling the mobile and base station transmission powers. The parameters used in the simulations are summarised in Table 1.

2. SYSTEM PARAMETERS

The performance of the LOLIA 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

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calls at one basestation provided that all slots exhibited an adequate channel quality. 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 inter-call periods were Poisson distributed with the mean values shown in the table.

Parameter	**Value**	**Parameter**	**Value**
Noisefloor	-104dBm	Multiple Access	TDMA
Frame length	0.4615ms	Cell radius	218m
Minimum BS transmit power	-20dBm	Minimum MS transmit power	-20dBm
Maximum BS transmit power	10dBm	Maximum MS transmit power	10dBm
Power control stepsize	1dB	Power control hysteresis	3dB
Number of basestations	49	Handover hysteresis	2dB
Outage SINR threshold	17dB	Re-allocation SINR threshold	21dB
Power control target SINR	27dB	Modulation scheme	4QAM
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	13.4m/s	Number of antenna elements	2 & 4
	(30mph)	Pathloss exponent	-3.5

Table 1: Simulation parameters.

The receiver antenna weights were calculated using the Sample Matrix Inversion (SMI) algorithm [9–11], using a reference signal eight bits in duration. The reference signal length 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 served mobile and the remaining seven were allocated to interfering mobiles.

A multipath environment was considered, for which the transmit/receive channel was assumed to be reciprocal, thus allowing the same antenna pattern to be used in both the up- and the down-links. This idealistic assumption has a limited applicability, but it simplified our investigations. The multipath environment consisted of the direct ray and two additional rays, each having a third of the direct ray's power. The Geometrically Based Single-Bounce Elliptical Model (GBSBEM) of [12] 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, each multipath ray would have an associated time delay, resulting in low correlation with the desired reference signal, causing them to be nulled, unless a space-time equalizer [13], was employed.

The up- and down-link SINR measurements were used by the power control algorithm to maintain the target SINR, independently controlling the mobile and base station transmit powers. The transmit power was only allowed to change by a given stepsize, and a reduction in the tranmission power was only possible if the target SINR was exceeded by a given threshold. This avoided constantly increasing and then decreasing the transmission power, which could potentially lead to instabilities and oscillations of the power control algorithm.

3. PERFORMANCE STUDY

The results presented here are based on the combination of adaptive beamforming at the basestation and fixed as well as dynamic channel allocation algorithms combined with the simple power control algorithm, of Section 2, at both the mobile stations and the basestations.

3.1. 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 following performance metrics have been widely used in the literature and were also advocated by Chuang [6]:

- 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 is below the value, where the call is deemed to be in outage.
- Grade of Service, GOS was defined by Cheng and Chuang [6] as:

$$\begin{aligned} GOS &= P\{\text{unsuccessful or low-quality call accesses}\} \\ &= P\{\text{call is blocked}\} + P\{\text{call is admitted}\} \times \end{aligned}$$

$$\begin{aligned} & P\{\text{low signal quality and call is admitted}\} \\ = \; & P_B + (1 - P_B) P_{low}. \end{aligned} \quad (1)$$

A handover or handoff event occurs when the quality of the channel used degrades, and hence the call is switched to a newly allocated channel. If the new channel belongs to the same basestation this is referred to as an intra-cell handover. Generally intra-cell handovers occur when the channel quality degrades due to interference, or because the channel allocation algorithm decides that a channel reallocation will help increase the system's performance and capacity. Inter-cell handovers occur mainly because the mobile moves outside the cell area, and hence the signal strength degrades, requiring a handover to a nearer basestation.

Handovers have a substantial effect on the performance of channel allocation algorithms. At high traffic loads the majority of forced call terminations are due to the lack of availability of channels to handover to, rather than due to interference. This can be a particular problem in microcellular systems, where the rate of handovers is significantly higher than in conventional cellular systems.

3.2. Performance of the LOLIA with and without power control

Simulations were conducted for a standard 7-cell FCA scheme and a 7-cell LOLIA system [8], both without power control, and an identical LOLIA network, with the inclusion of power control. The FCA results were included in order to provide a standard benchmark against which the other results could be compared.

Figure 1(a) shows the new call blocking probability versus the mean normalized carried traffic, expressed in terms of Erlangs/km^2/MHz. From this figure it can be seen that the LOLIA network offers superior blocking performance, and also benefits the most from increasing the number of antenna elements. The addition of power control improved the algorithm's performance further, with the two element antenna's blocking probability approaching that of the four element antenna without power control.

From Figure 1(b) it can be seen that the power control algorithm does not improve the call dropping probability of the LOLIA. Whilst offering similar call dropping performance to the LOLIA without power control at the highest traffic loads of about 280 Erlangs/km^2/MHz, its performance soon degrades until it performs similarly to an FCA system. However, at these traffic levels the probability of a dropped call is low, and the overall network performance is unlikely to suffer significantly. The increased number of dropped calls may be due to the significantly reduced new call blocking probability, resulting in many more calls entering the network, only to be dropped due to insufficient network capacity.

The probability of low quality access occurring is shown in Figure 2(a). In general, the power controlled variant of the LOLIA offers a lower probability of low quality access, than the standard LOLIA, with the greatest performance gains seen at the highest levels of traffic carried. The probability of low quality access could have been reduced further upon increasing the 'Target SINR' setting, but the higher resultant levels of interference in the network resulted in an excessive call dropping rate.

The Grade-Of-Service (GOS) illustrated in Figure 2(b) is determined using Equation 1, hence the close resemblance to Figure 2(a) and the similar performance characteristics for given teletraffic levels.

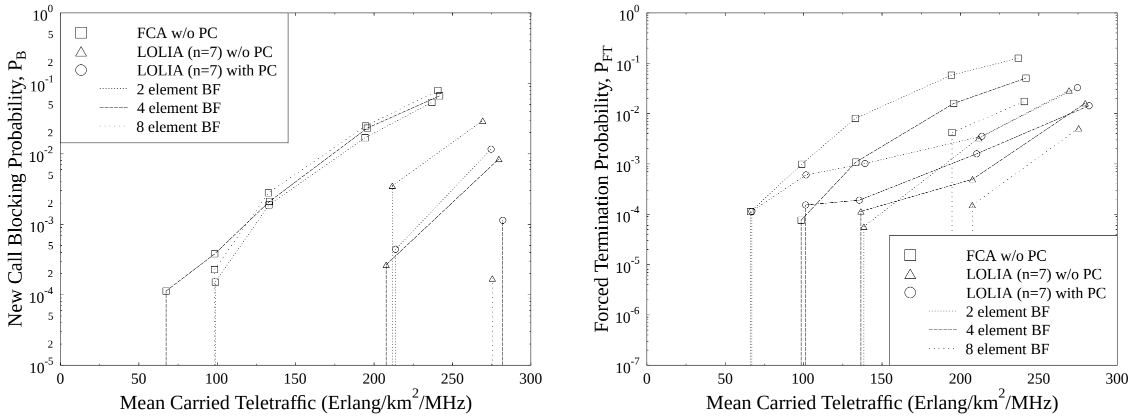
Figure 3 shows the probability of a low quality access occurring, when the basestation or mobile is transmitting at full power. With a four element antenna array, and at a traffic level of about 65 Erlangs /km^2/MHz, up to a third of all low quality accesses occur when not transmitting at full power. This suggests that the background interference level is fairly low, since the maximum transmission power is not used, and that the commencement of a new call raises the interference level sufficiently to inflict a low quality access. However, for higher traffic loads almost all low quality accesses occur when the maximum transmit power is used, confirming the high levels of co-channel interference present in the network. Therefore, it seems that the low quality outages, for a heavily loaded system, tend to occur when the user is transmitting at full power, but from Figure 4 it can be seen that even at these loads, the mean transmitting power is still some 4dB less than the maximum transmit power. Hence, increasing the maximum transmission power would reduce the number of low quality accesses, whilst maintaining a lower mean transmission power than for an identical network without power control.

From the mean transmission power results of Figure 4 it can be seen that, as expected, the mean transmission power increases as the amount of teletraffic carried increases due to the higher levels of interference to be overcome. At high traffic loads there is a significant difference between the mean transmission powers of the mobile stations and the basestations, resulting from the fact that the interfering basestations, on the downlink, are further away from the served mobile, than the interfering mobiles are from the serving basestation on the uplink. This is further exacerbated by the omni-directional nature of the mobiles' antennas and the directional nature of the antennas at the basestations.

The mean power transmitted by the mobile stations ranges from -3.7dBm, for a traffic load of about 17 Erlangs/km^2/MHz, or 200 users, with a two element antenna array, to a maximum of 5.6dBm for a traffic load of 280 Erlangs/km^2/MHz, corresponding to 3200 users, with a four element antenna array. When compared to the fixed transmission power of 10dBm for an identical network without power control, the reductions in transmitted power are significant, especially for lower levels of teletraffic, and should greatly extend mobile station battery lives.

3.3. Overview of Results

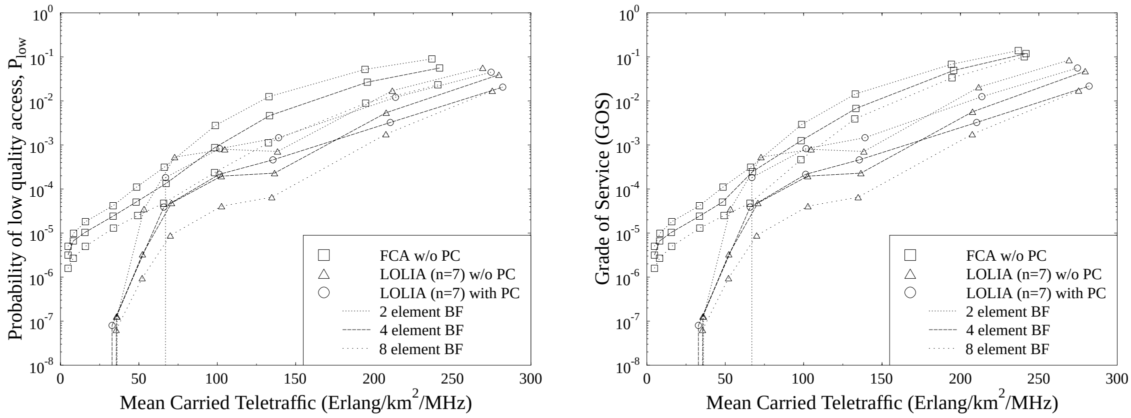
In our investigations we have investigated FCA and LOLIA, with and without power control, as well as with adaptive antenna arrays at the basestations in a multipath propagation environment. However, no single algorithm performs "best" in terms of every performance metric. Therefore, in order to compare our results for the various schemes, it was necessary to consider a combination of performance metrics. Sometimes an algorithm may provide excellent performance



(a) New call blocking performance

(b) Call dropping performance

Figure 1: New call blocking and call dropping performance versus mean carried traffic, for comparison of the Locally Optimized Least Interference Algorithm, with 7 "local" basestations, with and without power control, and of Fixed Channel Allocation, using a 7-cell reuse cluster, without power control, under uniform traffic, for 2 and 4 element antenna arrays with beamforming in a multipath environment of Section 2.



(a) Probability of low quality performance

(b) Grade-Of-Service performance

Figure 2: Probability of low quality access and Grade-Of-Service performance versus mean carried traffic, for comparison of the Locally Optimized Least Interference Algorithm, with 7 "local" basestations, with and without power control, and of Fixed Channel Allocation using a 7-cell reuse cluster, without power control, under uniform traffic, for 2 and 4 element antenna arrays with beamforming in a multipath environment of Section 2.

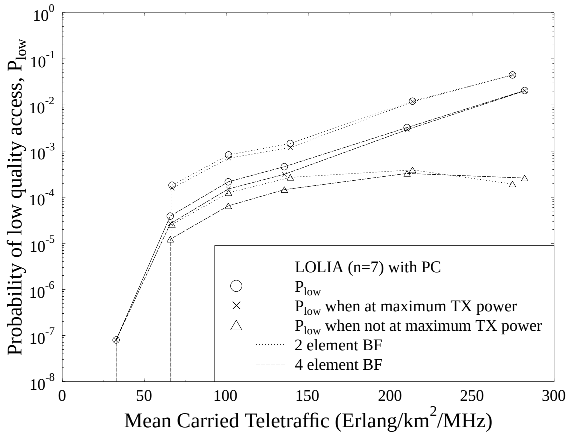


Figure 3: Probability of low quality performance due to insufficient transmit power per call versus mean carried traffic, of the Locally Optimized Least Interference Algorithm, with 7 "local" basestations, with power control, under uniform traffic, for 2 and 4 element antenna arrays with beamforming in a multipath environment of Section 2. Maximum transmission power was +10dBm. When not at maximum transmission power, the transmission power was determined by the power control algorithm, and was restricted to the range from -20dBm to +10dBm.

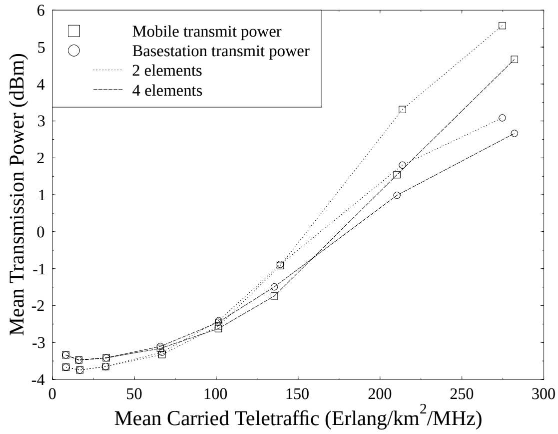


Figure 4: Mean transmission power versus mean carried traffic, of the Locally Optimized Least Interference Algorithm, with 7 "local" basestations, with power control, under uniform traffic, for 2 and 4 element antenna arrays with beamforming in a multipath environment of Section 2.

Algorithm	**Conservative** $P_{FT} = 1\%$, $P_{low} = 1\%$ $GOS = 4\%$, $P_B = 3\%$		**Lenient** $P_{FT} = 1\%$, $P_{low} = 2\%$ $GOS = 6\%$, $P_B = 5\%$	
	No. of Users	**Traffic** (Erlangs/km^2/MHz)	**No. of Users**	**Traffic** (Erlangs/km^2/MHz)
FCA, 2 elements	1520	126	1670	139
FCA, 4 elements	1940	160	2250	184
FCA, 8 elements	2730	209	2940	223
LOLIA (n=7), 2 elements	2250	198	2500	219
LOLIA (n=7), 4 elements	2650	230	2930	255
LOLIA (n=7), 8 elements	3025	260	>3200	>280
Power control				
LOLIA (n=7), 2 elements	2325	207	2705	237
LOLIA (n=7), 4 elements	2880	254	3065	270

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 the multipath environment of Section 2.

in terms of one metric, but poor performance in terms of 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 $GOS \leq 6\%$.

It can be seen from Table 2 that the channel allocation algorithm supporting the highest number of users, for a given quality, is the LOLIA with power control. All the channel allocation algorithms appear to benefit from the use of more antenna elements, with the FCA scheme exhibiting the greatest gains in terms of the number of users supported by the network. Capacity improvements of 28% were obtained in moving from a two element array to an array of four elements, and a gain of 80% was achieved, when replacing the two element array with an eight element array. The standard LOLIA 7 algorithm consistently carried more traffic than the FCA algorithm, but the performance gains achieved by increasing the number of antenna elements were smaller, at 17% and 34% for four and eight element antenna arrays, when compared to a two element array. The LOLIA 7 with power control carried yet more traffic, with up to 8% more users supported, than the equivalent LOLIA 7 network having no power control. Increasing the number of antenna elements from two to four resulted in a 24% increase in the number of users supported by the network.

When compared to the benchmark FCA algorithm, for a two element antenna array, the LOLIA 7 enabled the network to support an additional 48% or 730 users, for the conservative scenario, and 50% or 830 users for the lenient scenario. Combining the LOLIA 7 with power control increased this to 53% or 805 users in the conservative configuration, and 62% or 1025 users in the lenient configuration. Large increases in the number of users supported by the four element antenna array, when employing the LOLIA 7, both with and without power control, were also observed. The minimum increase was 30% and the greatest increase was 48%.

3.4. Conclusions

In this contribution we have briefly considered the performance of the fixed channel allocation scheme in conjunction with adaptive antenna arrays, and examined the performance of the LOLIA with adaptive antenna arrays and power control in a multipath propagation environment. The FCA algorithm benefitted most from the use of the adaptive antenna arrays, but it was unable to support as many users with a given quality criteria as the LOLIA 7 algorithm without power control. The addition of power control to the LOLIA 7 improved its performance still further. The benefits of using power control extend beyond pure network capacity gains to improved call quality, whilst supporting more users and significantly extended battery life.

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