DYNAMIC CHANNEL ALLOCATION TECHNIQUES USING ADAPTIVE MODULATION AND ADAPTIVE ANTENNAS

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ABSTRACT

This contribution studies the impact of adaptive modulation (AQAM) on network performance, when applied to a cellular network using adaptive antennas with Fixed Channel Allocation (FCA) and locally distributed Dynamic Channel Allocation (DCA) sch-emes. The performance advantages of using adaptive modulation are quantified in terms of overall network performance, mean transmitted power and the average network throughput. With the advent of AQAM 33% and 87% increased number of users can be supported by FCA and DCA, respectively.

1. INTRODUCTION

Dynamic Channel Allocation (DCA) schemes, in general, offer substantially improved new call blocking, call dropping, and Grade-Of-Service (GOS) performance, when compared to Fixed Channel Allocation (FCA) algorithms. In previous work it was shown [1] that the Locally Optimised Least Interference Algorithm (LOLIA), based upon the locally optimised DCA algorithms proposed by Delli Priscoli et al [2], provided the best overall compromise in terms of network performance.

Since a cellular network is typically interference limited, adaptive antennas sited at cellular basestations are ideally suited for application in this field [3]. Given that each mobile in the network is uniquely identifiable, the so-called Sample Matrix Inversion (SMI) algorithm [4] may be invoked to obtain the antenna array receiver weights. In a Frequency Division Duplexing (FDD) network the weights calculated for use on the up-link may not be suitable for use on the down-link due to the often non-reciprocal channel characteristics. However, using a feedback loop from the mobile to the basestations would allow the determination of the down-link weights [5]. An alternative solution is to use Time Division Duplexing (TDD) with a sufficiently small dwell-time, such that the channel does not vary significantly between the up- and the down-link time slots [3].

The idea behind adaptive modulation is to select a modulation mode according to the instantaneous radio channel quality [6]. Thus, if the channel exhibits a high Signal to Interference plus Noise Ratio (SINR), then a high order modulation mode may be employed. Likewise, if the channel has a low SINR, using a high order modulation mode would result in an unacceptably high Bit Error Rate (BER) and ransmission Frame Error Rate (FER) and hence a more robust, but lower throughput, modulation mode would be invoked. The FER was evaluated for approximately half-rate Bose-Chaudhuri-Hocquenghem (BCH) codes, which employed interleaving over the different number of bits conveyed by the different modem modes.

The proposed power control and modulation mode switching algorithm invoked in our simulations attempted to minimize the transmitted power whilst maintaining a high throughput with a less than 5% target FER. The pseudo-code of the proposed algorithm was as follows :

```
determine lower SINR out of up- and down-link SINRs
if in 16QAM mode
  if lower  SINR < 16QAM drop SINR
    drop to 4QAM mode
  else if lower  SINR < 16QAM reallocation SINR
    if at maximum transmit power then revert to 4QAM
    else increase transmit power
  else if lower SINR < 16QAM target SINR
    increase transmit power
  else if lower SINR > 16QAM target SINR+hysteresis
    decrease transmit power
else if in 4QAM mode
  if lower SINR < 4QAM drop SINR
    drop to BPSK mode
  else if lower SINR < 4QAM reallocation SINR
    if at maximum transmit power then revert to BPSK
    else increase transmit power
  else if lower SINR < 4QAM target SINR
    increase transmit power
  else if lower SINR > 16QAM target SINR+hysteresis
    change to 16QAM mode
  else if lower SINR > 4QAM target SINR+hysteresis
    if at maximum transmit power then
      reduce transmit power
    else change to 16QAM
else if in BPSK
  if lower SINR < BPSK drop SINR
    outage occurs
  else if lower SINR < BPSK reallocation SINR
    if not at maximum transmit power
      then increase transmit power
```

The financial support of the following organisations is gratefully acknowledged: Motorola ECID, Swindon, UK; European Community, Brussels, Belgium; Engineering and Physical Sciences Research Council, Swindon, UK; Mobile Virtual Centre of Excellence, UK.

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else if lower SINR > 4QAM target SINR+hysteresis
  change to 4QAM
else if lower SINR > BPSK target_hysteresis
  if at maximum transmit power then
    reduce transmit power
  else change to 4QAM
```

2. EXPERIMENTAL CONDITIONS

2.1. Performance Metrics

The following performance metrics have been widely used in the literature and were also advocated by Chuang [7]:

- 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 up- or down-link signal quality is below the level required by the specific transceiver for maintaining a given target performance.
- Probability of Outage, P_{out} is defined as the probability that the SINR value is below the value, where the call is deemed to be in outage.
- Grade of Service (GOS) was defined by Cheng and Chuang [7] as:

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

2.2. System Parameters

A GSM-like microcellular system, having the parameters defined in Table 1, was used to investigate the performance of AQAM in conjunction with adaptive antenna arrays, for both FCA and LOLIA DCA schemes. The maximum capacity of the system was limited through the use of eight timeslots and just seven carrier frequencies, in order to maintain an acceptable computational load. If a channel allocation request for a new call could not be satisfied immediately, it was queued. If not serviced within 5s, it was classed as blocked. The call duration and inter-call periods were Poisson distributed with the mean values shown in Table 1.

Three parameters were used to model the physical layer, the 'Outage SINR', the 'Reallocation SINR' and the 'Target SINR'. When the up- or down-link SINR for a given mobile drops below the 'Reallocation SINR', defined as the average SINR necessary for a 5% transmission Frame Error Rate (FER) using QPSK/4QAM over a narrowband Rayleigh fading channel, then the mobile requests a new physical channel to handover to, initiating an intra- or inter-cell handover. If the signal quality drops below the 'Outage SINR', defined as the average SINR required to maintain a 10% FER, then an outage occurs. A prolonged outage leads to the call being dropped. The 'Target SINR' is the SINR to be maintained by the power control algorithm. The propagation environment considered consisted of a Line-Of-Sight (LOS) ray and two additional rays, each having a third of the power of the LOS ray, with angles of arrival at the basestation determined using the so-called Geometrically Based

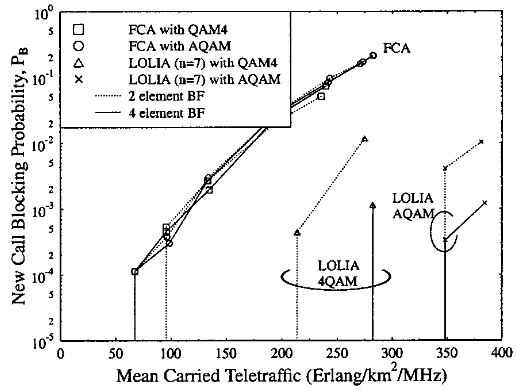

Figure 1: Call blocking, or forced termination, probability versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

Single-Bounce Elliptical Model (GBSBEM) of [8] with parameters chosen such that the multipath rays had one-third of the received power of the direct ray. It was assumed that all of these multipath rays arrived with zero time delay relative to the LOS path, or that a space-time equalizer [9] was employed, thus making full use of the additional received signal energy, at the expense of consuming degrees of freedom of the antenna array.

A further assumption was that the up- and down-link channels were identical, thus allowing the same antenna pattern to be used in both the up- and the down-links, as in a TDD system.

3. PERFORMANCE OF AN AQAM BASED NETWORK USING POWER CONTROL

This section presents the simulation results obtained for a network using burst-by-burst adaptive modulation in order to improve network performance. Simulations were conducted for both a standard 7-cell FCA scheme and a 7-cell LOLIA system. The results obtained for a 4-QAM based network using power control were included for comparison purposes.

Figure 1 shows the new call blocking probability versus the mean normalized carried traffic. From this figure it can be seen that in conjunction with the LOLIA there are no blocked calls except for the highest level of traffic, when using a two element antenna array. However, in general, the FCA algorithm exhibited a higher blocked call probability.

The call dropping probability is depicted in Figure 2 and shows that, when invoking adaptive modulation, the FCA algorithm performs better than the LOLIA below a traffic load of about 225 Erlangs/km^2/MHz. The FCA scheme consistently offered a lower call dropping probability, when employing AQAM compared to when using the fixed 4-QAM modulation scheme. However, the AQAM-assisted LOLIA using two element adaptive antenna array performed slightly worse, than when using 4-QAM for traffic levels below about 200 Erlangs/km^2/MHz. Nonetheless,

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
BPSK outage SINR	13dB	BPSK reallocation SINR	17dB
BPSK target SINR	21dB	4QAM outage SINR	17dB
4QAM reallocation SINR	21dB	4QAM target SINR	27dB
16QAM outage SINR	24dB	16QAM reallocation SINR	27dB
16QAM target SINR	32dB	Pathloss exponent	-3.5
Number of basestations	49	Handover hysteresis	2dB
Number of timeslots/carrier	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

Table 1: Simulation parameters.

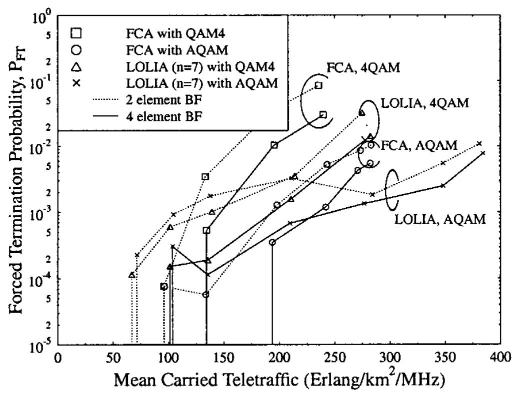

Figure 2: Call dropping performance versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

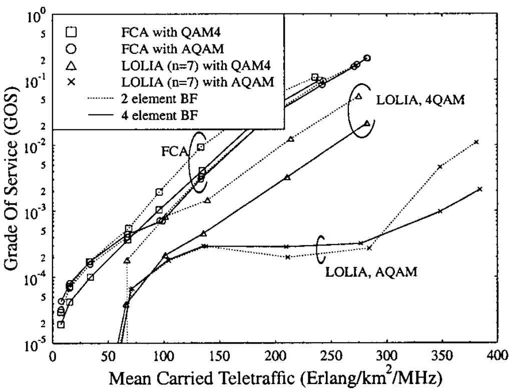

Figure 3: Grade-Of-Service performance versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

above this level the LOLIA performance remained relatively constant, whereas for 4-QAM the dropping probability increased fairly sharply.

From Figure 3 it can be seen that the Grade-Of-Service (GOS) - as defined in Section 2.1 - of the FCA algorithm did not benefit from AQAM to the same extent as the LOLIA. The FCA scheme using AQAM and a two element antenna array offered a marginally lower - i.e. better - GOS than fixed 4-QAM combined with a four element antenna array. Conversely, the GOS of the LOLIA was reduced by up to a factor of 200 at a traffic load of about 280 Erlangs/km^2/MHz. Above this load the GOS increased steeply due to the non-zero blocking probability incurred under this traffic loading.

As seen in Figure 4, AQAM reduced the mean number of handovers per call for both the FCA scheme and the LOLIA. The number of handovers per call for the 4QAM-assisted LOLIA was low, hence only a slight reduction could be achieved, but for the FCA scheme significant reductions were observed.

Figure 5 shows that the probability of a low quality access was reduced due to AQAM for both the FCA scheme and the LOLIA. For traffic loads below 60 Erlangs/km^2/MHz, the FCA algorithm using AQAM behaved similarly to when using fixed 4-QAM, but when more moderate levels of traffic were reached, the advantage of adaptive modulation increased. Likewise, for low traffic levels, the LOLIA gained little from investing in AQAM, but for higher traffic loading the probability of a low quality access occurring levelled off to a near-constant value.

The average modem throughput expressed in bits per symbol versus the mean carried teletraffic is shown in Figure 6. The Figure shows how the mean number of bits per symbol decreased as the network traffic increased. The FCA

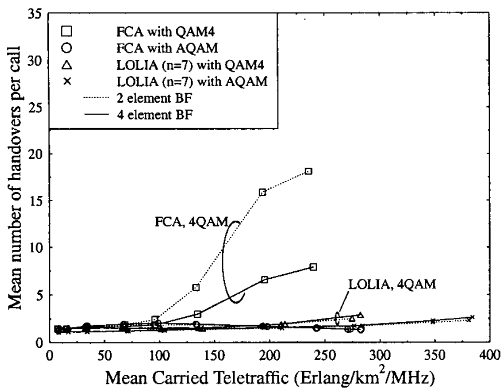

Figure 4: Mean number of handovers per call versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

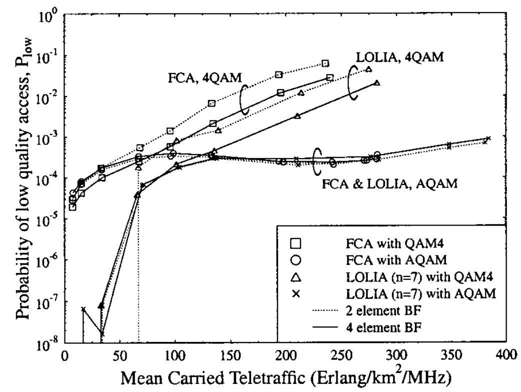

Figure 5: Probability of low quality access versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

algorithm offered the least throughput with its performance degrading near-linearly with increasing network traffic. The LOLIA, especially for the lower levels of traffic, offered a higher modem throughput for a given level of teletraffic carried, with the performance gracefully decreasing, as the carried teletraffic continued to increase.

The mean transmission power results of Figure 7 demonstrate how the employment of AQAM can reduce the power transmitted, both for the up- and the down-link. At low traffic levels the FCA algorithm performed noticeably worse, in transmitted power terms, than the LOLIA. However, as the traffic loads increased, the difference became negligible. In contrast, the gap between the up- and the down-link powers was close to zero for the lighter traffic loads, but as the level of network traffic increased, so did the difference, with 2dB extra transmit power required on the up-link for the maximum traffic load simulated. This resulted from the interfering mobiles being located closer to the serving basestation in statistical terms, than the interfering basestations are to the served mobile. The mean power reduction - when compared to a fixed transmission power of 10dBm - varied from approximately 1dB to more than 8dB. A 1dB reduction in transmission power is not particularly significant for the mobile user, especially since at this network load a throughput of only 2 bits/symbol is possible. The difference between the network using adaptive modulation and that without, though, is the overall improved call quality that can be achieved in these circumstances.

3.1. Summary of Results

In order to arrive at a meaningful comparison of our results, it is necessary to consider a combination of the network performance metrics. For example, an algorithm may perform very well in one respect, yet have poor performance when measured using an alternative metric. Therefore, the following conservative and lenient scenarios were defined [1]:

- *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 $GOS \leq 6\%$.

Due to the enhanced network performance resulting from the employment of AQAM, a further constraint of a minimum throughput of 2 bits/symbol was invoked. This ensured a fair comparison with the fixed 4-QAM based network.

Table 2 shows how the network invoking AQAM performed, when compared to the fixed 4-QAM based network. Using FCA and a two element antenna array in conjunction with AQAM resulted in at least an additional 33% of users supported by the network. Furthermore, these additional users benefitted from a superior network performance in all respects, except for the blocking probability, whilst maintaining a 25% higher network throughput. Even more significant network capacity increases were observed for the LOLIA, with up to an 87% improvement in the number of users supported.

4. CONCLUSIONS

We have examined the performance of an AQAM-assisted mobile cellular network in contrast to a fixed 4-QAM based network. At high levels of network traffic the network users benefitted from improved call quality for a given transmit power and modem throughput. The network was thus capable of supporting more users with a higher user satisfaction, than for a similar network using fixed 4-QAM. For low numbers of network users it offered superior call quality, reduced transmission powers and higher modem throughput, than for identical scenarios over a fixed 4-QAM network. Thus, for a given network traffic loading or number of users, our network employing AQAM was capable of achieving an increased mean modem throughput whilst offering a better quality of service. Our future work involves the investigation of network capacity for a CDMA-based UMTS network.

Algorithm	Conservative $P_{FT} = 1\%$, $P_{low} = 1\%$ $GOS = 4\%$, $P_B = 3\%$			Lenient $P_{FT} = 1\%$, $P_{low} = 2\%$ $GOS = 6\%$, $P_B = 5\%$		
	Users	Traffic	Limiting Factor	Users	Traffic	Limiting Factor
4QAM						
FCA, 2 elements	1795	148	P_{low}	1980	162	P_{FT}
FCA, 4 elements	2315	189	P_{low}	2385	194	P_{FT}
LOLIA (n=7), 2 elements	2325	207	P_{low}	2705	237	P_{low}
LOLIA (n=7), 4 elements	2880	254	P_{low}	3065	270	P_{FT}
AQAM						
FCA, 2 elements	2390	197	P_B	2740	217	P_B
FCA, 4 elements	2490	199	P_B	2840	220	P_B
LOLIA (n=7), 2 elements	4340	376	BPS	4340	376	BPS
LOLIA (n=7), 4 elements	>4400	-	-	>4400	-	-

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 a **multipath environment**.

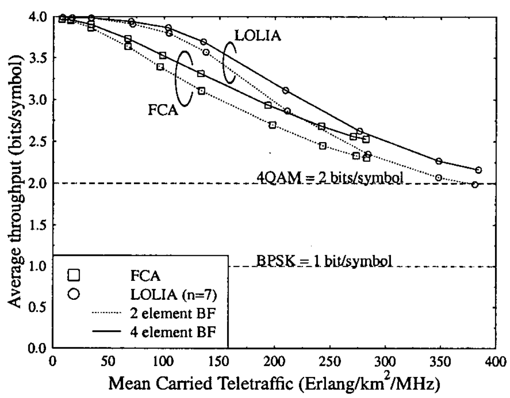

Figure 6: Mean throughput in terms of bits per symbol versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

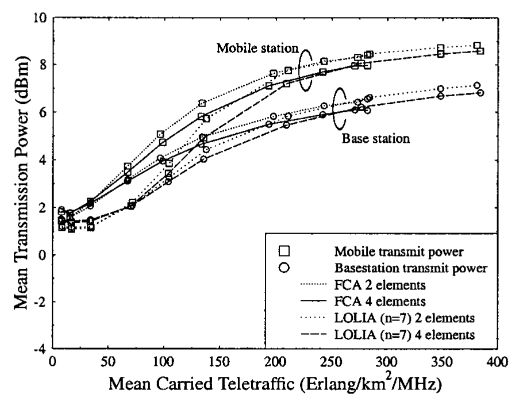

Figure 7: Mean transmit power versus mean carried traffic of the LOLIA, with 7 'local' basestations, and of FCA employing a 7-cell reuse cluster, **with and without AQAM**.

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