Aggregate throughput gains due to downlink CIR enhancement in an HDR-type network

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Abstract-**The relationship between aggregate throughput and distribution of Carrier-to-Interference (C/I) Ratio in the downlink of an interference-limited High Data Rate wireless network is investigated. It is shown that as much as 8dB of C/I improvement is needed, in order to effect a doubling of aggregate throughput. This directs us instead towards exploiting throughput-enhancing strategies which offer parallelism, such as higher sectorisation or multiple-input-multiple-output (MIMO) techniques.**

I. INTRODUCTION

In this paper we investigate the relationship between aggregate (mean) throughput and distribution of Carrier-to-Interference Ratio (CIR or C/I), in the downlink of an interference-limited High Data Rate (HDR) wireless network of the general type described in [1]. Such a system would employ Adaptive Modulation and Coding (AMC) in order to maximise aggregate downlink system throughput.

For conventional second-generation (2G) mobile CDMA wireless networks, providing a predominantly fixed bitrate service such as voice, we continually strive to reduce the *required* modem C/I by some factor (say xdB) whilst maintaining at the same level some chosen signal quality measure (such as bit or frame error ratio). This reduction, which may be achieved by some improved User Equipment (UE) receiver processing (e.g. improved Digital Signal Processing, provision of additional receiver branches [2] etc.), will consequently deliver an xdB improvement in system capacity (when converted to a linear measure) [3]. This is because all UEs are maintained at a similar C/I on their wanted traffic channel (through the operation of power control), each with an identical throughput (given by the speech encoder datarate). If we obtain a flat xdB improvement in modem performance for all UEs, whilst maintaining their individual data rates the same, then we can increase by 'xdB' (in linear measure) the number of UEs served, and hence increase the overall system (aggregate) throughput by the same amount. The same benefits accrue if we can effect a flat xdB improvement in observed mean C/I for all UEs (e.g. through using advanced antenna processing techniques, such as beamforming), whilst maintaining the same basic modem performance. These arguments apply equally to the downlink or uplink. In the case of the downlink, this argument is subject to the caveat that there must be enough spare orthogonal traffic channels (i.e. Walsh codes) available to handle the extra UEs.

In the downlink of an HDR-type cellular network, however, the Base Stations ('Node Bs') always transmit at full power. Each UE has a different observed C/I, and the system chooses a level of modulation and coding and/or symbol repetition commensurate with that C/I, in order to maximise the number of information bits transmitted per modulation symbol during each slot (the so-called 'bit-loading'). The question now is, if we manage to improve the observed C/I for every UE by some amount, say xdB, what *now* is the increase in *overall* throughput of the system? In the case of an HDR-type system, the answer is not so simple to derive as for the conventional 2G CDMA system, since the improvement in bit loading will be different for different UEs, depending on their initial C/I.

II. ANALYSIS

For ease of analysis, we will assume a system using 'Shannon' (noise-like) encoding [4], and 'long' coding blocks that approach the Shannon rate (bit loading) for negligible error probability. So using the Shannon capacity formula from [4] the bit loading, C_S, as a function of C/I, is given by:

$$C_S = \log_2\left(1+\frac{C}{I}\right) \tag{1}$$

By examining (1) it becomes apparent that at low C/I we get a halving in bit loading for every halving of the C/I. However, at high C/I we only get a +1bit-per-modulation-symbol increase in bit loading for every doubling of the C/I. That this same characteristic is also approximately true of 'real-life' AMC code sets is evident from the description of the code set in [1] (tables 1 and 2). In said real-life AMC code set, very low C/Is are dealt with by symbol repetition. Conversely, high bit loading is achieved at high C/I through use of high-order QAM modulation, which requires an approximate doubling in C/I if the number of QAM constellation points are doubled (thereby increasing the bit loading by one).

To obtain the aggregate throughput gain due to an across-the-board xdB of improvement in observed C/I we need to average the gain across the whole distribution of UEs. For the reasons described above, if the aggregate throughput is dominated by UEs with a low C/I, then this should lead to an xdB throughput increase (in linear measure). However, if aggregate throughput is dominated by the 'high end' UEs, then the aggregate throughput gain will be significantly more modest.

The actual distribution of C/I across many randomly-located UEs has been obtained through Monte-Carlo simulation of a wireless network, using the following assumptions:

- Regular tricellular grid of bases
- 'N=1' (i.e. universal) frequency reuse
- Uniformly random UE positions
- Single slope 40dB/ decade median pathloss law

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- 5.6dB sigma Lognormally-distributed Large-Scale Fading (shadowing), independent from any given UE to different Node Bs, same to different sectors of the same Node B
- No Small-Scale (i.e. Rayleigh) Fading considered
- No angle scattering
- N_T:N_R=1:1 multiple-input-multiple-output (MIMO) processing only
- 'Real-life' 60-degree 3dB beamwidth, 3-sector antennas

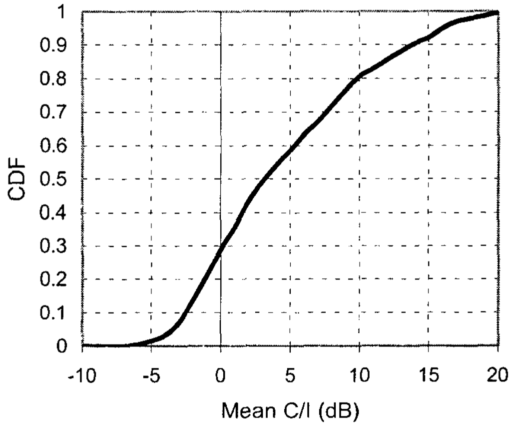

Fig. 1 Network 'Geometry'

The resultant C/I distribution, often termed the Network 'Geometry', obtained using the above assumptions is shown in Fig. 1. This shows a median C/I of approximately +3dB, and 10th and 90th percentiles of approximately -3dB and +13dB respectively. Averaging the aggregate capacity, using (1), over 1dB bins between -10dB and +30dB we obtain an aggregate throughput of approximately 2.2bps/Hz. In order to calculate the aggregate capacity due to an xdB impovement in observed mean C/I we 'shift' the C/I distribution in Fig. 1 'to the right' by xdB, and calculate the new aggregate capacity.

III. RESULTS

The relative capacity benefits obtained as a result of applying different levels of xdB 'right shift' to the C/I distribution of Fig. 1 are shown in Fig. 2. It can be seen that for x=0dB we get 1-fold capacity gain (of course), and to get 2-fold capacity gain we need approximately 8dB of C/I benefit. For points in between, the curve of capacity gain (linear) versus x (in dB) is approximately linear giving, for example, about a 1.3-fold improvement for a 3dB C/I improvement.

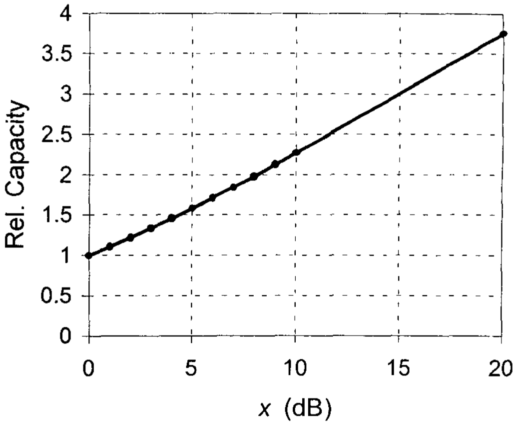

Fig. 2 Relative capacity benefit for xdB C/I improvement

IV. CONCLUSIONS

Comparing this 8dB of right shift required to achieve 2-fold capacity to the 3dB of C/I improvement needed to double the capacity in a conventional CDMA network downlink, we see that for such HDR-type systems we need to work hard to significantly improve the throughput if we are going to achieve it *purely* on the basis of achieving C/I improvements. This directs us instead towards exploiting alternative strategies offering parallelism, such as higher sectorisation or MIMO techniques [5]. These will allow us to realise the sorts of multiplicative throughput gains which are required in order to bring the Wireless Internet dream to fruition.

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