Capacity Improvement in the Downlink of WCDMA with Radio over Fibre Access Network

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Abstract: In this paper, the capacity improvement in the downlink of WCDMA is investigated. The performance of WCDMA Radio over Fibre access network during Macrodiversity mode is evaluated. We computed the required E_b/N_o for different cases applying the Macrodiversity Combining method. Our simulation results demonstrate that, for a given service, the capacity increased by 13%-46% (depending on the channel model and the mobile speed) in the case of the Macrodiversity link as compared to the single link.

Introduction

Radio over Fibre (RoF) technology had been proposed in the past as a delivery technique for 1st and 2nd generation mobile cellular systems [1-5]. It was argued that with such an arrangement the cost of deploying and maintaining a mobile cellular network can be substantially reduced with the benefit of higher flexibility for radio network planning and operation. Similar arguments can be raised in the case of 3rd generation (3G) systems given their complexity and the wide range of services they are expected to support and provide.

In 3G systems, Wideband Code Division Multiple Access (WCDMA) has been selected as the primary multiple access technique. A soft handover algorithm is employed to switch radio communication from one Node B to another as the mobile station move amongst the cells. During soft handover more than one Node B are connected simultaneously to the mobile station allowing for coverage and/or capacity improvement through Macrodiversity.

This paper investigates through computer simulations the capacity improvement in the Downlink of WCDMA with RoF. The amount of Macrodiversity gain achievable in vehicular and indoor to outdoor pedestrian test environment with different mobile speeds is also investigated. Only the Frequency Division Duplex (FDD) component is simulated here, although the principle could be applied to the Time Division Duplex (TDD) component as well as other CDMA systems such as cdma2000 and IS-95 cellular systems, provided that an antenna remoting system such as RoF is used.

Macrodiversity model

Macrodiversity in Downlink of WCDMA with RoF access network can be modelled as shown in figure (1). The transmitted signal of each link can be written as:

$$S_0(t) = A_{(0)}\cos(wct)\sum_n d_n c_n R(t - nTc) \qquad (1)$$

where ωc and $A_{(0)}$ are the angular frequency and amplitude of the carrier respectively, d_n is the data value, c_n is the PN spreading code, and R(t) is impulse response of the root raise cosine filter. The received despread and descrambled signal may be represented by:

$$r_l(t) = s_l(t) + n_l(t) + \mathrm{O(t)} \qquad (2)$$

The received signal $s_l(t)$ is modelled as

$$S_l(t) = A_{(l)}\cos(w_o t + f_l(t))\sum_n d_n c_n R(t - nTc - t_l) \qquad (3)$$

where $A_{(l)}$ represents the amplitude and ϕ the phase of the channel on the ith path. The term $n_l(t)$ represents the additive noise and interference on the same path and O(t) is optical link noise.

The received signal from active base stations is summed together using Maximum Ratio Combining (MRC). The signals from the various fingers are brought into time alignment and then combined coherently using the channel estimates. For MRC, the received signal in each finger is multiplied by the conjugate of the channel estimate (including the amplitude) before the signals are combined. Hence

$$r_{MRC} = \sum_{i=l}^{M} w_i s_l \qquad (4)$$

The weighting factor w_i is found to be proportional to the square root of the SNR of the channel l [6-7]. By using the characteristic function, the pdf of the SNR can be obtained from the statistics of s_l. Finally, the Bit Error Probability *Pb* for each branch can be obtained.

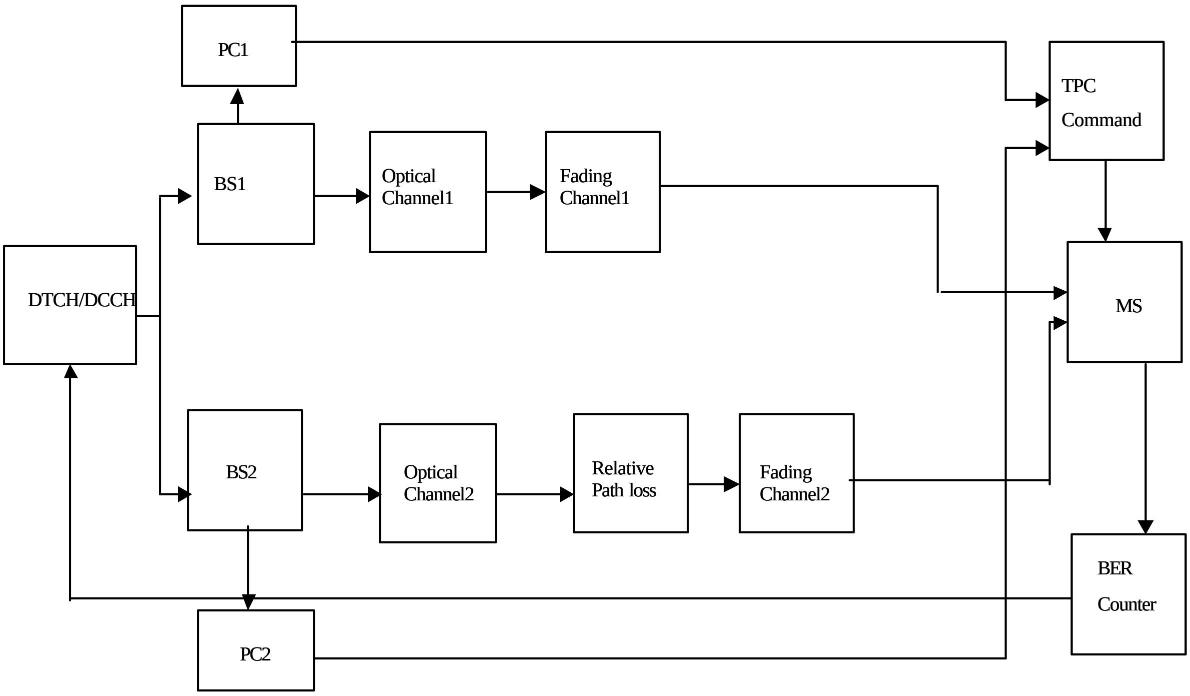

Figure 1 Macrodiversity Simulation Model in the Downlink With RoF.

The signal given by (3) modulates the Laser Diode (LD). The LD nonlinearity is modeled by a third-order polynomial without memory [8]. The optical signal output is shown in equation (7):

$$P(t) = P_t[1 + I'(t) + a_2 I'^2(t) + a_3 I'^3(t)] + h(t) \qquad (5)$$

where P(t) is the average transmitted optical power, $I'(t)$ is the LD current, a_2 and a_3 are the second and third-order coefficients respectively, and $\eta(t)$ is background noise.

Simulation results

The results of the simulations show the BER as a function of E_b/N_o for the Pedestrian and Vehicular channels with equal and different path loss with various mobile speeds. The system working point (E_b/N_o @ 10^{-3} BER) is calculated by adding the overhead (processing gain and voice activity factor).

Figures 2 and 3 show the BER performance for single and Macrodiversity links. The gain of the Macrodiversity has been calculated between the two values of E_b/N_o of single link and the Macrodiversity at the system working point. The simulation results show that using Macrodiversity in the Downlink of RoF network could result in a reduction of E_b/N_o of more than 2dB.

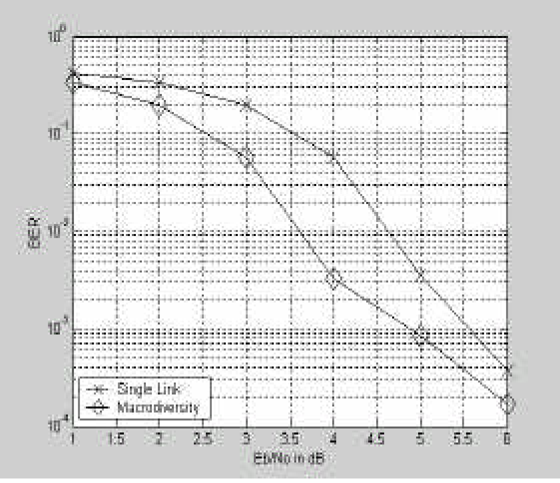

Figure 2 BER for Vehicular (A) channel with 3km/h mobile speed.

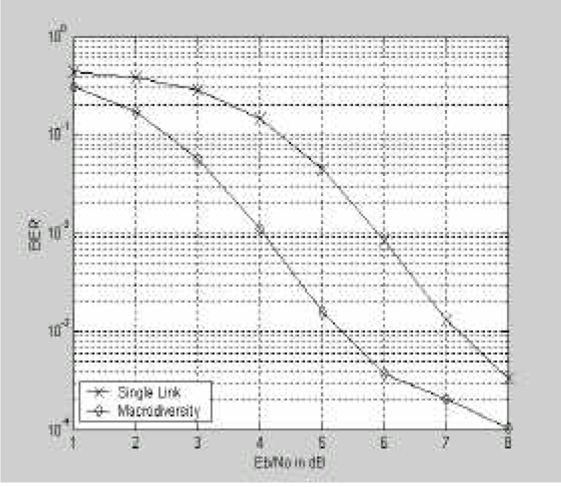

Figure 3 BER for Pedestrian (A) with 3km/h mobile speed.

It is shown that there is higher gain in the case where the two base stations have equal path loss. The Macrodiversity gain decreases when the difference in path loss between the two BSs increases. Because the power control can track and balance the variations in the received signal by the channel, the system working point reaches its lowest value at a mobile speed of 3km/h.

Increasing the mobile speed has the disadvantage of decreasing the effectiveness of the power control and phase recovery algorithm. However, it has the advantage of increasing the ability of the interleaver to spread the error bursts. Thus, the combined overall effect is that the system working point remains unchanged. The results show that the higher variation in the received power, the higher the E_b/N_o target needs to be to provide the same quality.

Capacity Calculations

System Capacity is determined by the amount of the interference level and the accepted level of Quality of Service (QoS) [9]. In the downlink capacity, the lower E_b/N_o necessitates lower transmitted power, which translates into more capacity.

The pole capacity is the theoretical maximum capacity if the mobiles have infinite transmits power available. In practice the capacity is a fraction of the pole capacity. Typical values are 50-60% of the pole capacity. The sustainable capacity is proportional to the processing gain, reduced by the required SNR [10].

$$E_b/(N_o + I_o) = \frac{W/R}{(N_o W/P_s) + N - 1} \tag{6}$$

For maximum capacity $Ps \longrightarrow \infty$. Therefore, the basic capacity equation can be reduced to:

$$N \approx \frac{W/R}{E_b/(N_o + I_o)} \tag{7}$$

By considering the effect of additional interference and the voice activity factor, the pole capacity equation is: mobile speeds. The capacity gain is higher in the Pedestrian channel with low mobile speed.

$$N_{pole} = \frac{W/R}{E_b/(N_o + I_o).(F+1)v} \tag{8}$$

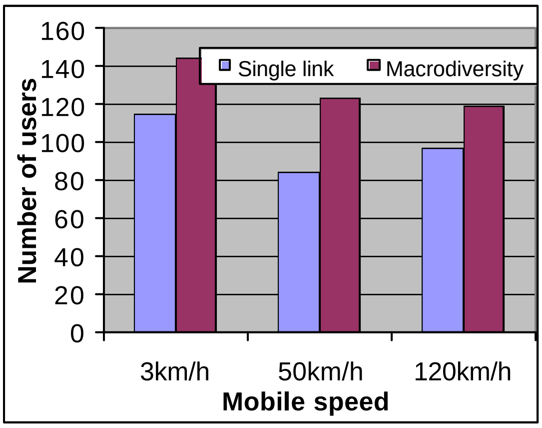

Figure 4 Capacity for Pedestrian A channel.

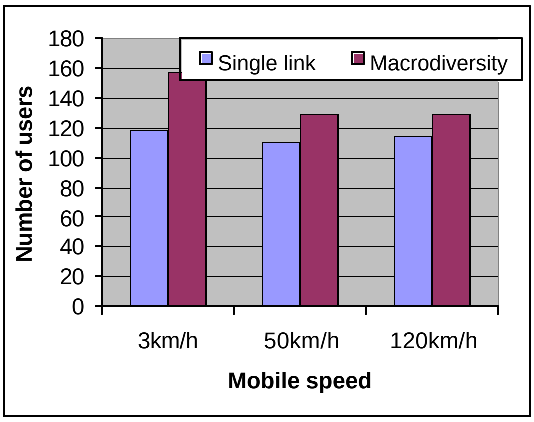

Figure 5 Capacity for Vehicular A channel.

The Load factor L_f defines in equation 9 shows how close to the maximum capacities the network operates.

$$L_f = \sum v_j . \frac{(E_b / N_o)}{W / R_j} .[(1-a_j)+i_j] \quad (9)$$

where α_j is the orthogonality factor in the cell power, received by user j. The capacity of the WCDMA system can be represented by the L_f and the total number of traffic transmitted by the network. Figures 4 and 5 show the capacity of Pedestrian and Vehicular A channel for different mobile speeds.

Conclusion

We have investigated the capacity improvement during Macrodiversity mode in the Downlink of WCDMA with RoF access network. The results of our simulation show that using Macrodiversity in the Downlink of RoF network could result in gain of more than 2dBn in E_b/N_o. The capacity in the DL was analysed according to Shannon theory. The pole capacity for the system was calculated for Pedestrian and Vehicular environment with different MS speed. Our simulation shows that significant capacity gain (up to 46%) can be realized through the use of Macrodiversity in RoF.

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