Abstract—The overlay of a frequency diversity spread spectrum system (FDSS) on the advanced mobile phone service (AMPS) system is studied. The worst case condition is considered. The down- and uplink capacity for both systems are given using a model of 25 cells. The performance of the AMPS and FDSS users is investigated. Results show that the overlay is feasible when a good selection of the overlay parameters is done.

Index Terms—AMPS, capacity, FDSS, overlay.

I. INTRODUCTION

The generation of the FDSS can be described as follows. A single data symbol with a time duration \( T_b \) is replicated into \( M \) parallel copies \( (M = 4 \sim 512) \). For the \( m \)-th user, the \( i \)-th branch data of the parallel stream is multiplied by a chip \( c_m[i] \) from a PN code or some orthogonal code of length \( M \) and then BPSK modulated on to a subcarrier \( (\omega_i) \) spaced apart from the neighboring subcarriers by \( N/T_b \), \( N \in [1, 2] \). The transmitted signal consists of the sum of the outputs of these branches. This process yields a multi-carrier signal with the subcarriers containing the coded data symbol. The processing gain of the FDSS system is \( M \). Fig. 1 shows the transmitter block diagram. The FDSS spectrum for \( M = 4 \) and \( N = 1 \) is depicted in Fig. 2. Using the FDSS technique; the subchannels with very low SNR can be suppressed in the receiver to improve the overall performance of the FDSS system [1]. This is done by reducing the branch gain \( D_{m,i} \) to a negligible value. Fig. 3 shows the receiver block diagram.

II. INTERFERENCE EVALUATION

A. Downlink Analysis for AMPS

In the AMPS system the ratio \( D/R \) is 4.58 where \( D \) is the distance between the cochannel cells that use the same set of frequencies, \( R \) is the radius of the cell. When unsectored cells are used the \( C/I \) ratio is equal to 18.6 dB and each channel is affected by 6 interfering channels (cochannels) [2]. Using three sectors cells the \( C/I \) ratio increases. For the AMPS system the worst case cochannel interference \( (I_1) \) for cells with three sectors is given by [3]

\[
I_1 = \left[ \frac{R^4}{(D + 0.7R)^4} + \frac{R^4}{D^4} \right] \times S \tag{1}
\]

where \( S \) is the power of the AMPS desired channel when the AMPS user is at the boundary of the cell.
The FDSS users are assumed to be uniformly distributed within the cells and the AMPS user under consideration is assumed to be at the intersection of three cells (worst case from the FDSS point of view). Using the 25 cells model, the interference from the FDSS users ($I_2$) is calculated as

$$I_2 \approx K_1 \times N_u \times \alpha \times F_s \times (b_1/b_2) \times (p_2/p_1) \times S$$

where $D_{cu}$ is the distance between the base station $c$ and the user under consideration, $N_u$ is the number of the FDSS users in each cell, $\alpha$ is the voice activity factor, which is equal to 0.4, $F_s$ is the sectorization factor, which is equal to 1/3, $b_1$ is the AMPS channel bandwidth (=30 kHz), $b_2$ is the FDSS system bandwidth, $p_1$ is the AMPS transmitted power and $p_2$ is the FDSS transmitted power. Using a 12 cells model, the value of $K_1$ is 3.312 [4].

The $C/I$ ratio of the AMPS system is given by

$$\frac{C}{I}_{AMPS} = \frac{S}{(I_1 + I_2)}$$

which should be equal to 18 dB (no margin) or higher than 18 dB (with margin).

### B. Downlink Analysis for FDSS

For the FDSS system, the receiver suppresses the subchannels with low SNR, therefore the interference ($I_3$) from the AMPS base stations is totally suppressed by the FDSS receiver, i.e.,

$$I_3 = 0.$$  (5)

The suppressed bandwidth $b_s$ is given by

$$b_s = B_{AMPS} \times \varepsilon$$

where $B_{AMPS}$ is the effective AMPS system bandwidth and $\varepsilon$ is a factor with a value of 1.00-1.050.

Since part of the FDSS spectrum will be suppressed in the receiver, then the effective bandwidth ($b_{eff}$) is given by

$$b_{eff} = b_{real} - b_s.$$  (7)

A model of 25 cells, which is shown in Fig. 4, is used to calculate the interference from other users of the FDSS system for the worst case condition (the FDSS user is at the edge of the home cell $A_1$ at a distance $R$ from the base station).

The worst case normalized interference of the FDSS users ($I_4$) is calculated to be as

$$I_4 = (K_2 + \mu) \times N_u \times \alpha \times F_s \times (b_{eff} / b_{real})$$

where $\mu$ is the no orthogonality factor ($0 \leq \mu \leq 1$). In (8), $\mu$ is due to the interference from the home cell and the factor $K_2$ is due to other cells interference.

Therefore, the $(C/I)_{FDSS}$ ratio and $E_b / N_o$ of the FDSS system are given, respectively by

$$\frac{(C/I)_{FDSS}}{E_b / N_o} = \frac{(b_{eff} / b_{real})/(I_1 + I_4)}{(b_{eff} / b_{real})/I_4} = \left[I_1 + I_4 \right] = \frac{(b_{eff} / b_{real})}{I_4}$$

$$\left[(2.365 + \mu) \times N_u \times \alpha \times F_s \right]^{-1}$$

$$E_b / N_o = \frac{(b_{eff} / b_{user})}{G_p \times (C/I)_{FDSS}}$$

where $b_{user}$ is the FDSS user bit rate. The ratio $E_b / N_o$ should be equal to or higher than 7 dB to obtain a BER less than $10^{-3}$ [5].

### C. Uplink Analysis for AMPS

For the AMPS system the cochannel interference ($I_5$) for cells with three sectors is given by

$$I_5 \approx \left[ \frac{R^4}{(4R)^3} + \frac{R^4}{D_{cu}^4} \right] \times S.$$  (13)

The interference from the FDSS users ($I_6$) is calculated (using simulation) to be

$$I_6 = K_3 \times uN_F \times \alpha \times F_s \times (b_{eff} / b_{real})$$

where $K_3$ is the interference from the FDSS system.
where $K_3 = 0.7$ resulted from simulation using the methodology given in [6] assuming an ideal power control in the FDSS uplink and a shadowing variance $\sigma$ of 8 dB. The factor $K_3$ is due the intercellular interference. The typical value of the factor $K_3$ is 0.6 [7].

The $C/I$ ratio of the AMPS system is given by

$$C/I\text{_{AMPS}} = S/(I_5+I_6).$$

(15)

D. Uplink Analysis for FDSS

Power control is used in the uplink of the FDSS. Since the interference ($I_7$) from the AMPS mobile stations is totally suppressed by the FDSS receiver, then

$I_7 = 0$.

(16)

Finally, the normalized interference of the FDSS users ($I_8$) is calculated through simulation to be:

$$I_8 \approx 1.7 \times N_a \times \alpha \times F_s \times (b_{eff}/b_{real})$$.

(17)

The ($C/I$)$_{FDSS}$ ratio and $E_b/N_o$ of the FDSS system are:

$$(C/I)_{FDSS} = (b_{eff}/b_{real})/(I_7+I_8) = (b_{eff}/b_{real})/I_8$$

(18)

$$(C/I)_{FDSS} = [1.7 \times N_a \times \alpha \times F_s]^{-1}$$

(19)

III. RESULTS

Assuming an AMPS bandwidth of 5.04 MHz for both up- and downlink, each cluster contains 168 cells. Thus each cell contains 24 channels assuming a cluster of 7. To make the overlay possible we let 630 kHz of the AMPS bandwidth without use, i.e., we have to scarify a little bit of the AMPS bandwidth to get the benefits of the overlay. The effective bandwidth of the AMPS system ($B_{AMPS}$) will be 4.41 MHz and the effective number of channels is reduced to 21 ch/cell. The FDSS total bandwidth is 5.04 MHz but the effective bandwidth is 608 kHz. The FDSS bit rate is assumed to be 8 kbit/sec and for this reason the subchannel bandwidth is 16 kHz. The processing gain is equal to 608/8 = 76. It is assumed that $\mu$ is 1 (worst case).

Fig. 5 shows the AMPS spectrum with 147 channels in use. The FDSS spectrum with 5.04 MHz bandwidth is depicted in Fig. 6 and the FDSS effective spectrum with effective bandwidth of 608 kHz is shown in Fig. 7.

Fig. 8 shows the performance of the downlink of the AMPS system overlaid by the FDSS system with $p_1/p_2 = 20$. If we use the ratio $C/I$ of 21 dB as the minimum accepted ratio (3-dB margin) then the AMPS
Fig. 9. The FDSS performance (downlink).

Fig. 10. The AMPS performance with $p_1 / p_2 = 20$, uplink.

system can tolerate up to 33 FDSS users.

Fig. 9 shows the performance of the FDSS system for the downlink with the same power ratio. It can be seen that the FDSS capacity is 35 users at $C/I$ of 7 dB. Thus the downlink capacity is 33 FDSS users due to the AMPS system constrains.

Fig. 10 shows the performance of the uplink of the AMPS system overlaid by the FDSS system with a power ratio of 20. The AMPS system can tolerate up to 26 FDSS users at $C/I$ of 21 dB.

Fig. 11 shows the performance of the uplink. It can be seen that the FDSS capacity is 70 users at $C/I$ of 7 dB for a power ratio of 20. Thus the uplink capacity is limited by the AMPS uplink. With a power ratio of 20 for both the up and down link, the uplink is the link that limits the overlay capacity.

If the ratio $p_1 / p_2$ in the downlink is increased to 22, the AMPS will tolerate 36 FDSS users in the downlink. Any further increase of this ratio will not increase the capacity of the overlay of the FDSS system. Fig. 12 shows the performance of the AMPS system for a power ratio of 22.

If the ratio $p_1 / p_2$ in the uplink is increased to 27, the AMPS will tolerate 35 FDSS users in the uplink. Any further increase of this ratio will not increase the capacity of the overlay of the FDSS system. Fig. 13 shows the performance of the AMPS system in the uplink for a power ratio of 27. Any further increase of the power ratio for both links will go in vain.

Table I shows the capacity of the mixed system for different power ratios.

IV. REMARKS

• Shadowing effects have not been considered in the analysis of the FDSS downlink. Shadowing can increase the capacity of the FDSS system if the interference links are shadowed more than the signal link or it can reduce the capacity if the signal link is shadowed more than the interference links. Our results can be considered as the average expected performance when shadowing is included.

• Using "Handover", the downlink capacity of the FDSS system will increase.

V. CONCLUSION

Analytical formulas for down- and uplink $C/I$ of AMPS as well as FDSS system when they share the same frequency band are derived. For a power ratio of 20, it can be noticed that 21 simultaneous users of the AMPS system can tolerate 26 simultaneous users of the FDSS users when $C/I$ is 21 dB. The total capacity of the mixed system is equal to $21 + 26 = 47$ users, instead of 24 AMPS users. In this way the total capacity is approximately doubled. With a
TABLE I
THE MIXED SYSTEM PERFORMANCE. * AMPS channels=21/cells.

<table>
<thead>
<tr>
<th>Power ratio</th>
<th>AMPS overlay UL</th>
<th>AMPS overlay DL</th>
<th>FDSS capacity UL</th>
<th>FDSS capacity DL</th>
<th>Overlay capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_1 / p_2 = 20$</td>
<td>26</td>
<td>33</td>
<td>70</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>$p_1 / p_2 = 22$ in DL</td>
<td>35</td>
<td>36</td>
<td>70</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>$p_1 / p_2 = 27$ in UL</td>
<td>&gt;35</td>
<td>&gt;36</td>
<td>70</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

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