Intelligent FDSS Overlay on GSM System (Uplink Analysis)

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Abstract. *The overlay of an intelligent frequency diversity spread spectrum system (FDSS) on the (GSM) system is studied. The uplink capacity of both systems is given using a model of 36 hexagonal macrocells. Performance of GSM and FDSS users is investigated. An original GSM system with 48 users/macrocell can be substituted by a mixed system, which has GSM system capacity of 48 users/macrocell and FDSS system capacity of 128 users/macrocell.*

Keywords

GSM, uplink capacity, FDSS, overlay.

1. Introduction

The actual second-generation mobile systems have to overcome their capacity limit migrating to the third generation system. In USA, the PCS band occupies the IMTS-2000 band. New solutions have to be provided to produce a soft transition. The overlay may solve this problem. Several works has covered this topic.

A standard overlaid GSM system based on a conventional broadband code division multiple access system (B-CDMA) over GSM system was proposed in [1]. The system performance of the uplink has been analyzed. Furthermore, in the B-CDMA base stations an agile notch filtering is assumed to be used.

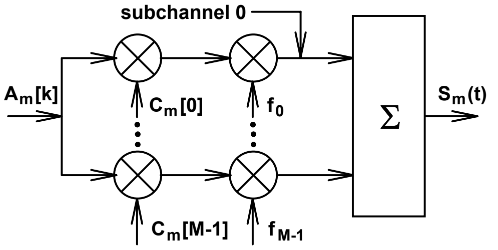

Fig. 1. The FDSS transmitter model.

An overlaid GSM system based on a conventional CDMA over GSM system has been analyzed in [2] and the performance of the uplink has been studied. Moreover, in CDMA transmitters and receivers, ideal notch filtering is assumed around the occupied GSM frequencies of the same cell.

Zhou et al. proposed the overlay of WCDMA system over the systems TDMA and NCDMA [3] emphasizing on the impact of interference suppression techniques on the mixed system performance. Papporth proposed CDMA overlay system using frequency diversity spread spectrum (FDSS) [4]. Acceptable number of overlay users is evaluated and compared with and without rejection filters.

This paper addresses the overlay of intelligent FDSS over the GSM system and studies the performance of the uplink of both systems.

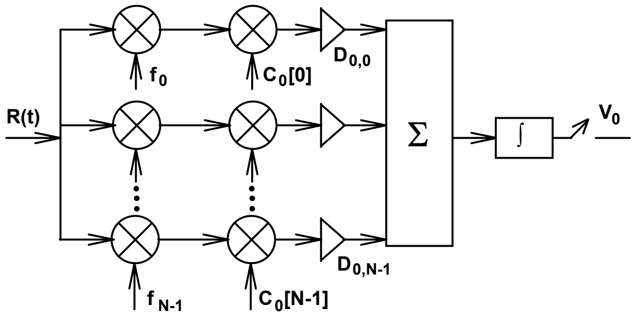

Fig. 2. The FDSS receiver model.

Section 2 of this paper describes the FDSS system and Section 3 gives the interference evaluation method for the GSM and the FDSS systems. In section 4, numerical results are given. Finally, section 5 draws the conclusions.

2. The FDSS Model

The generation of the FDSS signal can be described as follows. A single data symbol with time duration T_b is replicated into M parallel copies (M = 32 to 512). For the m-th user, the i-th branch data of the parallel stream is multiplied by a chip $c_m[i]$ from some orthogonal code of length M and then BPSK modulated on to a subcarrier (f_i) spaced a part from the its neighboring subcarriers by $C_s = 1/T_b$. The transmitted signal consists of the sum of the outputs of these branches. This process yields a multi-carrier code division multiple access (MC-CDMA) signal with the subcarriers containing the coded data symbol with a processing gain of the FDSS system of M. Fig. 1 depicts the transmitter model. Using the FDSS technique; subchannels with very low SNR can be suppressed in the receiver to improve the overall performance of the FDSS system [4]. This is done by reducing the branch gain $D_{m,i}$ to a negligible value. Fig. 2 shows the receiver model.

Using side information, the intelligent FDSS system omits the transmission of a replica if there is a strong narrow-band interference in corresponding frequency slot [4].

3. Interference Evaluation

A model of 36 macrocells shown in Fig. 3 has been used to analyze the uplink performance of both systems.

This evaluation is developed assuming the following:

- The GSM and FDSS base stations are collocated;
- Perfect power control is utilized in the uplink of both FDSS and GSM systems;
- The propagation exponent is 4;
- Each GSM and FDSS macrocell has 3 perfect sectors;
- The transmitted power by GSM user at the macrocell edge is P_1 and that the power transmitted by FDSS user at the edge of the macrocell is P_2.
- The received power of the desired signal by GSM base station antenna is S_{GSM} and the received power of desired signal at FDSS base station antenna is S_{FDSS}.
- The relation $S_{GSM}/S_{FDSS} = P_1/P_2$.

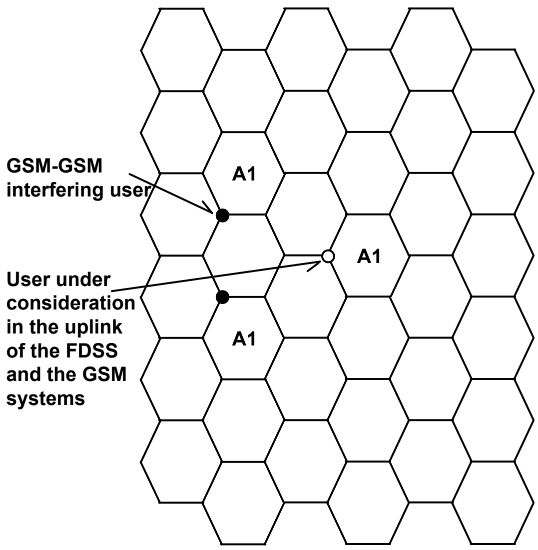

Fig. 3. The 36 macrocells model.

In the analysis we will assume that due to the FDSS system intelligence, the FDSS mobile users will not transmit any signal within the band occupied by the GSM system within the same macrocell. In this way, all subcarriers suppressed by the FDSS transmitter will be quasi totally attenuated in the FDSS base station receiver. Thus, the effective GSM interference at the FDSS base station due to the GSM users of the same macrocell is ≈ 0. Also, the effective FDSS interference at the GSM base station due to the FDSS users of the same macrocell is ≈ 0.

3.1 Uplink Analysis of GSM

For the GSM system, the worst case cochannel interference I_1 for macrocells with three sectors (see Fig. 3) is:

$$I_1 \approx \left[\frac{R^4}{(\sqrt{13}R)^4} + \frac{R^4}{(\sqrt{13}R)^4} \right] S_{GSM} \ , \tag{1}$$

where R is the macrocell radius.

I_2 is calculated by 1 due to the fact that for the worst case GSM cochannel interference, the GSM under consideration is at a distance R from its base station mean while each of the two GSM interfering users has a distance of $\sqrt{13}R$ from the base station of the GSM user under consideration.

The FDSS mobiles will not transmit any signal at the GSM bands used in the same macrocell. Thus the FDSS intracellular interference that affect the GSM system is quasi null and the only FDSS interference that affects the GSM system is the FDSS intercellular interference. In this way, the interference I2 from the FDSS users is calculated as (see appendix A):

$$I_2 \approx K\, N_{FDSS}\, \alpha\, Fs\, (b_{GSM} / b_{FDSS})\, S_{FDSS} \ , \tag{2}$$

where the intercellular interference factor K = 0.66 [5], N_{FDSS} is the number of the FDSS users/macrocell, α is the source activity factor, F_s = 1/3 is the sectorization factor for three ideal sectors macrocell, b_{GSM} = 200 kHz is the GSM channel bandwidth, b_{FDSS} is the FDSS principal bandwidth.

Hence, the C/I ratio of the GSM system is given by

$$(C/I)_{GSM} = S_{GSM} / (I_1 + I_2) \ ; \tag{3}$$

the ratio $(C/I)_{GSM}$ should be 10 dB or higher

3.2 Uplink Analysis of FDSS

Here we will consider a perfect power control in the uplink of the FDSS and the GSM systems. The FDSS base station receiver will suppress its subcarriers affected by the GSM signal of the same macrocell. Thus the GSM intracellular interference that affect the FDSS system is quasi null. The intercellular interference from the GSM system I_3 is given by:

$$I_3 \approx K \cdot 0.125 N_{GSM} \cdot S_{GSM} \cdot Fs \ , \tag{4}$$

where NGSM is the number of the effective GSM users/ macrocell. Here, the factor 0.125 is due to the fact that one GSM user of 8 is transmitting within a given time.

Finally, interference I_4 due the FDSS users is calculated as:

$$I_4 \approx (K+1)\ Nu\ \alpha\ Fs\ S_{FDSS}\ . \quad (5)$$

Here the factor 1 is due to the intracellular interference mean while K is due to the intercellular interference.

Hence, the $(C/I)_{FDSS}$ ratio and E_b/N_0 of the FDSS system are

$$(C/I)_{FDSS} = \frac{S_{FDSS}}{(I_3 + I_4)}\ , \quad (6)$$

and

$$(E_b/N_0)_{FDSS} = G_{pf}\ (C/I)_{FDSS}\ , \quad (7)$$

where G_{pf} is the FDSS final processing gain after the suppression of the effected sub-channels.

The number of suppressed subchannels N_s due to jamming bandwidth B_j is given by:

$$N_s \approx \left\lceil \left(\frac{B_j}{C_s} \right) \right\rceil + 2\ , \quad (8)$$

where C_s is the subchannel separation = bit rate.

The total suppressed carriers M_s is given by:

$$M_s = N_s\ N_{GSM}\ , \quad (9)$$

where N_{GSM} is the number of the GSM channels within the FDSS principal bandwidth. In this way, the FDSS final processing gain G_{pf} is given by:

$$G_{pf} = M - M_s\ . \quad (10)$$

4. Numerical Results

Assuming an GSM bandwidth of 4.8 MHz, each cluster has capacity of 192 users, so for 4 macrocells cluster, each macrocell has a capacity of 48 GSM users. The FDSS total bandwidth (principal + sidelobes) is 4.8 MHz. The FDSS principal bandwidth is 3.84 MHz and the bit rate is assumed to be 15 kbit/sec (C_s = 15 kHz). Therefore, the original processing gain is (3840/15 = 256). We will study the uplink capacity of the macrocell which has a GSM channels at (800 to 1000) kHz, (1600 to 1800) kHz, (2400 to 2600) kHz, (3200 to 3400) kHz and (4000 to 4200) kHz. Due to the GSM interference and to reduce its effect to quasi null effect, the FDSS receiver will suppress 80 subchannels, i.e, 240 kHz for each 200 kHz GSM channel. In this way the effective FDSS processing gain P_{gf} is 176.

Due to the existence of 5 GSM channels within the FDSS principal bandwidth, then, the total number of the interfering GSM users/macrocell is 40 (5 · 8). Since that any GSM user transmits it signal within one slot out of 8 slots, then, the number of the interfering GSM users that are transmitting within a given time is 40/8 = 5. For calculation voice activity factor α = 0.5 is assumed.

Fig. 4 shows the FDSS original spectrum with 3.84 MHz principal bandwidth. Fig. 5 shows the FDSS spectrum transmitted by the FDSS mobile user after suppressing 5 × 16 sub-channels (5 × 240 kHz) due to existence of 5 × 200 kHz GSM channels. The effective received signal at the GSM base station within the 200 KHz channel bandwidth is less than –17dB (quasi null).

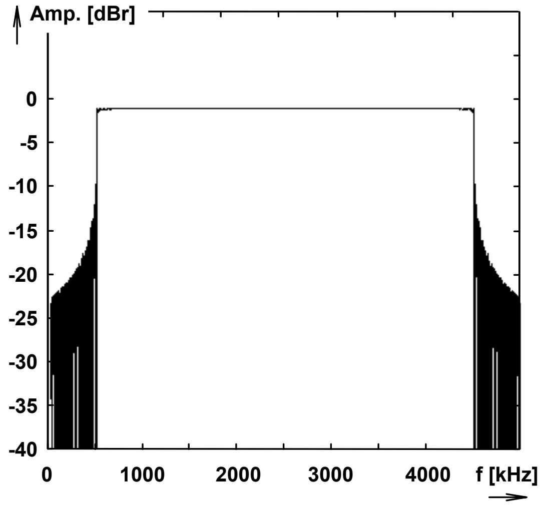

Fig. 4. The original FDSS spectrum.

We suppose that the power ratio P_1/P_2 = 10. Fig. 6 shows the uplink performance (SNR) of the GSM system overlaid by the FDSS system for which, the C/I ratio has been calculated using (3). From this figure we can calculate the number of the FDSS user N_t that the GSM system can tolerate reducing its SNR from a given value to 10 dB. It can notice that the GSM system can tolerate up to 160 of FDSS users/macrocell at SNR ≈ 10 dB, thus N_t = 160 FDSS users/macrocell.

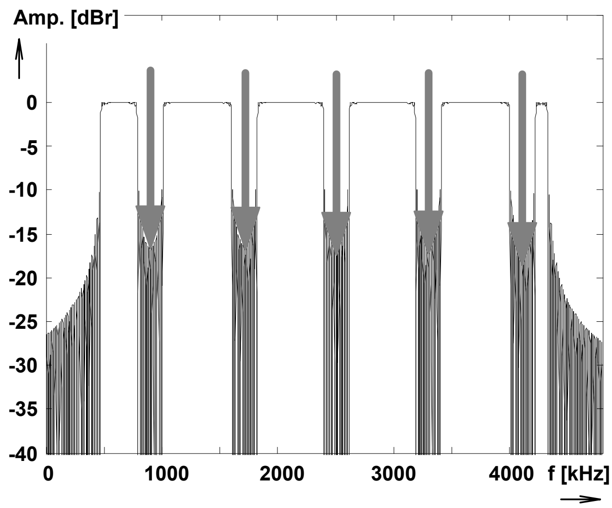

Fig. 5. The FDSS mobile user transmitted spectrums with 5 interfering GSM channels.

Fig. 7 shows the uplink performance of the FDSS system for the same power ratio. The ratio E_b/N_0 has been calculated using (7). The aim of this figure is to show us the FDSS capacity NFDSS calculated at the required E_b/N_0 of

6 dB. It can be noticed that the FDSS capacity is 120 users/ macrocell.

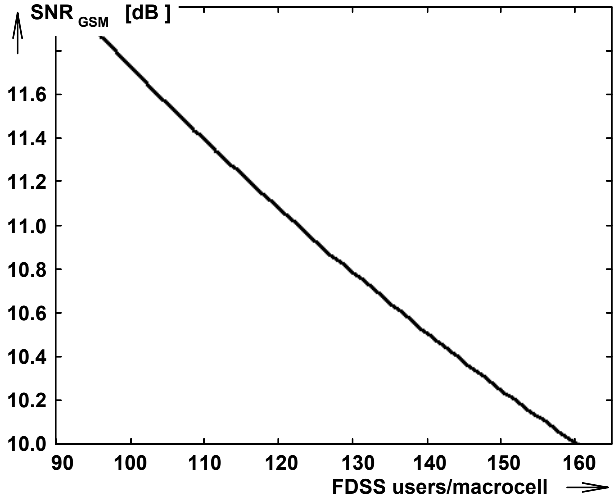

Fig. 6. The GSM uplink performance (SNR vs. FDSS users per macrocell) when $P_1/P_2 = 10$.

The extra FDSS overlay capacity is $N_{extra} = \min(N_t, N_{FDSS})$.

From the above given examples, the extra FDSS overlay capacity is 120 FDSS users/macrocell due to the FDSS system limitations ($N_{FDSS} < N_t$).

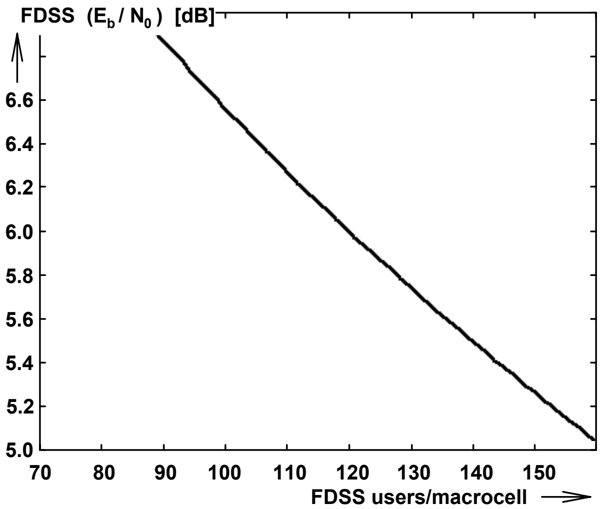

Fig. 7. The FDSS uplink performance (E_b/N_0 vs. FDSS users per macrocell) when $P_1/P_2 = 10$.

Next, we suppose that the power ratio $P_1/P_2 = 8$. Fig. 8 shows the uplink performance of the GSM system overlaid by the FDSS system. We can notice that the GSM system can tolerate 128 of FDSS users/macrocell ($N_t = 128$).

Fig. 9 shows the uplink performance of the FDSS system for the same power ratio $P_1/P_2 = 8$. It can be noticed that the FDSS capacity is 128 users at E_b/N_0 of 6 dB. Thus the extra FDSS overlay capacity is 128 FDSS users per macrocell ($N_{FDSS} = N_t$).

Finally, we suppose that the power ratio $P_1/P_2 = 6$. Fig. 10 shows the uplink performance of the GSM system overlaid by the FDSS system. It can be noticed that the GSM system can tolerate 96 of FDSS users/macrocell ($N_t =$ $= 96$).

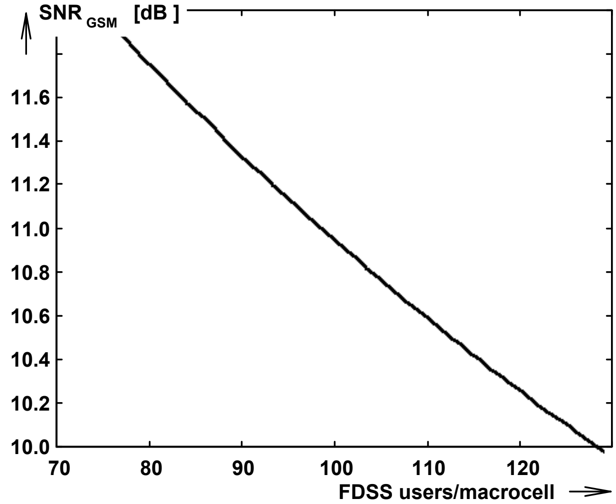

Fig. 8. The GSM uplink performance (SNR vs. FDSS users per macrocell) when $P_1/P_2 = 8$.

Fig. 11 shows the uplink performance of the FDSS system for the same power ratio. It can be noticed that the FDSS capacity is 136 users at E_b/N_0 of 6 dB. Thus the extra FDSS overlay capacity is 96 FDSS users/macrocell due to the GSM system limitations (N_t < NFDSS).

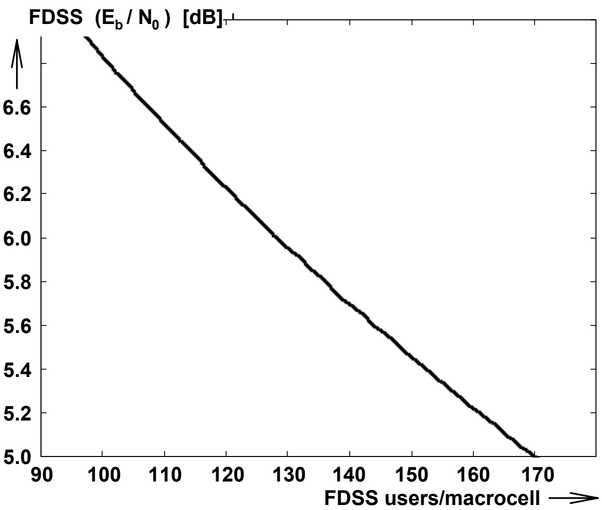

Fig. 9. The FDSS uplink performance (E_b/N_0 vs. FDSS users per macrocell) when $P_1/P_2 = 8$.

From the above results, we can conclude that the maximum possible extra overlay capacity is 128 FDSS/macrocell got at power ratio $P_1/P_2 = 8$. Since that the maximum GSM mobile transmitted power is 1 W to 2 W, then, the maximum FDSS mobile transmitted power should be in order of 125 mW to 250 mW, i.e., (21 to 24) dBm which is a reasonable transmitted power for spread spectrum systems. For P_1/P_2 in the range of 7.5 to 10, quasi maximum extra overlay capacity is got.

Practically, due to non-ideal GSM interference suppressing, FDSS imperfect power control and non-ideal 3 sectors, extra overlay capacity is of order 100 FDSS.

5. Conclusions

Analytical formulas for uplink C/I of GSM as well as FDSS system when they share the same frequency band are given. For a power ratio (P_1/P_2) of 8, the GSM system can tolerate up to 128 FDSS users/macrocell mean while the FDSS system capacity is 128 FDSS users/macrocell. Thus the extra overlay capacity is 128 FDSS users/macrocell. The total capacity of the mixed system is (48+128=176 users/macrocell) instead of 48 GSM users/macrocell. In this way the total capacity is 3.67 times the GSM capacity.

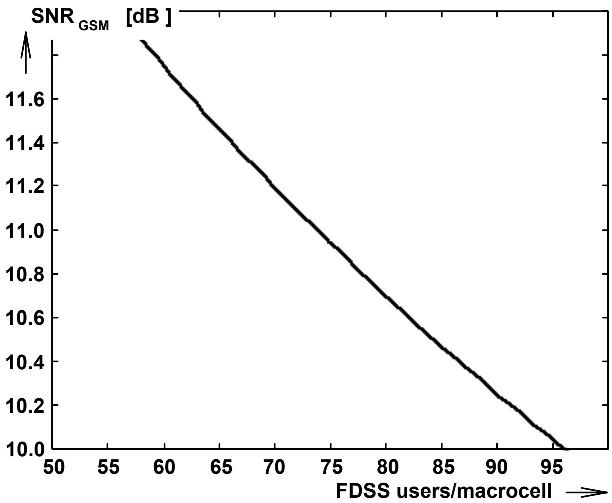

Fig. 10. The GSM uplink performance (SNR vs. FDSS users per macrocell) when $P_1/P_2 = 6$.

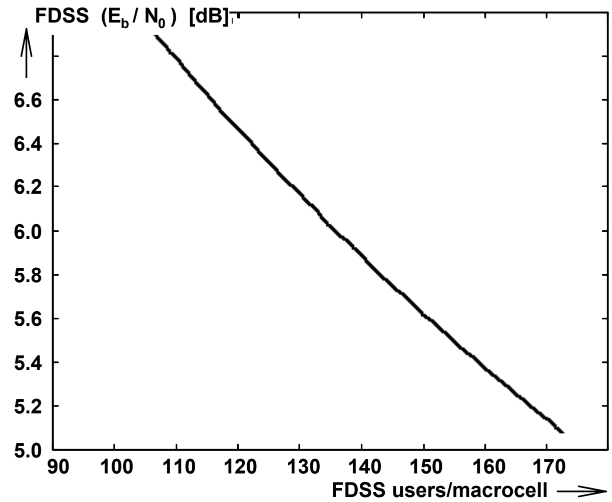

Fig. 11. The FDSS uplink performance (E_b/N_0 vs. FDSS users per macrocell) when $P_1/P_2 = 6$.

Appendix

To calculate the FDSS intercellular interference that affects the GSM user under consideration we have:

- The FDSS interference power P_1 within the GSM channel is given by:

$$P_1 = S_{FDSS}\left(b_{GSM} / b_{FDSS}\right) \tag{A1}$$

- Since that the FDSS mobile activity factor is α then the effective intercellular interference power P_2 is:

$$P_2 = P_1\,\alpha \tag{A2}$$

- Due to the fact that the macrocell has more than sector, then, the FDSS interference power P_3 will be reduced by the factor F_s (sectorization factor)

$$P_3 = P_2\,F_s \tag{A3}$$

- Since that P_3 is due to single FDSS user, then, for N FDSS users, the interference power P_4 will be:

$$P_4 = P_3\,N_{FDSS} \tag{A4}$$

  P_4 represents the effective interference that affects the GSM user under consideration of the same macrocell. To calculate the effective interference I due to other macrocells we have to use the well known K factor that gives the effect of other cells interference (intercellular interference factor) with a well known value of 0.50 to 0.66 depending on the shadowing severity.

- Thus the other cells interference I will be given by:

$$I \approx K\,N_{FDSS}\,\alpha\,F_s\,(b_{GSM} / b_{FDSS})\,S_{FDSS} \tag{A5}$$

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