# Macrodiversity technique for improvement in BER in wireless systems

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*Indexing terms: Mobile communication systems, Cellular radio, Bit error rate*

The authors analyse a novel macrodiversity scheme, the multiply-detected macrodiversity (MDM) scheme, which relies on post-detection combining, as opposed to the traditional macrodiversity techniques, which are selection-based. The average fraction of the cell area is evaluated with an improved bit error rate (BER) performance, average BER improvement, and improvement in the average outage probability, relative to three other selection-based macrodiversity schemes. As a point of reference, the average improvement in BER is always at least one order of magnitude throughout at least 25% of the cell area, when the probability of the co-channel interferer's presence is not >70%.

*Introduction:* Conventional macrodiversity methods consist of receiving a mobile unit transmission at a number of base-stations simultaneously and selecting the one with the best signal quality. The criterion for the best signal quality can be the signal with [1]: (i) the strongest power - the (*S*)-diversity; (ii) the largest signal-to-interference ratio - the (*S*/*I*)-diversity; (iii) the largest sum of signal and interference - the (*S*+*I*)-diversity.

In addition, the scheme in which the mobile always communicates with the 'closest' base-station is referred to here as the no-macro-diversity scheme.

In the proposed MDM scheme, there is no selection; a number of the received signals are post-detection combined by a maximum-likelihood decision algorithm, which maximises the probability of the correct decision. The scheme, which operates in the narrowband (TDMA) wireless regime, shows a significant improvement in the BER throughout large portions of the cell area.

*Operation of MDM scheme:* At any point in time, the mobile's transmission is received and detected by a number of base-stations, with which the mobile maintains communication links with quality above some minimal value. These base-stations are referred to here as the base-station coverage set (BCS). The detected signals are then conveyed to one single point in the network (which could be the destination) over the wireline network. Every so often, the quality of the links between the mobile and the BCS stations is measured by the BCS stations. These measurements are then transmitted to the central point (determination of the frequency of the measurements is outside the scope of this Letter). At the central point, the maximum-likelihood decision algorithm (the MDM decision algorithm) is used on the 'bit-by-bit' basis. An example of the MDM decision algorithm when $|BCS| = 3$, is shown in Table 1. (In this Table, $P_c^{(i)}$ and $P_e^{(i)}$ are the probability of correct and erroneous bit detections at the base-station *i*, respectively. These probabilities are calculated based on the measured signal qualities at the base-stations. The appropriate operating condition (A, B, C, or D) is then established, which determines the column of final decision to be used.)

**Table 1:** MDM decision algorithm

| Quality of links' reception (inputs) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Condition | | | A | B | C | D | Condition |
| $P_c^{(0)} \cdot P_c^{(1)} \cdot P_e^{(2)}$ | | | > | > | > | < | $P_e^{(0)} \cdot P_e^{(1)} \cdot P_c^{(2)}$ |
| $P_c^{(0)} \cdot P_e^{(1)} \cdot P_c^{(2)}$ | | | > | > | < | > | $P_e^{(0)} \cdot P_c^{(1)} \cdot P_e^{(2)}$ |
| $P_e^{(0)} \cdot P_c^{(1)} \cdot P_c^{(2)}$ | | | > | < | > | > | $P_c^{(0)} \cdot P_e^{(1)} \cdot P_e^{(2)}$ |
| BS0 | BS1 | BS2 | Final decisions | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 | |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | |
| 0 | 1 | 1 | 1 | 0 | 1 | 1 | |
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | |
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| Detected signals (inputs) | | | MDM decision (outputs) | | | | |

Note that the MDM scheme is based on post-detection combining. A pre-detection combining method yields greater BER improvement, however requires a significantly more bandwidth in the wireline network, to the point that it may not be altogether practical. Also, the MDM scheme could be further improved if soft detections (rather than hard detections) are transmitted from the BCS to the central point. This is currently under investigation.

The MDM scheme addresses the uplink direction only, which is more problematic, since the mobile's transmitting power is considerably lower than the base-station emitted power.

*Network model:* To evaluate the improvement of the MDM scheme, we used the following models:

*Network and traffic models:* (i) As shown in Fig. 1, a representative mobile, *M*, is associated with a set of three basestations, BS0, BS1 and BS2. (ii) Channel reuse is based on FCA with a reuse factor of 7. Each cell has a fixed radius of 1 km. (iii) $\rho(i)$ represents the probability that a channel assigned to the mobile *M* in cell *j* is (re)used in the co-channel cell *i* ($i \neq j$). We further assume that $\rho(I_1) = \rho(I_2) = ... = \rho(I_6) = \rho$, where $\{I_1, I_2, ..., I_6\}$ is the set of co-channel cells. In this Letter, we refer to $\rho$ as the channel occupancy.

*Radio propagation, interference, and modulation models:* (i) The signal attenuation exponent, *r*, can assume values of: 2.0, 2.5, 3.0, 3.5, and 4.0. (ii) We only consider the 'first-tier' co-channel interference. In addition, the interfering mobiles are fixed at their 'worst' locations; i.e., closest to the receiving base-stations. (iii) We assume the power (in dB) of the signal, as well as each of the six possible interferences, follow the lognormal distribution with a standard deviation ($\sigma$) of 4 or 8dB at the receiving site of the associated base-stations. (iv) Owing to large-scale diversity, we assume that the shadowing across different paths are uncorrelated. (v) We assume that the co-channel interferences add in power. Furthermore, we assume that the error-rate statistics of the total interfering power can be approximated by the error-rate statistics of Gaussian distributed noise. This approximation is valid when the number of interferers is sufficiently large. However, even when the number of interferers is not large, the error introduced by this approximation is not substantial (see [2]). (vi) We assume that no power control is implemented. (vii) The mobiles' transmission power is determined so that 90% of the time, the closest base-station receives a signal power level of at least –105dBm when the mobile is on the cell fringe. (viii) We neglect the fast-fading problem, assuming that the microscopic diversity scheme is implemented. (ix) Wireless signals are modulated using the quadrature phase shift keying (QPSK) modulation scheme. With an AWGN of $V = 10^{-15}$ W, the bit error rate (BER) is given by [3]:

$$Pe = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{signal}{V + \sum_{1,2,3,4,5,6} interference}}\right) \quad (1)$$

(x) We assume that, owing to other practical limitations, there is a floor of $10^{-8}$ on the achievable BER for any wireless link.

*Average gain area and average gain:* We define *gain* as:

$$gain \stackrel{\mathrm{def}}{=} \log_{10}\left(\frac{P_e^{MDM}}{P_e^{Ref}}\right) \quad (2)$$

where $P_e^{Ref}$ and $P_e^{MDM}$ are the BERs of one of the reference schemes and the MDM scheme, respectively. The gain area is defined as the portion of the cell area in which the expected gain is >1 (i.e., one order of magnitude BER improvement). Since there are six possible interferers, each of which is either present or not, the gain and the gain area are averaged over all 64 possible interferers' constellations, to yield the average gain (AG) and the average gain area (AGA), respectively. These average values should be interpreted as the expected values when a large number of measurements are taken at a specific location at different times. For $\sigma = 8.0$ and $r = 3.5$, AGA and AG relative to different reference schemes are shown in Figs. 2 and 3, respectively. AGA and AG always decrease with increase in the channel occupancy. AGA and AG are largest when compared with the no-macrodiversity scheme and smallest, when compared with the *S*/*I* diversity (Fig. 3). Also, both AGA and AG increase with $r$ and decrease with $\sigma$ (not shown here).

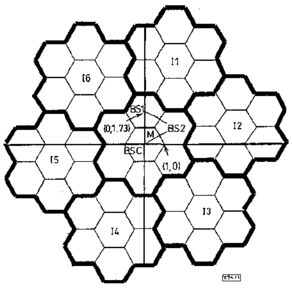


**Fig. 1** *Seven-cell cluster*

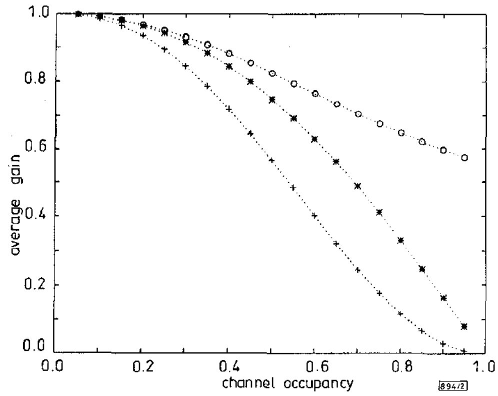


**Fig. 2** *Comparison of AGA-s*

$r$ = 3.5 sigma = 8.0, floor = $10^{-8}$
O no-macrodiversity, ✳ S-diversity, + S/I-diversity

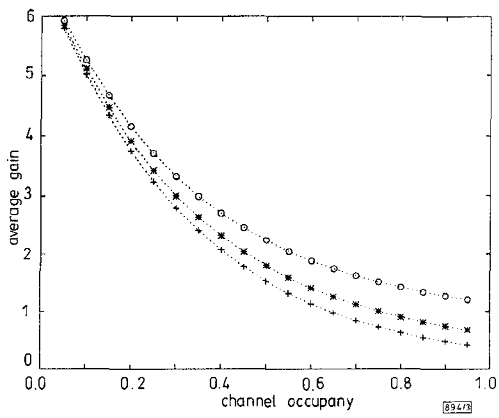


**Fig. 3** *Comparison of AG-s*

$r$ = 3.5 sigma = 8.0, floor = $10^{-8}$
O no-macrodiversity, ✳ S-diversity, + S/I-diversity

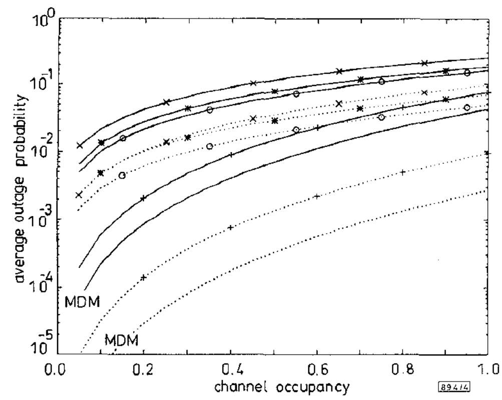


**Fig. 4** *Comparison of AOP-s*

$r$ = 4.0, sigma = 4.0 ($X$ = 0.5, $Y$ = 0.866)
——— threshold = $1 \times 10^{-5}$, ·········· threshold = $1 \times 10^{-3}$
× no-macrodiversity, ✳ S+I-diversity, O S-diversity, + S/I-diversity

*Average outage probability (AOP):* We define the outage probability as the probability of the BER being above some threshold and we present here results for threshold values of $10^{-3}$ or $10^{-5}$. In our study, the outage events are affected by the propagation loss, shadowing effect and the co-channel interference. (We assume that fast-fading is eliminated through a microdiversity scheme.) The expected values of outage probability (AOP) at a location on a cell boundary are shown in Fig. 4 for different schemes against channel occupancy. AOP increases with an increase in channel occupancy and decreases with $r$ and with $\sigma$ (the last two results are not shown here). The improvement of the MDM scheme is more significant for smaller channel occupancy. The most improvement is relative to the no-macrodiversity case, followed by the ($S$+$I$)-diversity, ($S$)-diversity, and ($S/I$)-diversity. However, even as compared with the ($S/I$)-diversity, the improvement is always at least a factor of 4 ($r$ = 4 and $\sigma$ = 4). Compared with ($S$)-diversity, the improvement is more than an order of magnitude.

*Conclusions:* The multiply-detected macrodiversity, in which the mobile's transmission is detected at a number of base-stations and post-detection combined has been simulated. The results show significant improvement in BER throughout a large fraction of the cellular coverage, as compared with a number of previously studied (macrodiversity) systems. The scheme offers most improvement close to the boundary between the cells, which is exactly the region where the reception is the weakest. In general, the MDM scheme providesmost improvement for large $r$, small $\sigma$, and small channel occupancy.


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## Performance of DS SS system under on-off wideband jamming

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*Indexing terms: Spread spectrum communication, Jamming*

A performance analysis of a direct sequence spread spectrum (DS SS) system under a periodic on-off wideband jammer is presented. Closed-form results of system bit error rate (BER) are derived for all possible cases of jammer duty cycle.

*Introduction:* DS SS systems have inherent immunity to sinusoidal or narrowband jamming [1]. When the jammer power is high, system performance can be improved by using various kinds of narrowband interference suppression filters [2, 3]. Unfortunately, many types of natural and man-made noise are impulsive in nature. As discussed in [4], a DS SS system cannot suppress these noises. To the best of the authors' knowledge, detailed analysis of DS SS system performance subject to periodic on-off wideband jamming is still lacking in the open literature, and is the goal of this Letter. Note that periodic impulsive noise can be considered as a special case of on-off wideband jamming.

*System model:* Fig. 1 shows a typical DS SS system operating in a periodic on-off jamming environment. It is well known that when there is only white Gaussian noise in the channel, the BER of the DS SS system can be written as

$$P_e = 0.5\,\mathrm{erfc}(\sqrt{\gamma_b}) \qquad (1)$$