EURASIP Journal on Wireless Communications and Networking 2004:2, 297–308

On the Performance of Multiuser MIMO in UTRA FDD Uplink

Jyri Hämäläinen
Nokia Networks, P.O. Box 319, 90651 Oulu, Finland
Email: jyri.k.hamalainen@nokia.com

Signal Processing Laboratory, Helsinki University of Technology, P.O. Box 3000, 02015 HUT, Finland

Kari Pajukoski
Nokia Networks, P.O. Box 319, 90651 Oulu, Finland
Email: kari.pajukoski@nokia.com

Esa Tiirola
Nokia Networks, P.O. Box 319, 90651 Oulu, Finland
Email: esa.tiirola@nokia.com

Risto Wichman
Signal Processing Laboratory, Helsinki University of Technology, P.O. Box 3000, 02015 HUT, Finland
Email: risto.wichman@hut.fi

Juha Ylitalo
4G Lab Center for Wireless Communications (CWC), University of Oulu, P.O. Box 4500, 90014 Oulu, Finland
Email: juha.ylitalo@ee.oulu.fi

Received 28 November 2003; Revised 13 August 2004

We study the uplink performance of MIMO systems in UTRA FDD using noise rise and system load as performance measures. Results show that the uplink coverage and capacity of the UTRA FDD mode are significantly improved by SIMO and MIMO techniques that require only minor modifications to existing 3GPP specifications. Receive diversity in base station increases coverage and capacity in a straightforward manner, but the gain from transmit diversity in mobile station is small because of the fast closed-loop power control, which is essential to CDMA uplink performance. However, multiple transmit antennas in the mobile can be used to achieve higher than 2 Mbps single-user data rates.

Keywords and phrases: MIMO, UTRA FDD uplink.

1. INTRODUCTION

The demand of the enhanced data throughput for both uplink and downlink directions is expected to grow rapidly in the near future when multimedia messaging is about to dominate the wireless communications. It is well acknowledged that multiantenna transceivers provide one of the most promising approaches to achieve high data rates in a bandwidth efficient manner [1].

Standardization of Universal Mobile Telecommunications System (UMTS) terrestrial radio access (UTRA) is carried out in the 3rd Generation Partnership Project (3GPP), and so far, MIMO discussion has concentrated mainly on high-speed downlink packet access (HSDPA), because the capacity demand imposed by projected data services (e.g., web browsing) burdens more heavily the downlink. However, when videophones become more popular, it is extremely important to reach high spectral efficiency also in the uplink direction. Furthermore, if multiantenna mobiles are deployed for HSDPA, it is important to study what is the gain of multiple transmit antennas in uplink.

In the UTRA framework, the feasibility of different MIMO methods varies between uplink and downlink. In downlink, different intracell users are separated by different orthogonal channelization codes, and the capacity is limited by the shortage of the channelization codes. Therefore, spectrally efficient MIMO techniques reusing the same channelization codes are necessary, and spatial multiplexing techniques like BLAST [2], single-stream transmission [3], and double-stream transmission [4] with space-time coding have been studied within WCDMA downlink. In addition to open-loop transmission techniques, closed-loop MIMO schemes exploiting antenna selection and rate control have been proposed [4, 5].

With increasing load in the network, the uplink may become a capacity bottleneck, and the more loading is allowed in the uplink, the larger is the required interference margin, and the smaller is the cell coverage [6]. Thus, the increased capacity demand in uplink reflects directly the number of base station sites and the overall cost of the network. In WCDMA uplink, different users are separated by long scrambling codes, and a single user may use the entire family of the orthogonal channelization codes. Thus, different data streams can be separated by different channelization codes, which makes the receiver implementation considerably simpler than in case of BLAST. Furthermore, the performance of the scheme is also better than that of the system, where the separation of different data streams is based solely on spatial signatures [7].

Deploying multiple antennas in the user equipment or base stations to support MIMO techniques is not straightforward due to concerns of cost, complexity, and visual impact. This is especially true in the present mobile terminals, where basic products with large production volumes may have at most two antennas. Multimode terminals supporting, for example, WCDMA, GSM, and GPS may already require several antennas even without applying MIMO processing. Furthermore, although two receiver chains in mobile terminal may be feasible when offering additional value to a consumer, it does not necessarily imply that two transmitter chains were a cost-efficient solution. Hence, it is important to carefully evaluate the performance gain of the additional transmit chain in the mobile.

In the following, we focus on the uplink of UTRA frequency-division duplex (FDD) mode. Recently, uplink MIMO performance has been studied in [8, 9] but not within UTRA framework. We concentrate on the methods that can be implemented with minor changes to the present UTRA FDD specifications, because it is not realistic to expect major revisions in UTRA standards. Besides the single-input multiple-output (SIMO) scheme, we study two basic MIMO approaches referred to as diversity MIMO and information MIMO. Diversity MIMO transmits the same data stream from separate antennas using different orthogonal channelization codes but the same scrambling code in different antennas.

MIMO capacity increases linearly as a function of $\min(M_t, M_r)$ (M_t and M_r refer to the number of transmit and receive antennas) at high SNR region, while fast power control in CDMA systems tends to maintain the SNR operation point of different users as low as possible in order to optimize coverage and capacity of the network. Thus, information MIMO techniques are useful to achieve high data rates while diversity MIMO can be used otherwise. According to the present standard, the maximum achievable user bit rate for SIMO or diversity MIMO without code puncturing is 2 Mbps. Therefore, we also study the performance of a simple information MIMO scheme, where different data streams are transmitted through separate antennas and each transmit antenna employs a different long scrambling code. For this method, user's peak bit rate without code puncturing becomes $M_t \times 2$ Mbps. We note that although a single base station receive antenna can be applied, the performance is seriously degraded if $M_r < M_t$. Therefore, a practical peak data rate is $\min\{M_t, M_r\} \cdot 2$ Mbps. Macro base stations typically employ two or four antennas, and it is expected that traditional two-antenna base stations dominate in number in the near future. Thus, in practice, mobile terminals and data modems may have four antennas at the maximum, while two antennas represent the most likely solution.

In case of fast transmit power control, different performance of two different MIMO algorithms with the same antenna configuration does not reflect directly to link or system capacity because the power control adjusts the E_b/N_0 target such that both techniques are able to support the same quality of service (QoS). In isolated cell, a better MIMO algorithm requires less transmit power, though, which increases cell coverage but does not increase the capacity, and the user may experience an extended battery life. In network level, a better MIMO algorithm reduces intracell interference and therefore it has a positive impact on system capacity. However, in case of information MIMO, the effect is small in WCDMA networks because high data rates will be deployed in the vicinity of base stations and not on cell edges. Such hot spots are already quite isolated and advanced information MIMO techniques rather increase the coverage of the hot spots when compared to more simple techniques. Furthermore, when the cell load is small, the effect of intercell interference on capacity is small, and consequently capacity gain of advanced information MIMO algorithm is small as well when compared to simple ones. Network planning typically favors reasonable cell loads to achieve a large cell coverage so that the number of base stations in the network remains economically viable.

The paper is structured as follows. Section 2 introduces system model and SIMO, diversity MIMO, and information MIMO techniques. Coverage and capacity of MIMO techniques are analyzed in Section 3, and it is shown that receive diversity is much more significant than transmit diversity for the performance of the system. Thus, it is concluded that instead of diversity, multiple transmit antennas in the mobile should be used for increasing peak data rates, and multiuser simulations in Section 4 concentrate on performance comparisons of SIMO and information MIMO. Concluding remarks are presented in Section 5.

2. SYSTEM MODEL

Let N_{own} and N_{other} refer to the number of own-cell and other-cell users, respectively. Then the received wideband signal in the baseband at time instant t in antenna i can be expressed in the form

$$r_i(t) = \sum_{n=1}^{N_{\text{own}}} y_n(t) + \sum_{n=1}^{N_{\text{other}}} z_n(t) + n(t), \tag{1}$$

where $n(t)$ is complex zero-mean Gaussian, $y_n(t)$ is the interference from nth own-cell user, and $z_n(t)$ is interference from nth other-cell user. In case of single-antenna transmission, the received wideband signal from user n is given by

$$\begin{aligned} y_n(t) = \sum_{i=-\infty}^{\infty} h_n(t) * \sqrt{\rho_n}\big(b_{d,n}[i]\beta_1 \cdot c_d(t - iT_d - \delta_n) \\ + jb_{c,n}[i]\beta_2 \cdot c_c(t - iT_c - \delta_n)\big) \\ \otimes s_{\text{dpch},n}(t - iT_s - \delta_n), \end{aligned} \tag{2}$$

where $*$ refers to convolution with multipath channel h_n, and $\otimes$ refers to chip-by-chip multiplication of user's scrambling code $s_{\text{dpch},n}$ and channelization codes c_d and c_c of dedicated physical data channel (DPDCH) and dedicated physical control channel (DPCCH), respectively. Total transmit power is given by ρ_n and power difference between DPDCH and DPCCH is adjusted by scaling factors β_1 and β_2, and user's transmitted bits in DPDCH and DPCCH are denoted by $b_{d,n}$ and $b_{c,n}$. The users are not synchronized in uplink, and the delay for user n is denoted by δ_n. Finally T_d, T_c, and T_s refer to lengths of the two channelization codes and the scrambling code.

In UTRA FDD mode, the spreading of the information is done by using channelization codes c_d of length 4–512 chips (in uplink, the maximum code length is 256 chips). The chip rate is 3.84 Mcps (Mega chips per second), which together with transmit pulse shaping leads to the signal bandwidth of approximately 5 MHz. On top of spreading, long scrambling codes s_{dpch} of length 38 400 chips are employed. While channelization codes are used in the downlink to separate different users within the same cell and separation between the cells is based on different scrambling codes, in the uplink, the scrambling codes are used to separate different users and channelization codes are employed when separating physical data and control channels of a user. In data channels, the error correction is done by applying the rate 1/3 binary turbo code with various interleaver sizes.

The present WCDMA FDD mode specification supports user data rates up to 2 Mbps both in downlink and uplink. In downlink, this would require the use of 3 parallel channelization codes with spreading factor 4 which would allocate 75% of code resources of the cell to a single user. In uplink, terminal transmitting such a high data rate is seen as a large interference source, but code resources of other intracell users are not affected. Hence, the code shortage limits the cell capacity in the downlink while the uplink capacity is basically interference limited.

Fast power control is an inherent characteristic of CDMA system, and it is applied in most of the downlink and uplink data channels in WCDMA. Uplink users in WCDMA are not synchronized and due to nonorthogonality of users' channelization codes, multiuser interference cannot be avoided. Accurate fast transmit power control is indispensable to uplink performance because otherwise, users in the vicinity of the base station would completely mask intracell users on cell edges. Exceptions among data channels, which operate without fast closed-loop power control, are high-speed downlink shared channel (HS-DSCH) and uplink random access channel (RACH), where the latter can carry only small data packets.

2.1. Multiantenna schemes

2.1.1. SIMO techniques

It is well known that multiantenna receiver techniques can provide remarkable capacity and coverage gains. This is due to the fact that after processing multiple replicas of the received signal, the signal-to-interference ratio increases together with diversity gain. The gains can be converted to higher data rates and increased number of users. More capacity gain can be achieved if a conventional maximal ratio combining (MRC)/Rake receiver is replaced with a more advanced parallel interference cancellation (PIC), where interfering signals are estimated, detected, regenerated, and removed.

Conventional PIC estimates multiple access interference (MAI) from tentative uncoded symbol decisions that are made before the decoding process. In the coded PIC, MAI is estimated based on decoded and regenerated wideband signals. That is, signals from all users are fully detected and decoded in the first stage of PIC, and MAI is then formed by the regenerated signals. Since the usual target frame error rate is 10%, most users are correctly detected already at the first stage and MAI is effectively removed. Cyclic redundancy check is used for error detection, and hard symbol decisions are used for correctly decoded users, whereas regenerated signals of incorrectly detected users apply soft decisions.

Coded PIC is more efficient than the conventional one, but it increases decoding delay and requires relatively high baseband processing capacity. An overview of different receiver techniques can be found, for example, in [6, 10].

2.1.2. Diversity MIMO

Well-known means for transmit diversity are provided by space-time block codes such as Alamouti code [11] or space-time transmit diversity (STTD) in 3GPP WCDMA downlink [12]. However, there is no need to use STTD and a single channelization code in UTRA FDD uplink because there is no shortage of channelization codes. This is illustrated in Figure 1 depicting the block diagrams of SIMO and two-antenna diversity MIMO transmission. Thus, the received signal from user n applying diversity MIMO becomes

$$\begin{aligned} y_n(t) = \sum_{i=-\infty}^{\infty} \sum_{m=1}^{M_t} h_{n,m}(t) * \frac{\sqrt{\rho_n}}{M_t}\big(b_{d,n}[i]\beta_1 \cdot c_{d,m}(t - iT_d - \delta_n) \\ + jb_{c,n}[i]\beta_2 \cdot c_{c,m}(t - iT_c - \delta_n)\big) \\ \otimes s_{\text{dpch},n}(t - iT_s - \delta_n), \end{aligned} \tag{3}$$

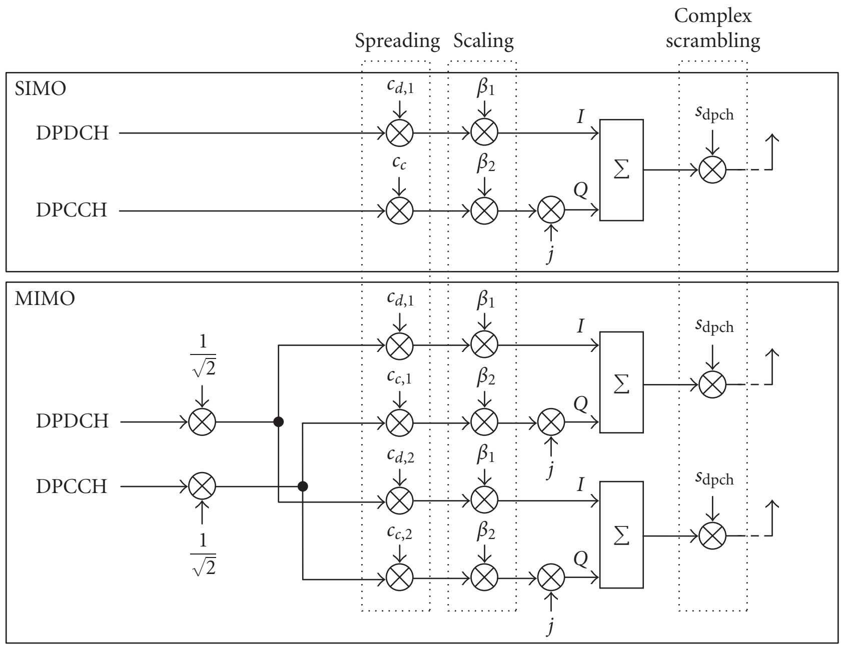

FIGURE 1: System model for SIMO and diversity MIMO.

where M_t refers to the number of transmit antennas. With diversity MIMO, mobile transmits the same data stream (DPDCH and DPCCH) simultaneously from M_t antennas. In order to separate the chip streams at the base station, each antenna uses different channelization codes $c_{d,m}$ and $c_{c,m}$. Thus, the scheme doubles the usage of uplink channelization codes when compared to single-antenna transmission or STTD, but without the need for space-time encoder/decoder. In case of flat fading and perfect channel state information in the receiver, the link performance is the same as with STTD because the diversity order of both schemes is two. However, the system utilizing orthogonal channelization codes is more robust because orthogonality of the received signals does not depend on the channel estimation as in the case of STTD.

In diversity MIMO, the improved uplink performance of a user within the cell is converted by power control to the decrease in transmit power, while the intracell load in the base station receiver remains unchanged. However, it is expected that improved uplink performance will provide coverage gain and reduction in intercell interference that is favorable from network point of view.

2.1.3. Information MIMO techniques

Information MIMO approach is better than SIMO or diversity MIMO if higher than 2 Mbps user data rates are needed, because according to WCDMA specification, such rates can be obtained by SIMO and diversity MIMO only if either code puncturing or multiple scrambling codes are employed. The former alternative is not recommended because the reduced code rate quite rapidly destroys system performance. On the other hand, due to the poor cross-correlation properties of the scrambling codes, the use of multiple scrambling codes is not a favorable choice either. Adaptive modulation and coding (AMC) with 16 or 64 QAM modulation might be able to provide a high data rate solution but our aim is to assume minimum changes in UTRA FDD specifications that do not support AMC in uplink at the moment. Furthermore, transmit precoding based on instantaneous channel state information in the transmitter is not applied because the UTRA FDD specification does not support the necessary feedback channel.

In case of information MIMO, the received wideband signal from the nth user is given by

$$y_n(t) = \sum_{i=-\infty}^{\infty} \sum_{m=1}^{M_t} h_{n,m}(t) * \frac{\sqrt{\rho_n}}{M_t} \big(b_{d,n,m}[i]\beta_1 \cdot c_{d,m}(t-iT_d-\delta_n) + jb_{c,n,m}[i]\beta_2 \cdot c_{c,m}(t-iT_c-\delta_n)\big) \otimes s_{\text{dpch},n,m}(t-iT_s-\delta_n). \quad (4)$$

Thus, data are multiplexed into two or more independent streams that are transmitted from separate antennas by employing different scrambling codes. All streams contain DPDCH and DPCCH so that in the base station, they can be interpreted as signals from different independent users, and consequently, the effective number of intracell users becomes $N_{\text{own}}M_t$.

The present specification allows the mobile to use only a single scrambling code as well as a single DPCCH and DPDCH. For the proposed information MIMO, the present UTRA FDD uplink specification should be changed such that the use of multiple scrambling codes is allowed in the mobile end. Then, it should be possible to independently apply DPCCH and DPDCH to each scrambling code. This does not represent a big change to radio interface because it only requires that a single user can set up M_t different links. For the effective use of several simultaneous links, some new code puncturing sets would also be needed.

3. ANALYSIS

When studying the uplink performance of different transmission schemes on the system level, an important performance measure is the noise rise, denoted by μ, which is defined as a ratio of the total received wideband power to the thermal noise power. While detecting a signal of a user in the base station, the wideband power corresponding to other users is seen as interference. Hence, noise rise is closely connected to the system load η. Formally this relation is given by [6]

$$\mu = \frac{1}{1-\eta}. \tag{5}$$

The more loading is allowed in the system, the larger is the required interference margin $\mu_0 = \max\{\mu\}$ and the smaller is the coverage area. Interference margin defines the maximum allowed noise rise and typically values 1.0–3.0 dB are used for coverage-limited cases with 20–50% load, and in capacity limited case, higher interference margins up to 6 dB can be used [6].

When comparing different transceiver techniques, the system load can be estimated from the sum of received wideband powers of different users. Signals from different users are mutually independent and from (1), the received wideband power in antenna i is given by

$$\mathrm{E}\left\{\left|r_i(t)\right|^2\right\} = I_{\text{total}} = I_{\text{own}} + I_{\text{other}} + P_N, \tag{6}$$

where P_N is the noise power and

$$\begin{aligned} I_{\text{own}} &= \sum_{n=1}^{N_{\text{own}}} \mathrm{E}\left\{\left|y_n(t)\right|^2\right\}, \\ I_{\text{other}} &= \sum_{n=1}^{N_{\text{other}}} \mathrm{E}\left\{\left|z_n(t)\right|^2\right\}. \end{aligned} \tag{7}$$

The received E_b/N_0 per data stream of user n is given by

$$\left(E_b/N_0\right)_n = \kappa_n \frac{P_{\text{Rx},n}}{I_{\text{total}} - P_{\text{Rx},n}}, \tag{8}$$

where $P_{\text{Rx},n}$ refers to the received power, and κ_n is the ratio between the bit rate and chip rate (processing gain) of user n. The system load becomes

$$\eta = (1+\nu)\sum_{n=1}^{N_{\text{own}}} \frac{N_{d,n}\kappa_n E_{\text{Rx},n}}{1+\kappa_n E_{\text{Rx},n}}, \tag{9}$$

where $\nu = I_{\text{other}}/I_{\text{own}}$ is the intercell-to-intracell interference ratio seen by the base station receiver, N_{own} is the number of own-cell users, $N_{d,n}$ is the number of data streams of the nth user, and $E_{\text{Rx},n}$ is the received energy per data bit divided by the noise spectral density (E_b/N_0) of the nth user [6]. Here E_b/N_0 is defined per antenna, and the desired E_b/N_0 depends on service requirements, interference, and the type of the receiver. For example, PIC can provide the same block error rate as Rake with lower received E_b/N_0.

According to (5), the theoretical capacity limit is reached when the load approaches the 100% level. Then (9) defines the corresponding maximum number of users. If all users employ the same service, the computation of the cell throughput is straightforward, and the maximum number of own-cell users is given by

$$N_{\text{own}} = \frac{\eta_0\left(1+\kappa E_{\text{Rx}}\right)}{N_d \kappa E_{\text{Rx}}(1+\nu)}, \tag{10}$$

where $\eta_0 = 1 - 1/\mu_0$ and the number of data streams N_d is the same for all users. If the number of receive antennas is doubled, it is expected that the received E_b/N_0 per antenna is roughly halved, because of the MRC in the receiver, and by (10), the maximum number of users can be doubled. Furthermore, the coverage of the service is expected to double as well. On the other hand, if we fix the number of receive antennas, double the number of transmit antennas, and employ transmit diversity, it is expected that mobile's transmit power is reduced. However, this change in the transmitter end does not reduce the received E_b/N_0 because power control drives the received power to the target level defined by QoS irrespective of the number of transmit antennas. On the contrary, the interference ratio ν becomes smaller because the intercell interference is reduced. This increases the cell capacity depending on the original value of ν.

Another approach to utilize multiple transmit antennas is to apply information MIMO technique and double the bit rate by using different scrambling codes in different transmit antennas. This enables data rates higher than 2 Mbps but transmit diversity gain will be lost. Thus, the key elements to understand the effect of MIMO on the uplink performance of UTRA FDD mode are the received E_b/N_0, transmitted power and their impact on intracell and intercell interference. In the following, we study these parameters more closely.

In the presence of $M_t \times M_r$-order diversity system, MRC, and flat fading, the mean received power of user n is given by

$$\mathrm{E}\left\{\left|y_n(t)\right|^2\right\} = \mathrm{E}\left\{\rho_n\gamma_n\right\}, \qquad \gamma_n = \sum_{m=1}^{M_tM_r}\gamma_{m,n}, \tag{11}$$

where $\gamma_{m,n}$ is the instantaneous power from mth channel, ρ_n is the transmit power, selected according to feedback commands, and M_r denotes the number of receive antennas. In the presence of ideal power control, we have $\rho_n = P_{\text{Rx}}^T/\gamma_n$, where P_{Rx}^T is the target power level of the nth user in the receiver. We note that P_{Rx}^T is proportional to the required E_b/N_0. In the following analysis, we use this ideal model with the exception that path loss cannot be compensated if the channel power response γ_n is smaller than a given threshold γ_0. Let $P_{\mathrm{Tx}}^{\max}$ be the maximum transmit power. Then we define

$$\rho_n = \begin{cases} \dfrac{P_{\mathrm{Rx}}^T}{\gamma}, & \gamma_n > \gamma_0, \\ P_{\mathrm{Tx}}^{\max}, & \gamma_n \le \gamma_0. \end{cases} \quad (12)$$

We note that here P_{Rx}^T is the received total power after Rake combining over M_r antennas. Hence, the target power is achieved always when $\gamma > \gamma_0$. We assume limited power control dynamics because coverage of most of the high data rate services is usually limited although basic services such as speech and 64 kbps data are supported everywhere. For these basic services, the limited power control dynamics is usually not a problem because the cell edge is in the handover area where the best base station among more than one alternative can be selected. However, for high data rate services, limited power control dynamics should be taken into account.

3.1. Cell coverage

If PC dynamics were unlimited, the expected received power in (11) would remain at the target level P_{Rx}^T all the time. However, given the upper bound $P_{\mathrm{Tx}}^{\max}$, the target level is not always reached. Consider first an extreme case where the mobile transmits continuously with maximum power. Then we have

$$\mathrm{E}\{\rho\gamma\} = M_r P_{\mathrm{Tx}}^{\max}\bar{\gamma}, \quad (13)$$

where $\bar{\gamma}$ is the mean received power in the base station before the MRC combining. Note that in the following, the user index n is excluded for clarity. The target power level is reached if $M_r P_{\mathrm{Tx}}^{\max}\bar{\gamma} = P_{\mathrm{Rx}}^T$. Then the maximum allowed path loss $L_{\max}$ is simply of the form $M_r P_{\mathrm{Tx}}^{\max}/P_{\mathrm{Rx}}^T$. The limit is usually, however, far too optimistic in low mobility environments because the channel-level crossing time is long when compared to frame length $(10 - 20$ milliseconds) leading to bursty frame errors during the fades, which seriously degrade QoS.

We study the mean received power $\bar{P}_{\mathrm{Rx}}$ from an own-cell user more closely. We have

$$\begin{aligned} \bar{P}_{\mathrm{Rx}} = \mathrm{E}\{\rho\gamma\} &= P_{\mathrm{Rx}}^T P(\gamma > \gamma_0) \\ &\quad + P_{\mathrm{Tx}}^{\max}\,\mathrm{E}\{\gamma \mid \gamma < \gamma_0\} P(\gamma < \gamma_0), \end{aligned} \quad (14)$$

where $P(\gamma > \gamma_0)$ refers to the probability that $\gamma > \gamma_0$. Assuming flat Rayleigh fading, diversity MIMO with uncorrelated antennas, and Rake receiver, the pdf of the channel power response after MRC is given by

$$f(\gamma) = \frac{M_t}{\Gamma(M_t M_r)\bar{\gamma}}\left(\frac{M_t\gamma}{\bar{\gamma}}\right)^{M_t M_r - 1} e^{-M_t\gamma/\bar{\gamma}}, \quad (15)$$

where the total transmit power is evenly divided between the transmit antennas. We note that in case of information MIMO, we should set $M_t = 1$ in (15) and divide the maximum transmit power by the number of transmit antennas.

In the following, the analysis is carried out only in the case of flat fading. The analysis can be extended to the multipath Rayleigh fading channels if channel taps are assumed to be uncorrelated, where the assumption holds only when sampling in the chip frequency. In multipath case, the analysis is very similar to the one given here. The only difference is that computation of mean powers is tedious since the pdf of the channel power response is formed as a weighted sum of functions of the form $\gamma^q \exp(-a\gamma)$. To avoid too complex and technical expressions, multipath case is omitted.

We denote the conditional expectation in (14) by Ξ. After applying the definition of f and substitution $t = M_t\gamma/\bar{\gamma}$, we obtain

$$\Xi = \frac{\bar{\gamma}}{M_t\Gamma(M_t M_r)}\int_0^{M_t\gamma_0/\bar{\gamma}} t^{M_t M_r} e^{-t}\,dt. \quad (16)$$

By [13, (6.5.1) and (6.5.13)], the integral can be expressed in terms of Poisson distribution

$$\mathcal{P}_M(x) = e^{-x}\sum_{m=0}^{M-1}\frac{x^m}{m!}. \quad (17)$$

We obtain

$$\Xi = \frac{P_{\mathrm{Rx}}^T M_r}{P_{\mathrm{Tx}}^{\max}\xi}\left(1 - \mathcal{P}_{M_t M_r + 1}(M_t\xi)\right), \quad (18)$$

where $\xi = \gamma_0/\bar{\gamma}$. It remains to evaluate the probabilities in (14). Using again the expression of f, substitution $t = M_t\gamma/\bar{\gamma}$, and (17), we find that

$$P(\gamma > \gamma_0) = \mathcal{P}_{M_t M_r}(M_t\xi). \quad (19)$$

After combining (14), (18), and (19), we get

$$\begin{aligned} \bar{P}_{\mathrm{Rx}} = P_{\mathrm{Rx}}^T\Big(&\mathcal{P}_{M_t M_r}(M_t\xi) \\ &+ \frac{M_r}{\xi}\left(1 - \mathcal{P}_{M_t M_r + 1}(M_t\xi)\right)\left(1 - \mathcal{P}_{M_t M_r}(M_t\xi)\right)\Big). \end{aligned} \quad (20)$$

Figure 2 displays the expected received powers as a function of the ratio of path loss L and $P_{\mathrm{Tx}}^{\max}$ for different antenna configurations. Consider an example where the maximum tolerated loss in the received power is less than 0.5 dB. Then we find from Figure 2 that the coverage gain from doubling the number of receive antennas is about 5 dB. Also, the gain from doubling the number of transmit antennas is noticeable.

From (13), we find that if the mobile is continuously transmitting with maximum power, the target level P_{Rx}^T is achieved when $L/P_{\mathrm{Tx}}^{\max}$ is less than 0, 3, and 6 dB for 1, 2, and 4 receive antennas, respectively. Hence, according to this logic, the range of the cell is directly defined by the number of receive antennas. However, as previously mentioned, in low-mobility environments, bursty frame errors degrade QoS. Since the power control tends to drive the received power to optimum value, already a relatively small loss may cause

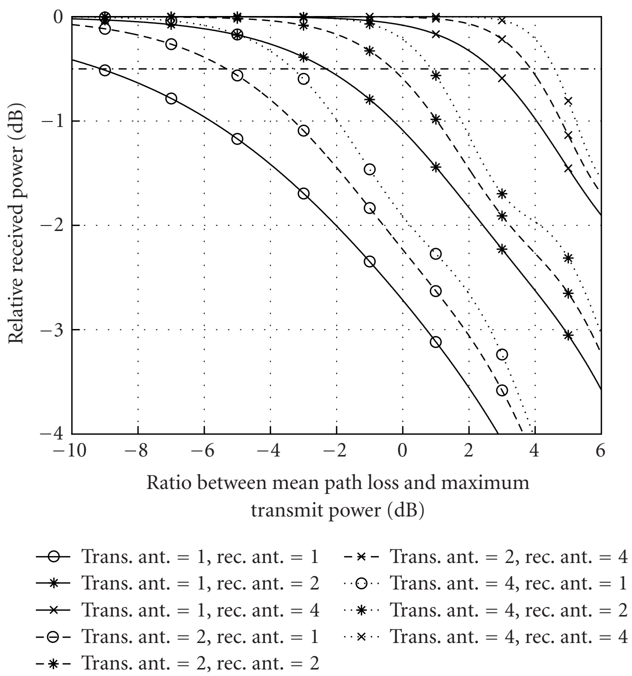

Figure 2: Expected received power as a function of $L/P_{\text{Tx}}^{\max}$ assuming 0 dB target power and flat Rayleigh fading for 1 (solid curves), 2 (dashed curves), and 4 (dotted curves) transmit antennas, while the number of receive antennas is 1 (-o-), 2 (-∗-), and 4 (-×-).

a frame error that further leads to the power increase request by open-loop power control. If the mobile is on the edge of the service area, consecutive "power-up" commands do not necessarily improve the QoS, but increase the intracell interference and consequently reduce the cell capacity. If the cell load is already high, the service is terminated rapidly. Thus, the coverage gain of MIMO also depends on the cell load.

Finally, we note that the curves in Figure 2 are not smooth when approaching the limit $L/P_{\text{Tx}}^{\max} = M_r$. This is due to the nature of the distribution corresponding to the limited transmit power.

3.2. Cell capacity

3.2.1. Diversity MIMO

Consider an example where all users employ the same service. Suppose we have two systems with diversity MIMO but different antenna configurations and the same number of users. Then by (10), we obtain

$$\frac{\eta_1}{\eta_2} = \frac{E_{\text{Rx},1}(1+\kappa E_{\text{Rx},2})}{E_{\text{Rx},2}(1+\kappa E_{\text{Rx},1})} \cdot \frac{1+\nu_1}{1+\nu_2}, \tag{21}$$

where numbers 1 and 2 refer to different antenna configurations. In the following, we assume that target E_b/N_0 per antenna is constant and inversely proportional to the number of receive antennas. Then

$$\frac{I_{\text{own},1}}{I_{\text{own},2}} = \frac{E_{\text{Rx},1}}{E_{\text{Rx},2}} = \frac{M_{r,2}}{M_{r,1}}. \tag{22}$$

This simplification is justified if most of the own-cell users are not in the edge of the service area, where E_b/N_0 can be corrupted as shown in previous coverage study. For the intercell interference, there holds

$$I_{\text{other}} = \sum_{n=1}^{N_{\text{other}}} \mathrm{E}\{\rho_n \gamma_n\} = \sum_{n=1}^{N_{\text{other}}} \mathrm{E}\{\rho_n\}\bar{\gamma}_n, \tag{23}$$

where transmit power ρ_n of user n in the interfering cell does not depend on the mean channel attenuation $\bar{\gamma}_n$ in the own cell. Since the expectation of ρ_n is proportional to the mean transmitted power $\bar{P}_{\text{Tx}}$, the power ratio between the two systems is given by

$$\frac{\mathrm{E}\{\rho_{n,2}\}}{\mathrm{E}\{\rho_{n,1}\}} = \frac{\bar{P}_{\text{Tx},2}}{\bar{P}_{\text{Tx},1}}. \tag{24}$$

Hence, the ratio between other cell interferences is given by

$$\frac{I_{\text{other},2}}{I_{\text{other},1}} = \frac{\bar{P}_{\text{Tx},2}}{\bar{P}_{\text{Tx},1}}. \tag{25}$$

After combining (22) and (25), we find that

$$\nu_2 = \frac{M_{r,2}}{M_{r,1}} \cdot \frac{\bar{P}_{\text{Tx},2}}{\bar{P}_{\text{Tx},1}} \cdot \nu_1. \tag{26}$$

It remains to compute the expected transmit power $\bar{P}_{\text{Tx}}$ for different antenna configurations. There holds

$$\bar{P}_{\text{Tx}} = \mathrm{E}\left\{\frac{P_{\text{Rx}}^T}{\gamma} \mid \gamma > \gamma_0\right\} P(\gamma > \gamma_0) + P_{\text{Tx}}^{\max} P(\gamma < \gamma_0). \tag{27}$$

Here we take into account the effect of the limited power control dynamics because the strongest interferers are expected to be located on the edge of the neighboring cells. We denote the conditional expectation in the equation above by Ξ. Then we obtain

$$\Xi = \frac{P_{\text{Rx}}^T M_t}{\bar{\gamma}\Gamma(M_t M_r)} \int_{M_t\gamma_0/\bar{\gamma}}^{\infty} t^{M_t M_r - 2} e^{-t} dt. \tag{28}$$

As previously pointed out, this integral can be expressed in terms of the Poisson distribution if $M_t M_r > 1$. However, if $M_t M_r = 1$, we obtain exponential integral function E_1, defined by [13, (5.1.1)]. It is found that

$$\Xi = P_{\text{Tx}}^{\max}\xi \cdot \begin{cases} E_1(\xi), & M_t M_r = 1, \\ \dfrac{M_t}{M_t M_r - 1}\mathcal{P}_{M_t M_r - 1}(M_t \xi), & M_t M_r > 1. \end{cases} \tag{29}$$

An expression for the mean transmit power can be deduced by applying this formula and (19). If $M_t M_r = 1$, there holds

$$\bar{P}_{\text{Tx}} = P_{\text{Tx}}^{\max}\left(\xi E_1(\xi) e^{-\xi} + 1 - e^{-\xi}\right). \tag{30}$$

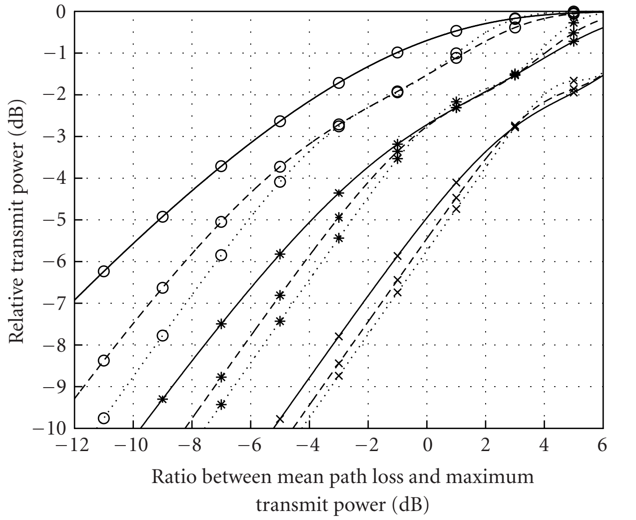

FIGURE 3: $\bar{P}_{\text{Tx}}/P_{\text{Tx}}^{\max}$ as a function of $L/P_{\text{Tx}}^{\max}$ assuming flat Rayleigh fading. The number of transmit antennas is 1 (solid curves), 2 (dashed curves), and 4 (dotted curves), while the number of receive antennas is 1 (-o-), 2 (-∗-), and 4 (-×-).

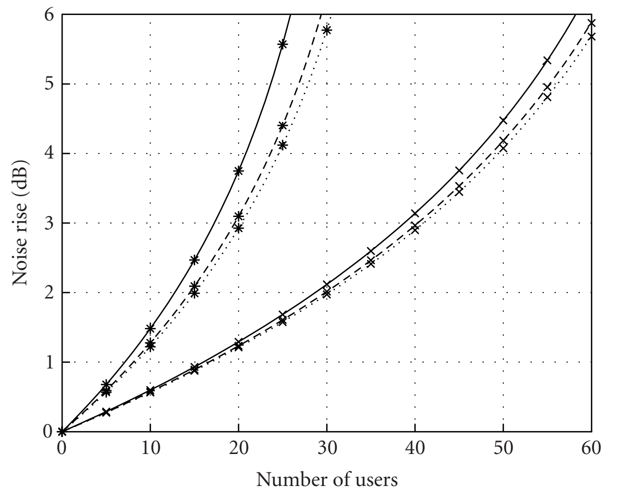

FIGURE 4: Noise rise as a function of 64 kbps users in flat Rayleigh fading environment. The number of transmit antennas is 1 (solid curves), 2 (dashed curves), and 4 (dotted curves), while the number of receive antennas is 2 (-∗-) and 4 (-×-). Initial interference ratio ν is 0.55.

Moreover, if $M_tM_r > 1$, we have

$$P_{\text{Tx}} = P_{\text{Tx}}^{\max}\left(\frac{\xi M_t \mathcal{P}_{M_tM_r-1}(M_t\xi)\mathcal{P}_{M_tM_r}(M_t\xi)}{M_tM_r-1} + \left(1-\mathcal{P}_{M_tM_r}(M_t\xi)\right)\right). \tag{31}$$

Figure 3 displays the expected transmit powers for different antenna configurations as a function of $L/P_{\text{Tx}}^{\max}$. It is seen that diversity gain decreases when $L/P_{\text{Tx}}^{\max}$ approaches the value M_r. The effect of the limited power control dynamics on the capacity gain depends on the cell load since the tolerance for received E_b/N_0 is small when the load is high. Then the limiting value for $L/P_{\text{Tx}}^{\max}$ is far less than M_r and it is justified to use asymptotic gains, obtained for small ξ. Now

$$\lim_{\xi\to 0}\frac{\bar{P}_{\text{Tx}}}{\xi P_{\text{Tx}}^{\max}} = \begin{cases}\infty, & M_tM_r = 1,\\ \dfrac{M_t}{M_tM_r-1}, & M_tM_r > 1,\end{cases} \tag{32}$$

and after applying the above result to (26), we find that

$$\nu_2 = \frac{M_{r,2}M_{t,2}(M_{t,1}M_{r,1}-1)}{M_{r,1}M_{t,1}(M_{t,2}M_{r,2}-1)}\nu_1. \tag{33}$$

This result could have also been deduced from the power rise result given in [14] (see also [15]). Thus, by using (21), (22), and (33), we can estimate the noise rise and capacity of a system with different antenna configurations provided that the service, E_b/N_0 of the reference case, and the initial interference ratio ν_1 are known.

TABLE 1: Simulation parameters.

Carrier frequency	1940 MHz
Chip rate	3.840 Mchips
Sampling rate	1 sample/chip
Power control	ON, both inner and outer loops
BLER target (QoS)	10%
Rake finger allocation	Known delays
Maximum number of allocated Rake fingers	5/receive antenna
Channel estimation	Estimated (DPCCH)
Signal-to-interference estimation	Estimated (DPCCH)

Figure 4 shows the noise rise as a function of the number of 64 kbps users. Naturally, higher than 64 kbps data rates can be implemented, but then the number of users is less and capacity figures are not as illustrative as in the selected case. Results are obtained by applying (5), (9), (21), (22), and (33). The baseline system has $M_r = 2$, $M_t = 1$, and the corresponding E_b/N_0 value 0.57 dB was obtained by link-level simulations (see Tables 1 and 2 for simulation parameters). The initial interference ratio ν in the baseline system is 0.55 corresponding to macrocell system with omnidirectional antennas [6].

The results in Figure 4 show that the gain from additional receive antennas is large while the gain from the transmit diversity is small. It is emphasized that the transmit diversity gain vanishes in isolated cell, where $\nu = 0$. On the other hand,

TABLE 2: Service-related parameters for 64 and 960 kbps circuit switched data.

Data rate DTCH/DCCH	64/2.4 kbps	960/0 kbps
Rate matching (DTCH)	16% repetition	0.5% puncturing
Channel coding	Turbo 1/3	Turbo 1/3
Interleaving period	10 ms	10 ms
Number of dedicated physical data channels	1	3
Spreading factor on DPCCH/DPDCH	256/16	256/4
Dedicated control bits in slot: pilot/PC/TFCI	6/2/2	6/2/2
Power ratio of DPCCH/DPDCH	−5.46 dB	−9.54 dB

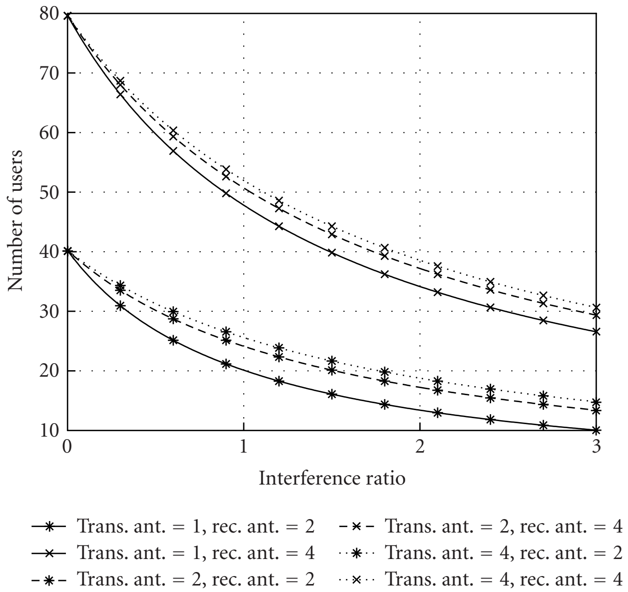

FIGURE 5: Number of 64 kbps users as a function of interference ratio ν when the cell load is 75% in flat Rayleigh fading environment. The number of transmit antennas is 1 (solid curves), 2 (dashed curves), and 4 (dotted curves), while the number of receive antennas is 2 (-∗-) and 4 (-×-).

if ν is large, the transmit diversity gain increases. This is illustrated in Figure 5 showing the number of 64 kbps users as a function of interference ratio when the cell load is 75%. Horizontal axis provides the value of ν for 1×2 system, and corresponding interference ratios for other cases are computed from (33).

The results in Figure 5 show that the transmit diversity gain remains relatively small even when initial ν is large. Hence, the receive diversity is much more effective than the transmit diversity when the aim is to increase the cell capacity.

3.2.2. Information MIMO

Suppose we have two systems applying different information MIMO techniques but the same antenna configuration. Then

$$\frac{\eta_1}{\eta_2} = \frac{1+\nu_1}{1+\nu_2} \tag{34}$$

provided that the target E_b/N_0 remains the same for both techniques. According to (26), we then have

$$\nu_2 = \frac{\bar{P}_{\mathrm{Tx},2}}{\bar{P}_{\mathrm{Tx},1}} \cdot \nu_1 \tag{35}$$

and it is found that the performance difference between the two information MIMO techniques reflects only the intercell interference ratio. Thus, the achievable gain depends on the system load and initial intercell interference ratio in a similar manner as in case of diversity MIMO with a fixed number of receive antennas. Therefore, it is expected that noticeable differences in system-level capacities of various information MIMO techniques are obtained only when different MIMO techniques have different E_b/N_0 targets, which arise, for example, when different interference cancellation techniques are applied. As mentioned before, transmit precoding based on instantaneous channel state information is not available because UTRA FDD specification does not support a suitable feedback channel. In the next section, we show by simulations that the MIMO performance can be greatly increased by employing PIC instead of Rake in the receiver.

4. SYSTEM SIMULATIONS

4.1. Simulation parameters

The main simulation parameters and assumptions are shown in Table 1. Full 3GPP link-level modeling was used with inner- and outer-loop power control and realistic channel and interference estimation algorithms. The service-related parameters for 64 kbps and 0.96 Mbps are summarized in Table 2. For more details, see [16].

The radio channel models were flat Rayleigh fading and Pedestrian B, where relative mean path powers are 0.0, −0.9, −4.9, −8.0, −7.8, and −23.9 dB with the delays 0, 200, 800, 1200, 2300, and 3700 nanoseconds. The latter model provides a realistic and challenging radio channel model for low mobility environments, and it is applied in feasibility studies of uplink of UTRA FDD mode [17]. In case of SIMO, our system model follows accurately the present UTRA FDD specifications and simulations are done following strictly the recommendations given in [18]. The simulation model based on the recommendations of [18] is widely used in 3GPP standardization because it is transparent to the experts on the field. In case of MIMO, our system model slightly differs from the present specification because we assume an additional scrambling code and corresponding DPCCH and

DPDCH. We have also introduced some code puncturing sets that do not comply with the present specifications, but the effect of these puncturing sets is minor.

System-level performance measures are the received energy per user bit and antenna, and the noise rise. When given in terms of the number of users, the former illustrates the increase in required received/transmitted power when the cell load is growing, and the latter shows the increase of the total interference power in the network.

4.2. *Simulation results*

4.2.1. *SIMO and diversity MIMO*

In case of 64 kbps service and SIMO, the simulated noise rise agrees with the analytical results of Figure 4 within 0.1 dB. For diversity MIMO, simulation results agree well with theoretical results only in case of two transmit and two receive antennas. Especially with four receive antennas, simulation results show no gain from additional transmit antennas, the resulting noise rise being approximately the same as in case of SIMO. This is because channel estimation losses due to the lower pilot power per transmit antenna destroy the additional diversity gain The simulations employed the conventional Rake receiver.

Since the diversity MIMO did not indicate noticeable gains, only the performance of SIMO with Rake, conventional PIC, and coded PIC was simulated for 0.96 Mbps service. This service can be provided in the framework of the present UTRA FDD specification, and therefore, there is no need to introduce the information MIMO.

Figure 6 depicts the received energy per bit and antenna for SIMO in terms of the number of 0.96 Mbps users assuming isolated cell and Pedestrian B channel with 3 km/h mobile speed. Isolated cell is assumed because it is common to provide high data rate services only in the inner part of the cell excluding the handover area. Then the coverage of the service becomes an important issue. It is important to note that the received energy per bit and antenna in Figure 6 was computed against AWGN, while the noise in target E_b/N_0 contains also interference.

A rough estimate for the coverage gain can be deduced from the results of Figure 6. This is due to the fact that the received power is proportional to the transmitted power and the gain in the received power indicates gain in the range of the service. It is found that the range gain from additional receive antennas is of the order of 3 dB in the single-user case, but it grows rapidly with additional users.

Figure 7 depicts the noise rise for SIMO system as a function of the number of 0.96 Mbps users. It is found that doubling the number of receive antennas from two to four almost doubles the cell capacity, and throughput of the order of 10 Mbps can be achieved assuming four receive antennas, coded PIC, and 75% load. We remind that 10% block error rate assumption should be taken into account when computing the throughput. The result indicates a relatively high spectral efficiency of almost 2 bps/Hz, which is obtained by well-known receiver algorithms with only four receive antennas in the base station and most importantly, without any changes in the present UTRA FDD standard. Furthermore, it should be noted that conventional PIC and coded PIC remarkably boost the system performance already with two receive antennas.

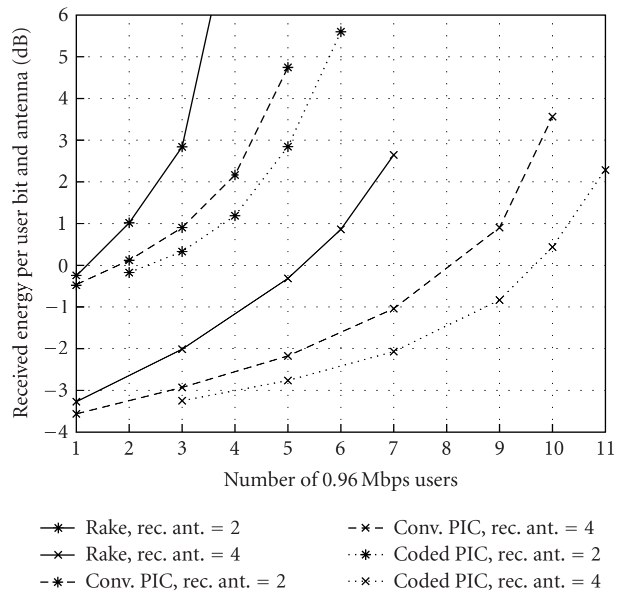

Figure 6: Received energy per user bit and antenna for SIMO system as a function of 0.96 Mbps users in isolated cell assuming Pedestrian B channel with 3 km/h mobile speed. The number of receive antennas is 2 (-∗-) and 4 (-×-), and the employed receivers are Rake (solid curve), conventional PIC (dashed curve), and coded PIC (dotted curve).

4.2.2. *Information MIMO*

If data services with bit rates higher than 2 Mbps are provided, information MIMO is a better solution than SIMO or diversity MIMO. The claim can be based on the results of Figure 8, which shows the received energy per bit and antenna for SIMO and MIMO as a function of user bit rate assuming isolated cell and Pedestrian B channel with 3 km/h mobile speed. The noise rise level corresponding to 50% load is depicted by dash-dotted line. The number of receive antennas is four in all cases and two transmit antennas are employed in MIMO system, and bit rates higher than 2 Mbps for SIMO and bit rates higher than 4 Mbps for MIMO are obtained by using code puncturing. Results corresponding to SIMO with coded PIC are excluded because there is practically no gain from coded PIC against conventional PIC if heavy code puncturing is applied.

The results show that user bit rates up to 6 Mbps can be achieved with coded PIC and 50% system load. Even higher data rates would be possible by allowing a higher load for a single user.

Due to the code puncturing, spectral efficiencies as high as in case of multiuser system with 0.96 Mbps users are not achieved. The MIMO scheme is not directly applicable in the present UTRA FDD system, but required changes to technical specifications are small. The changes include the use of multiple control channels—one for each transmit antenna—

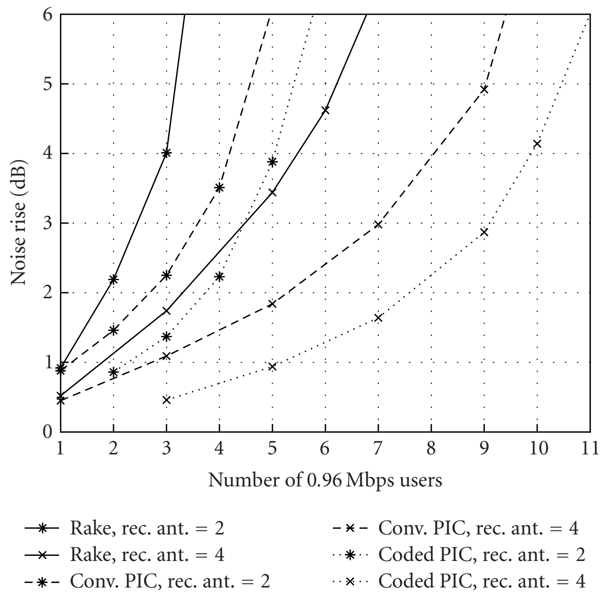

Figure 7: Noise rise for SIMO system as a function of 0.96 Mbps users in isolated cell assuming Pedestrian B channel with 3 km/h mobile speed. The number of receive antennas is 2 (-∗-) and 4 (-×-), and the employed receivers are Rake (solid curve), conventional PIC (dashed curve), and coded PIC (dotted curve).

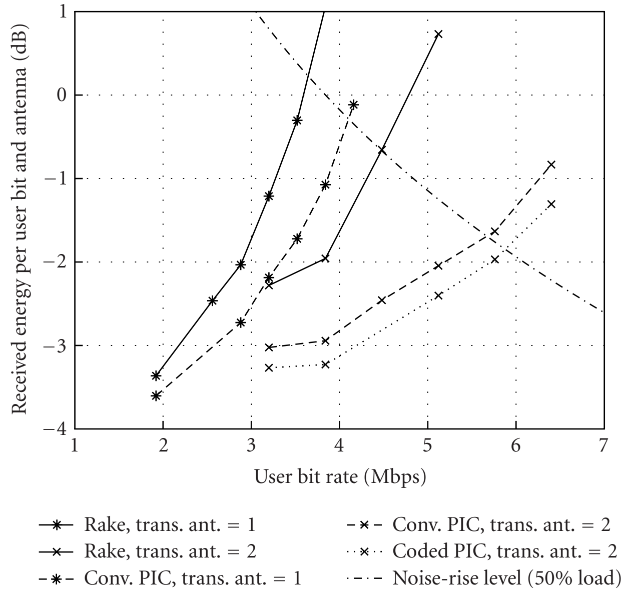

Figure 8: Received energy per user bit and antenna for SIMO and MIMO systems with 4 receive antennas as a function of user bit rate in isolated cell assuming Pedestrian B channel and 3 km/h mobile speed. The number of transmit antennas is 1 (-∗-) and 2 (-×-). Employed receivers are Rake (solid curve), conventional PIC (dashed curve), and coded PIC (dotted curve). Dash-dotted curve shows the noise-rise level corresponding to 50% load.

and some new code puncturing rules for the highest data rates.

The results show that already with two transmit antennas, the MIMO system provides remarkably better performance than SIMO. Assuming more than two mobile antennas, even higher data rates can be obtained. However, if the number of receive antennas does not increase at the same time, the gain from additional transmit antennas will be smaller than the one obtained in Figure 8, where the number of transmit antennas was doubled from one to two. In principle, data rates depicted in Figure 8 can be increased by employing AMC, but the topic is not studied here because AMC would require major changes in the present standard, while only minor changes are needed for the information MIMO scheme.

5. CONCLUSIONS

The performance of SIMO, diversity MIMO, and a simple information MIMO schemes was considered assuming Rake, PIC, and coded PIC receivers. The coverage and capacity of SIMO and diversity MIMO were studied by means of analytical tools and the results were confirmed with simulations. Furthermore, a case study of the information MIMO algorithm was examined by simulations.

Results showed that the uplink coverage and capacity of UTRA FDD mode are significantly increased by SIMO and MIMO. While the performance increase from additional base station antennas reflects straightforwardly the coverage and capacity results, transmit diversity gain from additional antennas in the mobile end is relatively small. This is due to the fact that in the link level, the inner-loop power control converts the increased diversity to decrease in the required transmission power. On the contrary, if user bit rates higher than 2 Mbps are needed, the gain from the information MIMO (spatial multiplexing) is large because heavy code puncturing as in case of SIMO can be avoided. Thus, multiple transmit antennas in mobile station should be used for spatial multiplexing and not for transmit diversity. Furthermore, the use of information MIMO requires only minor changes to the present WCDMA specification.

Simulations showed that doubling the number of receive antennas in the base station from two to four almost doubles the cell capacity, and throughput of the order of 10 Mbps can be achieved assuming coded PIC and 75% system load. The result indicates a spectral efficiency of almost 2 bps/Hz that is achieved by well-known receiver methods without any changes in the present UTRA FDD standard. Furthermore, single-user bit rates up to 6 Mbps can be achieved by using information MIMO with two transmit antennas, four receive antennas, coded PIC, and 50% load.

REFERENCES

[1] G. Foschini and M. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, vol. 6, no. 3, pp. 311–335, 1998.

[2] G. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," *Bell Labs Technical Journal*, vol. 1, no. 2, pp. 41–59, 1996.

[3] J. R. Fonollosa, R. Gaspa, X. Mestre, et al., "The IST METRA project," *IEEE Communications Magazine*, vol. 40, no. 7, pp. 78–86, 2002.

[4] 3GPP, "Multiple-input multiple output in UTRA," 3GPP TSG-RAN Tech. Rep. (TR) 25.876, version 1.3.0, 2004.

[5] H. Zhuang, L. Dai, S. Zhou, and Y. Yao, "Low complexity per-antenna rate and power control approach for closed-loop V-BLAST," *IEEE Trans. Communications*, vol. 51, no. 11, pp. 1783–1787, 2003.

[6] H. Holma and A. Toskala, Eds., *WCDMA for UMTS*, John Wiley & Sons, Chichester, UK, revised edition, 2001.

[7] A. Mantravadi, V. Veeravalli, and H. Viswanathan, "Spectral efficiency of MIMO multiaccess systems with single-user decoding," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 3, pp. 382–394, 2003.

[8] J.-A. Tsai and B. Woerner, "Performance of orthogonal transmit waveforms for CDMA uplink systems in MIMO Rayleigh channels," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC '02)*, vol. 1, pp. 206–209, Orlando, Fla, USA, March 2002.

[9] J. Shen and A. Burr, "Iterative multi-user-antenna detector for MIMO CDMA employing space-time turbo codes," in *Proc. IEEE Global Telecommunications Conference (GLOBECOM '02)*, vol. 1, pp. 419–423, Taipei, Taiwan, November 2002.

[10] T. Ojanperä and R. Prasad, Eds., *Wideband CDMA for Third Generation Mobile Communications*, Artech House Publishers, Norwood, Mass, USA, 1998.

[11] S. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 8, pp. 1451–1458, 1998.

[12] 3GPP, "Physical channels and mapping of transport channels onto physical channels (FDD)," 3GPP TSG-RAN Tech. Spec. (TS) 25.211, version 5.5.0, 2003.

[13] M. Abramowitz and I. Stegun, Eds., *Handbook of Mathematical Functions*, National Bureau of Standards, Washington, DC, USA, 1972.

[14] S. Ariyavisitakul and L. Chang, "Signal and interference statistics of a CDMA system with feedback power control," *IEEE Trans. Communications*, vol. 41, no. 11, pp. 1626–1634, 1993.

[15] A. Viterbi, *CDMA: Principles of Spread Spectrum Communication*, Addison-Wesley, Reading, Mass, USA, 1995.

[16] 3GPP, "Base station (BS) radio transmission and reception (FDD)," 3GPP TSG-RAN Tech. Spec. (TS) 25.104, version 6.3.0, 2003.

[17] 3GPP, "Feasibility study for enhanced uplink for UTRA FDD," 3GPP TSG-RAN Tech. Rep. (TR) 25.896, version 1.0.2, 2003.

[18] ITU, "Guidelines for evaluation of radio transmission technologies for IMT-2000," Recommendation ITU-R M.1225, 1997.

Jyri Hämäläinen received his M.S. and Ph.D. degrees from the University of Oulu in 1992 and 1998, respectively, in applied mathematics. Since 1999, he has been with Nokia, where he has worked on various aspects of mobile telecommunications systems. Since 2002, he has also been a part-time special researcher in Signal Processing Laboratory, Helsinki University of Technology. His current research interests include multiantenna transmission and reception techniques, and MIMO channel models.

Kari Pajukoski received his B.S.E.E. in 1992. He is a student in the University of Oulu, Finland. He is currently with Nokia Networks, Oulu, Finland, where he is working on various topics related to WCDMA and its evolution. His current research interests include radio performance and transceiver algorithms.

Esa Tiirola received his M.S.E.E. in 1998 from the University of Oulu, Finland. He is currently with Nokia Networks, Oulu, Finland, where he is working on various topics related to WCDMA and its evolution. His current research interests include radio performance, transceiver algorithms, and adaptive antenna array systems.

Risto Wichman received his M.S. and D.S. (Tech.) degrees in digital signal processing from Tampere University of Technology, Tampere, Finland, in 1990 and 1995, respectively. From 1995 to 2001, he worked at Nokia Research Center as a Senior Research Engineer. In 2002, he joined Signal Processing Laboratory, Department of Electrical and Communications Engineering, Helsinki University of Technology, where he acts as a Professor since the beginning of 2003. His major research interests include multiantenna transceiver algorithm design for 3G and 4G wireless communication systems and MIMO channel modeling.

Juha Ylitalo received his M.S.E.E., Lic.Tech., and Dr. Tech. degrees in electrical engineering from the University of Oulu, Oulu, Finland, in 1981, 1985, and 1987, respectively. He held various research positions at the University of Oulu and the Academy of Finland. He was a Visiting Scientist at the Mayo Clinic, Rochester, Minn, USA, in 1984–1985, at Ruhr University of Bochum, Germany, in 1991–1992, and at the University of Trondheim, Norway, in 1994–1995. He joined Nokia in 1995. Since April 2004, he has been employed by Elektrobit Ltd. and the Centre for Wireless Communications, University of Oulu. His research interests include digital synthetic aperture radar techniques, beamforming and diversity schemes, multidimensional radio channel measurement and modeling, and multiantenna receiver algorithms for mobile communication systems. In recent years, he has been involved in performance evaluation of UMTS applying multiple antennas in transmission and reception (MIMO). Dr. Ylitalo is an author or coauthor of more than 70 scientific articles or conference publications and he has several patents. He is a coauthor in two recent books on UMTS.

Special Issue on
Wireless Mobile Ad Hoc Networks

Call for Papers

Wireless mobile ad hoc networks (MANETs), due to their dynamic nature, pose many unique challenges compared to traditional wired or cellular wireless networks. MANETs must be self-organized without any requirement for base stations. Their topologies are unpredictable due to mobility and change with the number and distribution of active nodes in the network. Fading and channel variations also induce changes in the network topology and introduce additional complexities in these networks. Given power and energy constraints, as well as the shared nature of the wireless medium, communications may be expected to be multihop. In such a harsh environment, robustness and quality of service (QoS) are essential factors to be considered. MANETs may consist of a heterogeneous mixture of nodes with variety of traffic types and different QoS requirements. Scaling laws for these networks are not fully understood. Many tradeoff studies related to capacity, delay, bandwidth, and energy consumption are currently under intense investigations.

The goal of this special issue is to collect cutting-edge research results in the field of wireless MANETs. We solicit papers that deal with pressing problems unique to wireless MANETs. The scope of this issue includes all aspects of MANETs, including scaling laws, tradeoff studies, coding, interference management, protocol design, cross-layer design, and, more importantly, fundamental limits of MANETs under different conditions. We seek original and unpublished work. The potential list of topics is not necessarily exhaustive and other appropriate subjects will be considered.

Topics of interest include (but are not limited to):

- Analytical framework and appropriate metrics for evaluation of MANETs
- Fundamental limits of multihop MANETs
- Capacity, delay, bandwidth, and energy tradeoffs
- Scalable energy-efficient protocols, and framework for analysis of protocols
- Error control schemes
- Network coding
- Interference management
- Cross-layer design
- Cooperation among nodes
- Hybrid networks containing static and mobile nodes
- QoS support for different traffic types

Authors should follow the EURASIP JWCN manuscript format described at http://www.hindawi.com/journals/wcn/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JWCN manuscript tracking system at http://www.mstracking.com/wcn/, according to the following timetable:

Manuscript Due	February 1, 2006
Acceptance Notification	June 1, 2006
Final Manuscript Due	September 1, 2006
Publication Date	4rd Quarter, 2006

GUEST EDITORS:

Hamid R. Sadjadpour, Baskin School of Engineering, University of California, Santa Cruz, CA 95064, USA; hamid@soe.ucsc.edu

Robert Ulman, Army Research Office, Research Triangle Park, NC 27709, USA; robert.ulman@us.army.mil

Anthony Ephremides, Department of Electrical Engineering, University of Maryland at College Park, MD 20742, USA; etony@mintaka.isr.umd.edu

Ananthram Swami, Army Research Lab, Adelphi, MD 20783-1197, USA; aswami@arl.army.mil

EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING

Special Issue on

Space-Time Channel Modeling for Wireless Communications

Call for Papers

Multiple-input multiple-output (MIMO) wireless communication systems exploit the spatial channel created by transmit and receive antenna arrays to increase quality, capacity, and coverage in wireless communication systems. A wide variety of techniques, including space-time coding, spatial multiplexing schemes, transmitter-receiver architecture, precoding methods together with established physical layer algorithms have been proposed or adopted for MIMO communication systems. Channel modeling plays an important part in validating and proving these systems. Despite rapid progress in MIMO communication systems, lack of understanding and modeling of spatial aspects of wireless channels is a critical obstacle to the further development of this technology.

Topics of interest include (but are not limited to):

- Space-time channel models based on physical propagation mechanisms
- MIMO channel simulators
- Channel models based on measurements
- Spatial correlation
- Fast fading and/or frequency-selective channels
- MIMO channel measurements
- Statistical MIMO channel models
- Modeling and measurement of angular power distributions
- Broadband MIMO channel models
- Spatial aspects of UWB and 60 GHz channels
- Multiuser MIMO channel models

Authors should follow the EURASIP JWCN manuscript format described at http://www.hindawi.com/journals/wcn/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JWCN's manuscript tracking system at http://www.mstracking.com/wcn/, according to the following timetable:

Manuscript Due	April 1, 2006
Acceptance Notification	August 1, 2006
Final Manuscript Due	November 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Thushara Abhayapala, Research School of Information Sciences and Engineering, The Australian National University, Canberra, Australia; thushara.abhayapala@anu.edu.au

Mérouane Debbah, Eurécom Institute, Sophia Antipolis, France; merouane.debbah@eurecom.fr

Rodney Kennedy, Wireless Signal Processing Program, National ICT Australia (NICTA), Australia; rodney.kennedy@anu.edu.au

EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING

Special Issue on

Millimeter-Wave Wireless Communication Systems: Theory and Application

Call for Papers

In 2001, the United States Federal Communications Commission (FCC) reserved 7 GHz of unlicensed spectrum between 57 to 64 GHz for the purpose of wireless communications. As a results, the millimeter-wave- (mmWave-) based technology has received increased attention in both academia and industry for very high-data-rate wireless personal area network (WPAN) applications such as high-speed internet access, streaming content download (e.g., HDTV, home theater, etc.), real-time streaming, and wireless data bus for cable replacement. In addition to the high-data-rate applications, energy propagation in the 60 GHz band has unique characteristics that give many other benefits such as excellent immunity to interference, high security, and frequency reuse. This has been proven when an industrial standard such as IEEE 802.15.3c has been introduced to develop alternative PHY for the existing 802.15.3 WPAN Standard based on mmWave technology.

The aim of this special issue is to present research in mmWave communication systems with emphasis on future applications in wireless communications.

Topics of interest include (but are not limited to):

- Radio propagation measurement and modeling
- Antenna design
- Transmission technologies (e.g., modulation and detection)
- Algorithm and signal processing
- Synchronization and channel estimation
- Multiple access
- Standardization and regulation issue (e.g., IEEE 802.15.43c)
- RF transceiver frontend and subsystems design
- System design, implementation, and performance
- Circuit/RFIC design (e.g., SiGe, BiCMOS, CMOS, etc.)
- Multiple-antenna system (e.g., mmWave-MIMO)
- Wireless network and related issues
- Applications

Authors should follow the EURASIP JWCN manuscript format described at http://www.hindawi.com/journals/wcn/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JWCN's manuscript tracking system at http://www.mstracking.com/wcn/, according to the following timetable:

Manuscript Due	May 1, 2006
Acceptance Notification	September 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Chia-Chin Chong, DoCoMo USA Labs, 181 Metro Drive, Suite 300, San Jose, CA 95110, USA; cchong@docomolabs-usa.com

Hiroyo Ogawa, Yokosuka Radio Communications Research Center, National Institute of Information and Communications Technology (NICT Yokosuka), 3-4, Hikarinooka, Yokosuka-shi, Kanagawa 239-0847, Japan; hogawa@nict.go.jp

Peter F. M. Smulders, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands; p.f.m.smulders@tue.nl

Su-Khiong Yong, Communication Lab, Samsung Advanced Institute of Technology, P.O. Box 111, Suwon 440-600, Korea; su.khiong.yong@samsung.com

Special Issue on

Signal Processing with High Complexity: Prototyping and Industrial Design

Call for Papers

Some modern applications require an extraordinary large amount of complexity in signal processing algorithms. For example, the 3rd generation of wireless cellular systems is expected to require 1000 times more complexity when compared to its 2nd generation predecessors, and future 3GPP standards will aim for even more number-crunching applications. Video and multimedia applications do not only drive the complexity to new peaks in wired and wireless systems but also in personal and home devices. Also in acoustics, modern hearing aids or algorithms for de-reverberation of rooms, blind source separation, and multichannel echo cancelation are complexity hungry. At the same time, the anticipated products also put on additional constraints like size and power consumption when mobile and thus battery powered. Furthermore, due to new developments in electroacoustic transducer design, it is possible to design very small and effective loudspeakers. Unfortunately, the linearity assumption does not hold any more for this kind of loudspeakers, leading to computationally demanding nonlinear cancelation and equalization algorithms.

Since standard design techniques would either consume too much time or do not result in solutions satisfying all constraints, more efficient development techniques are required to speed up this crucial phase. In general, such developments are rather expensive due to the required extraordinary high complexity. Thus, de-risking of a future product based on rapid prototyping is often an alternative approach. However, since prototyping would delay the development, it often makes only sense when it is well embedded in the product design process. Rapid prototyping has thus evolved by applying new design techniques more suitable to support a quick time to market requirement.

This special issue focuses on new development methods for applications with high complexity in signal processing and on showing the improved design obtained by such methods. Examples of such methods are virtual prototyping, HW/SW partitioning, automatic design flows, float to fix conversions, automatic testing and verification, and power aware designs.

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JES's manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	December 1, 2005
Acceptance Notification	March 1, 2006
Final Manuscript Due	June 1, 2006
Publication Date	3rd Quarter, 2006

GUEST EDITORS:

Markus Rupp, TU Wien, Gusshausstr. 25/389, A-1040 Wien, Austria; mrupp@nt.tuwien.ac.at

Thomas Kaiser, University of Duisburg-Essen, 47057 Duisburg, Germany; thomas.kaiser@uni-duisburg.de

Gerhard Schmidt, Harman Becker / Temic-SDS, Germany; gerhard.schmidt@temic-sds.com

Jean-Francois Nezan, IETR/Image group Lab, France; jean-francois.nezan@insa-rennes.fr

EURASIP JOURNAL ON EMBEDDED SYSTEMS

Special Issue on Field-Programmable Gate Arrays in Embedded Systems

Call for Papers

Field-Programmable Gate Arrays (FPGAs) are increasingly used in embedded systems to achieve high performance in a compact area. FPGAs are particularly well suited to processing data straight from sensors in embedded systems. More importantly, the reconfigurable aspects of FPGAs give the circuits the versatility to change their functionality based on processing requirements for different phases of an application, and for deploying new functionality.

Modern FPGAs integrate many different resources on a single chip. Embedded processors (both hard and soft cores), multipliers, RAM blocks, and DSP units are all available along with reconfigurable logic. Applications can use these heterogeneous resources to integrate several different functions on a single piece of silicon. This makes FPGAs particularly well suited to embedded applications.

This special issue focuses on applications that clearly show the benefit of using FPGAs in embedded applications, as well as on design tools that enable such applications. Specific topics of interest include the use of reconfiguration in embedded applications, hardware/software codesign targeting FPGAs, power-aware FPGA design, design environments for FPGAs, system signalling and protocols used by FPGAs in embedded environments, and system-level design targeting modern FPGA's heterogeneous resources.

Papers on other applicable topics will also be considered. All papers should address FPGA-based systems that are appropriate for embedded applications. Papers on subjects outside of this scope (i.e., not suitable for embedded applications) will not be considered.

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JES manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	December 15, 2005
Acceptance Notification	May 1, 2006
Final Manuscript Due	August 1, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Miriam Leeser, Northeastern University, USA; mel@coe.neu.edu

Scott Hauck, University of Washington, USA; hauck@ee.washington.edu

Russell Tessier, University of Massachusetts, Amherst, USA; tessier@ecs.umass.edu

Special Issue on Formal Methods for GALS Design

Call for Papers

As chips grow in speed and complexity, global control of an entire chip using a single clock is becoming increasingly challenging. In the future, multicore and large-scale systems-on-chip (SoC) designs are therefore likely to be composed of several timing domains.

Global Asynchrony and Local Synchrony (GALS) is emerging as the paradigm of choice for SoC design with multiple timing domains. In GALS systems, each timing domain is locally clocked, and asynchronous communication schemes are used to glue all of the domains together. Thus, unlike purely asynchronous design, GALS design is able to make use of the significant industrial investment in synchronous design tools.

There is an urgent need for the development of sound models and formal methods for GALS systems. In synchronous designs, formal methods and design automation have played an enabling role in the continuing quest for chips with ever greater complexity. Due to the inherent subtleties of the asynchronous circuit design, formal methods are likely to be vital to the success of the GALS paradigm.

We invite original articles for a special issue of the journal to be published in 2006. Articles may cover every aspect related to formal modeling and formal methods for GALS systems and/or target any type of embedded applications and/or architectures combining synchronous and asynchronous notions of timing:

- Formal design and synthesis techniques for GALS systems
- Design and architectural transformations and equivalences
- Formal verification of GALS systems
- Formal methods for analysis of GALS systems
- Hardware compilation of GALS system
- Latency-insensitive synchronous systems
- Mixed synchronous-asynchronous systems
- Synchronous/asynchronous interaction at different levels
- Clocking, interconnect, and interface issues in deep-submicron design
- Modeling of interfaces between multiple timing domains
- System decomposition into GALS systems
- Formal aspects of system-on-chip (SoC) and network-on-chip (NoC) designs
- Motivating case studies, comparisons, and applications

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JES manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	December 15, 2005
Acceptance Notification	April 15, 2006
Final Manuscript Due	July 15, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Alain Girault, Pop Art Project, INRIA Rhône-Alpes, 38334 Saint-Ismier Cedex, France; alain.girault@inrialpes.fr

S. Ramesh, Department of Computer Science and Engineering, Indian Institute of Technology, Bombay, Mumbai-400 076, India; ramesh@cse.iitb.ac.in

Sandeep Kumar Shukla, Electrical and Computer Engineering Department, Virginia Tech, Blacksburg, VA 24061, USA; sandeep@cs.albany.edu

Jean-Pierre Talpin, ESPRESSO, IRISA/INRIA Rennes, 35042 Rennes Cedex, France; jean-pierre.talpin@irisa.fr

Special Issue on Embedded Vision System

Call for Papers

Vision systems allow computers to understand images, and to take appropriate actions, often under hard real-time constraints.

Most vision systems need high computer performance. The decisive constraint to develop pattern recognition or monitoring systems was therefore to consider computer hardware with excellent key features to fulfill the high requirements. This causality has several disadvantages. The costs of the final products are high, the size of the hardware becomes voluminous, the electromagnetic capability is reduced, and the energy consumption is often a problem. Therefore, the pressure to realize vision systems on the base of Embedded Systems was and is still increasing dramatically. Meanwhile, the number of possible applications has exploded since several disadvantages of classic systems can be avoided. The history of mobile phones evolution is one of the best examples. It would not have been possible without Embedded Systems, and especially not in such an affordable way. However, it is not necessary to consider only the mass market where Embedded Vision Systems can improve the current situation dramatically. If many cameras are installed to watch a scene, one is able to define a virtual camera, which always shows the most important angle of a view. If a bank note should be checked under the conditions of high accuracy, high probability of error recognition, and high throughput, the realization is only feasible, if the computer is assisted by a network of special parallelized chips. Usually, the algorithms can be divided into three areas, the prestage, where data is compressed, the specialized computational phase, and the interpretation stage. With this setup, the bandwidth and the data throughput may be improved in an amazing way.

Many other ideas could be presented. The main issues are the parallelization of processes, as well as the communications between them, which are based on networked chip sets. The challenge for the research work is to find optimal structures concerning real-time problems, energy consumption, low-price solutions, and so forth. However, not all algorithms for vision systems are suitable to be implemented in Embedded Systems; better solutions have to be discovered. In this sense many tasks and problems in the research field have to be solved, and many application areas are concerned.

This special issue focuses on new results of research work in the field of Embedded Vision Systems. Several main keywords are:

- Innovative architectures for embedded vision systems
- Innovative sensor systems for embedded vision applications
- Architectural considerations in complex image-processing programs in an embedded environment
- FPGA designs for image processing applications
- DSP and FPGA: alternative and/or complement
- Networking for distributed embedded vision systems
- Performance bottlenecks/solutions for high-performance vision systems
- Smart camera systems
- Virtual camera systems
- Object tracking
- Automotive applications
- Traffic flow measurement systems
- Robot and machine vision
- Bioinspired vision systems
- Verification methods for mission-critical embedded computer vision systems

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JES manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	May 1, 2006
Acceptance Notification	September 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Dietmar Dietrich, Vienna University of Technology, Gusshausstrasse 25-27/E384, 1040 Vienna, Austria; dietrich@ict.tuwien.ac.at

Heinrich Garn, ARC Seibersdorf research GmbH, 2444 Seibersdorf, Austria; heinrich.garn@arcs.ac.at

Udo Kebschull, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany; kebschul@kip.uni-heidelberg.de

Christoph Grimm, Institute of Microelectronic Systems, University of Hannover, Appelstrasse 4, 30167 Hannover, Germany; grimm@ims.uni-hannover.de

Moshe Ben-Ezra, Real-Time Vision and Modeling Department, Siemens Corporate Research, 755 College Road East, 08540 Princeton NJ, USA; moshe.ben-ezra@siemens.com

Hindawi Publishing Corporation
http://www.hindawi.com

EURASIP JOURNAL ON EMBEDDED SYSTEMS

Special Issue on Synchronous Paradigm in Embedded Systems

Call for Papers

Synchronous languages were introduced in the 1980s for programming reactive systems. Such systems are characterized by their continuous reaction to their environment, at a speed determined by the latter. Reactive systems include embedded control software and hardware. Synchronous languages have recently seen a tremendous interest from leading companies developing automatic control software and hardware for critical applications. Industrial success stories have been achieved by Schneider Electric, Airbus, Dassault Aviation, Snecma, MBDA, Arm, ST Microelectronics, Texas Instruments, Freescale, Intel .... The key advantage outlined by these companies resides in the rigorous mathematical semantics provided by the synchronous approach that allows system designers to develop critical software and hardware in a faster and safer way.

Indeed, an important feature of synchronous paradigm is that the tools and environments supporting development of synchronous programs are based upon a formal mathematical model defined by the semantics of the languages. The compilation involves the construction of these formal models, and their analysis for static properties, their optimization, the synthesis of executable sequential implementations, and the automated distribution of programs. It can also build a model of the dynamical behaviors, in the form of a transition system, upon which is based the analysis of dynamical properties, for example, through model-checking-based verification, or discrete controller synthesis. Hence, synchronous programming is at the crossroads of many approaches in compilation, formal analysis and verification techniques, and software or hardware implementations generation.

We invite original papers for a special issue of the journal to be published in the first quarter of 2007. Papers may be submitted on all aspects of the synchronous paradigm for embedded systems, including theory and applications. Some sample topics are:

- Synchronous languages design and compiling
- Novel application and implementation of synchronous languages
- Applications of synchronous design methods to embedded systems (hardware or software)
- Formal modeling, formal verification, controller synthesis, and abstract interpretation with synchronous-based tools
- Combining synchrony and asynchrony for embedded system design and, in particular, globally asynchronous and locally synchronous systems
- The role of synchronous models of computations in heterogeneous modeling
- The use of synchronous modeling techniques in model-driven design environment
- Design of distributed control systems using the synchronous paradigm

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JES's manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	June 1, 2006
Acceptance Notification	October 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Alain Girault, INRIA, France; alain.girault@inrialpes.fr

S. Ramesh, IIT Bombay, India; ramesh@cse.iitb.ac.in

Jean-Pierre Talpin, IRISA, France; jean-pierre.talpin@irisa.fr

Special Issue on

Embedded Systems for Portable and Mobile Video Platforms

Call for Papers

Video coding systems have been assuming an increasingly important role in application areas other than the traditional video broadcast and storage scenarios. Several new applications have emerged focusing on personal communications (such as video-conferencing), wireless multimedia, remote video-surveillance, and emergency systems. As a result, a number of new video compression standards have emerged addressing the requirements of these kinds of applications in terms of image quality and bandwidth. For example, the ISO/MPEG and ITU standardization bodies have recently jointly established the new AVC/H.264 video coding standard.

In such a wide range of applications scenarios, there is the need to adapt the video processing in general, and in particular video coding/decoding, to the restrictions imposed by both the applications themselves and the terminal devices. This problem is even more important for portable and battery-supplied devices, in which low-power considerations are important limiting constraints. Examples of such application requirements are currently found in 3G mobile phones, CMOS cameras and tele-assistance technologies for elderly/disabled people.

Therefore, the development of new power-efficient encoding algorithms and architectures suitable for mobile and battery-supplied devices is fundamental to enabling the widespread deployment of multimedia applications on portable and mobile video platforms. This special issue is focused on the design and development of embedded systems for portable and mobile video platforms. Topics of interest cover all aspects of this type of embedded system, including, not only algorithms, architectures, and specific SoC design methods, but also more technological aspects related to wireless-channels, power-efficient optimizations and implementations, such as encoding strategies, data flow optimizations, special coprocessors, arithmetic units, and electronic circuits.

Papers suitable for publication in this special issue must describe high-quality, original, unpublished research. Prospective authors are invited to submit manuscripts on topics including but not limited to:

- Power-efficient algorithms and architectures for motion estimation, discrete transforms (e.g., SA-DCT, WT), integer transforms, and entropy coding
- Architectural paradigms for portable multimedia systems
- Low-power techniques and circuits, memory, and data flow optimizations for video coding
- Adaptive algorithms and generic configurable architectures for exploiting intrinsic characteristics of image sequences and video devices
- Aspects specifically important for portable and mobile video platforms, such as video transcoding, video processing in the compressed domain, and error resilience (e.g., MDC)
- Ultra-low-power embedded systems for video processing and coding
- Heterogeneous architectures, multithreading, MPSoC, NoC implementations
- Design space exploration tools, performance evaluation tools, coding efficiency and complexity analysis tools for video coding in embedded systems

Authors should follow the EURASIP JES manuscript format described at http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JES manuscript tracking system at http://www.mstracking.com/es/, according to the following timetable:

Manuscript Due	June 1, 2006
Acceptance Notification	October 1, 2006
Final Manuscript Due	January 1, 2007
Publication Date	2nd Quarter, 2007

GUEST EDITORS:

Leonel Sousa, INESC-ID, IST, Universidade Técnica de Lisboa, 1000-029 Lisboa, Portugal; las@inesc-id.pt

Noel O'Connor, School of Electronic Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland; noel.oconnor@eeng.dcu.ie

Marco Mattavelli, Signal Processing Laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland; marco.mattavelli@epfl.ch

Antonio Nunez, IUMA, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain; nunez@iuma.ulpgc.es

Hindawi Publishing Corporation
http://www.hindawi.com