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Rate-Optimal Multiuser Scheduling with Reduced Feedback Load and Analysis of Delay Effects

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We propose a feedback algorithm for wireless networks that always collects feedback from the user with the best channel conditions and has a significant reduction in feedback load compared to full feedback. The algorithm is based on a carrier-to-noise threshold, and closed-form expressions for the feedback load as well as the threshold value that minimizes the feedback load have been found. We analyze two delay scenarios. The first scenario is where the scheduling decision is based on outdated channel estimates, and the second scenario is where both the scheduling decision and the adaptive modulation are based on outdated channel estimates.

1. INTRODUCTION

In a wireless network, the signals transmitted between the base station and the mobile users most often have different channel fluctuation characteristics. This diversity that exists between users is called *multiuser diversity* (MUD) and can be exploited to enhance the capacity of wireless networks [1]. One way of exploiting MUD is by *opportunistic scheduling* of users, giving priority to users having good channel conditions [2, 3]. Ignoring the feedback loss, the scheduling algorithm, that maximizes the average system spectral efficiency among all time division multiplexing- (TDM-) based algorithms, is the one where the user with the highest carrier-to-noise ratio (CNR) is served in every time slot [2]. Here, we refer to this algorithm as *max CNR scheduling* (MCS).

To be able to take advantage of the MUD, a base station needs feedback from the mobile users. Ideally, the base station only wants feedback from the user with the best channel conditions, but unfortunately each user does not know the CNR of the other users. Therefore, in current systems like Qualcomm's high data rate (HDR) system, the base station collects feedback from all the users [4].

One way to reduce the number of users giving feedback is by using a *CNR threshold*. For the *selective multiuser diversity* (SMUD) algorithm, it is shown that the feedback load is reduced significantly by using such a threshold [5]. For this algorithm only the users that have a CNR above a CNR threshold should send feedback to the scheduler. If the scheduler does not receive a feedback, a random user is chosen. Because the best user is not chosen for every time slot, the SMUD algorithm however introduces a reduction in system spectral efficiency. In addition it can be hard to set the threshold value for this algorithm. Applying a high threshold value will lead to low feedback load, but will additionally reduce the MUD gain and hence the system spectral efficiency. Using a low threshold value will have the opposite effect: the feedback load reduction is reduced, but the spectral efficiency will be higher.

The feedback algorithm proposed here is inspired by the SMUD algorithm, in the sense that this new algorithm also employs a feedback threshold. However, if none of the users succeeds to exceed the CNR threshold, the scheduler requests full feedback, and selects the user with the highest CNR. Consequently, the MUD gain [1] is maximized, and still the feedback load is significantly reduced compared to the MCS algorithm. Another advantage with this novel algorithm is that for a specific set of system parameters it is possible to find a threshold value that minimizes the feedback load.

For the new feedback algorithm we choose to investigate two important issues, namely, (i) how the algorithm can be optimized, and (ii) the consequences of delay in the system. The first issue is important because it gives theoretical limits for how well the algorithm will perform. The second issue is important because the duration of the feedback collection process will often be significant and this will lead to a reduced performance of the opportunistic scheduling since the feedback information will be outdated. The consequences of delay are analyzed by looking separately at two different effects: (a) the system spectral efficiency degradation arising because the scheduler does not have access to instantaneous information about CNRs of the users, and (b) the bit error rate (BER) degradation arising when both the scheduler and the mobile users do not have access to instantaneous channel measurements.

Contributions

We develop closed-form expressions for the feedback load of the new feedback algorithm. The expression for the threshold value which minimizes the feedback load is also derived. In addition we obtain new closed-form expressions for the system spectral efficiency degradation due to the *scheduling delay*. Finally, closed-form expressions for the effects of *outdated channel estimates* are obtained. Parts of the results have previously been presented in [6].

Organization

The rest of this paper is organized as follows. In Section 2, we present the system model. The feedback load is analyzed in Section 3, while Sections 4 and 5 analyze the system spectral efficiency and BER, respectively. In Section 6 the effects of delay are discussed. Finally, Section 7 lists our conclusions.

2. SYSTEM MODEL

We consider a single cell in a wireless network where the base station exchanges information with a constant number N of mobile users which have identically and independently distributed (i.i.d.) CNRs with an average of $\overline{\gamma}$. The system considered is TDM-based, that is, the information transmitted in time slots with a fixed length. We assume flat-fading channels with a coherence time of one time slot, which means that the channel quality remains roughly the same over the whole time slot duration and that this channel quality is uncorrelated from one time slot to the next. The system uses adaptive coding and modulation, that is, the coding scheme, the modulation constellation, and the transmission power used depend on the CNR of the selected user [7]. This has two advantages. On one hand, the spectral efficiency for each user is increased. On the other hand, because the rate of the users is varied according to their channel conditions, it makes it possible to exploit MUD.

We will assume that the users always have data to send and that these user data are robust with respect to delay, that is, no real-time traffic is transmitted. Consequently, the base station only has to take the channel quality of the users into account when it is performing scheduling.

The proposed feedback algorithm is applicable in at least two different types of cellular systems. The first system model is a time-division duplex (TDD) scenario, where the same carrier frequency is used for both uplink and downlink. We can therefore assume a reciprocal channel for each user, that is, the CNR is the same for the uplink and the downlink for a given point in time. The system uses the first half of the time slot for downlink and the last half for uplink transmission. The users measure their channel for each downlink transmission and this measurement is fed back to the base station so that it can decide which user is going to be assigned the next time slot. The second system model is a system where different carriers are used for uplink and downlink. For the base station to be able to schedule the user with the best downlink channel quality, the users must measure their channel for each downlink transmission and feed back their CNR measurement. For both system models the users are notified about the scheduling decision in a short broadcast message from the base station between each time slot.

3. ANALYSIS OF THE FEEDBACK LOAD

The first step of the new feedback algorithm is to ask for feedback from the users that are above a CNR threshold value γ_{th}. The number of users n being above the threshold value γ_{th} is random and follow a *binomial distribution* given by

$$\Pr(n) = \binom{N}{n}\left(1 - P_\gamma(\gamma_{\text{th}})\right)^n P_\gamma^{N-n}(\gamma_{\text{th}}), \quad n = 1, 2, \ldots, N, \tag{1}$$

where $P_\gamma(\gamma)$ is the cumulative distribution function (CDF) of the CNR for a single user. The second step of the feedback algorithm is to collect full feedback. Full feedback is only needed if all users' CNRs fail to exceed the threshold value. The probability of this event is given by inserting $\gamma = \gamma_{\text{th}}$ into

$$P_{\gamma^*}(\gamma) = P_\gamma^N(\gamma), \tag{2}$$

where γ^* denotes the CNR of the user with the best channel quality.

We now define the *normalized feedback load* (NFL) to be the ratio between the average number of users transmitting feedback, and the total number of users. The NFL can be expressed as a the average of the ratio n/N, where n is the number of users giving feedback:

$$\begin{aligned}\overline{F} &= \frac{N}{N}P_\gamma^N(\gamma_{\text{th}}) + \sum_{n=1}^{N}\frac{n}{N}\binom{N}{n}\left(1 - P_\gamma(\gamma_{\text{th}})\right)^n P_\gamma^{N-n}(\gamma_{\text{th}}) \\ &= P_\gamma^N(\gamma_{\text{th}}) + \left(1 - P_\gamma(\gamma_{\text{th}})\right)\sum_{n=1}^{N}\binom{N-1}{n-1} \\ &\quad \times \left(1 - P_\gamma(\gamma_{\text{th}})\right)^{n-1}P_\gamma^{N-n}(\gamma_{\text{th}}) = P_\gamma^N(\gamma_{\text{th}}) \\ &\quad + \left(1 - P_\gamma(\gamma_{\text{th}})\right)\sum_{k=0}^{N-1}\binom{N-1}{k}\left(1 - P_\gamma(\gamma_{\text{th}})\right)^k P_\gamma^{N-1-k}(\gamma_{\text{th}}) \\ &= 1 - P_\gamma(\gamma_{\text{th}}) + P_\gamma^N(\gamma_{\text{th}}), \quad N = 2, 3, 4, \ldots,\end{aligned} \tag{3}$$

where the last equality is obtained by using binomial expansion [8, equation (1.111)]. For $N = 1$ full feedback is needed, and $\overline{F} = 1$. In that case the feedback is not useful for multiuser scheduling, but for being able to adapt the base station's modulation according to the channel quality in the reciprocal TDD system model described in the previous section.

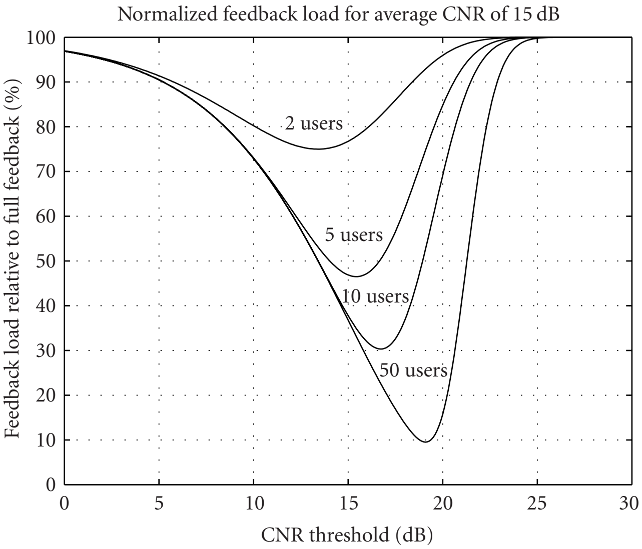

FIGURE 1: Normalized feedback load as a function of γ_{th} with $\overline{\gamma} = 15\,\text{dB}$.

A plot of the feedback load as a function of γ_{th} is shown in Figure 1 for $\overline{\gamma}= 15\,\text{dB}$. It can be observed that the new algorithm reduces the feedback significantly compared to a system with full feedback. It can also be observed that one threshold value will minimize the feedback load in the system for a given number of users.

The expression for the threshold value that minimizes the average feedback load can be found by differentiating (3) with respect to γ_{th} and setting the result equal to zero:

$$\gamma_{\text{th}}^{*} = P_{\gamma}^{-1}\left(\left(\frac{1}{N}\right)^{1/(N-1)}\right), \quad N = 2, 3, 4, \ldots, \tag{4}$$

where $P_{\gamma}^{-1}(\cdot)$ is the inverse CDF of the CNR. In particular, for a Rayleigh fading channel, with CDF $P_{\gamma}(\gamma) = 1 - e^{-\gamma/\overline{\gamma}}$, the optimum threshold can be found in a simple closed form as

$$\gamma_{\text{th}}^{*} = -\overline{\gamma}\ln\left(1 - \left(\frac{1}{N}\right)^{1/(N-1)}\right), \quad N = 2, 3, 4, \ldots. \tag{5}$$

4. SYSTEM SPECTRAL EFFICIENCIES FOR DIFFERENT POWER AND RATE ADAPTATION TECHNIQUES

To be able to analyze the system spectral efficiency we choose to investigate the *maximum average system spectral efficiency* (MASSE) theoretically attainable. The MASSE (bit/s/Hz) is defined as the maximum average sum of spectral efficiency for a carrier with bandwidth W (Hz).

4.1. *Constant power and optimal rate adaptation*

Since the best user is always selected, the MASSE of the new algorithm is the same as for the MCS algorithm. To find the MASSE for such a scenario, the probability density function (pdf) of the highest CNR among all the users has to be found. This pdf can be obtained by differentiating (2) with respect to γ. Inserting the CDF and pdf for Rayleigh fading channels ($p_{\gamma}(\gamma) = (1/\overline{\gamma})e^{-\gamma/\overline{\gamma}}$), and using binomial expansion [8, equation (1.111)], we obtain

$$p_{\gamma^*}(\gamma) = \frac{N}{\overline{\gamma}}\sum_{n=0}^{N-1}\binom{N-1}{n}(-1)^n e^{-(1+n)\gamma/\overline{\gamma}}. \tag{6}$$

Inserting (6) into the expression for the spectral efficiency for optimal rate adaptation found in [9], the following expression for the MASSE can be obtained [10, equation (44)]:

$$\begin{aligned}\frac{\langle C\rangle_{\text{ora}}}{W} &= \int_0^{\infty}\log_2(1+\gamma)p_{\gamma^*}(\gamma)d\gamma \\ &= \frac{N}{\ln 2}\sum_{n=0}^{N-1}\binom{N-1}{n}(-1)^n\frac{e^{(1+n)/\overline{\gamma}}}{1+n}E_1\left(\frac{1+n}{\overline{\gamma}}\right),\end{aligned} \tag{7}$$

where ora denotes *optimal rate adaptation* and $E_1(\cdot)$ is the *first-order exponential integral function* [8].

4.2. *Optimal power and rate adaptation*

It has been shown that the MASSE for optimal power and rate adaptation can be obtained as [10, equation (27)]

$$\begin{aligned}\frac{\langle C\rangle_{\text{opra}}}{W} &= \int_0^{\infty}\log_2\left(\frac{\gamma}{\gamma_0}\right)p_{\gamma^*}(\gamma)d\gamma \\ &= \frac{N}{\ln 2}\sum_{n=0}^{N-1}\binom{N-1}{n}\frac{(-1)^n}{1+n}E_1\left(\frac{(1+n)\gamma_0}{\overline{\gamma}}\right),\end{aligned} \tag{8}$$

where opra denotes *optimal power and rate adaptation* and γ_0 is the optimal cutoff CNR level below which data transmission is suspended. This cutoff value must satisfy [9]

$$\int_{\gamma_0}^{\infty}\left(\frac{1}{\gamma_0} - \frac{1}{\gamma}\right)p_{\gamma^*}(\gamma)d\gamma = 1. \tag{9}$$

Inserting (6) into (9), it can subsequently be shown that the following cutoff value can be obtained for Rayleigh fading channels [10, equation (24)]:

$$\sum_{n=0}^{N-1}\binom{N-1}{n}(-1)^n\left(\frac{e^{-(1+n)\gamma_0/\overline{\gamma}}}{(1+n)\gamma_0/\overline{\gamma}} - E_1\left(\frac{(1+n)\gamma_0}{\overline{\gamma}}\right)\right) = \frac{\overline{\gamma}}{N}. \tag{10}$$

5. M-QAM BIT ERROR RATES

The BER of coherent M-ary quadrature amplitude modulation (M-QAM) with two-dimensional Gray coding over an additive white Gaussian noise (AWGN) channel can be approximated by [11]

$$\text{BER}(M,\gamma) \approx 0.2\exp\left(-\frac{3\gamma}{2(M-1)}\right). \tag{11}$$

The constant-power *adaptive continuous rate* (ACR) M-QAM scheme can always adapt the rate to the instantaneous CNR. From [12] we know that the constellation size for continuous-rate M-QAM can be approximated by $M \approx (1+3\gamma/2K_0)$, where $K_0 = -\ln(5\,\mathrm{BER}_0)$ and BER_0 is the target BER. Consequently, it can be easily shown that the theoretical constant-power ACR M-QAM scheme always operates at the target BER.

For physical systems only integer constellation sizes are practical, so now we restrict the constellation size M_k to 2^k, where k is a positive integer. This adaptation policy is called *adaptive discrete rate* (ADR) M-QAM, and the CNR range is divided into $K+1$ *fading regions* with constellation size M_k assigned to the kth fading region. Because of the discrete assignment of constellation sizes in ADR M-QAM, this scheme has to operate at a BER lower than the target. The average BER for ADR M-QAM using constant power can be calculated as [12]

$$\langle \mathrm{BER}\rangle_{\mathrm{adr}} = \frac{\sum_{k=1}^{K} k\overline{\mathrm{BER}}_k}{\sum_{k=1}^{K} k p_k}, \tag{12}$$

where

$$\overline{\mathrm{BER}}_k = \int_{\gamma_k}^{\gamma_{k+1}} \mathrm{BER}\,(M_k,\gamma)\,p_{\gamma^*}(\gamma)d\gamma, \tag{13}$$

$$p_k = \left(1-e^{-\gamma_{k+1}/\overline{\gamma}}\right)^N - \left(1-e^{-\gamma_k/\overline{\gamma}}\right)^N \tag{14}$$

is the probability that the scheduled user is in the fading region k for CNRs between γ_k and γ_{k+1}.

Inserting (11) and (6) into (13) we obtain the following expression for the average BER within a fading region:

$$\overline{\mathrm{BER}}_k = \frac{0.2N}{\overline{\gamma}}\sum_{n=0}^{N-1}\binom{N-1}{n}(-1)^n\frac{e^{-\gamma_k a_{k,n}}-e^{-\gamma_{k+1}a_{k,n}}}{a_{k,n}}, \tag{15}$$

where $a_{k,n}$ is given by

$$a_{k,n} = \frac{1+n}{\overline{\gamma}} + \frac{3}{2(M_k-1)}. \tag{16}$$

When power adaptation is applied, the BER approximation in (11) can be written as [11]

$$\mathrm{BER}_{\mathrm{pa}}(M,\gamma) \approx 0.2\exp\left(-\frac{3\gamma}{2(M-1)}\frac{S_k(\gamma)}{S_{\mathrm{av}}}\right), \tag{17}$$

where $S_k(\gamma)$ is the power used in fading region k and S_{av} is the average transmit power. Inserting the continuous power adaptation policy given by [11, equation (29)] into (17) shows that the ADR M-QAM scheme using optimal power adaptation always operates at the target BER. Correspondingly, it can be shown that the continuous-power, continuous-rate M-QAM scheme always operates at the target BER.

6. CONSEQUENCES OF DELAY

In the previous sections, it has been assumed that there is no delay from the instant where the channel estimates are obtained and fed back to the scheduler, to the time when the optimal user is transmitting. For real-life systems, we have to take delay into consideration. We analyze, in what follows, two delay scenarios. In the first scenario, a *scheduling delay* arises because the scheduler receives channel estimates, takes a scheduling decision, and notifies the selected user. This user then transmits, but at a possibly different rate. The second scenario deals with *outdated channel estimates*, which leads to both a scheduling delay as well as suboptimal modulation constellations with increased BERs.

Outdated channel estimates have been treated to some extent in previous publications [12, 13]. However, the concept of scheduling delay has in most cases been analyzed for wire-line networks only [14, 15]. Although some previous work has been done on scheduling delay in wireless networks [16], scheduling delay has to the best of our knowledge not been looked into for cellular networks.

6.1. Impact of scheduling delay

In this section, we will assume that the scheduling decision is based on a perfect estimate of the channel at time t, whereas the data are sent over the channel at time $t+\tau$. We will assume that the link adaptation done at time $t+\tau$ is based on yet another channel estimate taken at $t+\tau$. To investigate the influence of this type of scheduling delay, we need to develop a pdf for the CNR at time $t+\tau$, conditioned on channel knowledge at time t. Let α and α_τ be the channel gains at times t and $t+\tau$, respectively. Assuming that the average power gain remains constant over the time delay τ for a slowly-varying Rayleigh channel (i.e., $\Omega = E[\alpha^2] = E[\alpha_\tau^2]$) and using the same approach as in [12] it can be shown that the conditional pdf $p_{\alpha_\tau|\alpha}(\alpha_\tau \mid \alpha)$ is given by

$$p_{\alpha_\tau|\alpha}(\alpha_\tau \mid \alpha) = \frac{2\alpha_\tau}{(1-\rho)\Omega}I_0\left(\frac{2\sqrt{\rho}\alpha\alpha_\tau}{(1-\rho)\Omega}\right)e^{-(\alpha_\tau^2+\rho\alpha^2)/(1-\rho)\Omega}, \tag{18}$$

where ρ is the correlation factor between α and α_τ and $I_0(\cdot)$ is the *zeroth-order modified Bessel function of the first kind* [8]. Assuming Jakes Doppler spectrum, the correlation coefficient can be expressed as $\rho = J_0^2(2\pi f_D\tau)$, where $J_0(\cdot)$ is the *zeroth-order Bessel function of the first kind* and f_D [Hz] is the maximum Doppler frequency shift [12]. Recognizing that (18) is similar to [17, equation (A-4)] gives the following pdf at time $t+\tau$ for the new feedback algorithm, expressed in terms of γ_τ and $\overline{\gamma}$ [17, equation (5)]:

$$p_{\gamma_\tau^*}(\gamma_\tau)=\sum_{n=0}^{N-1}\binom{N}{n+1}(-1)^n\frac{\exp\left(-\gamma_\tau/\overline{\gamma}\left(1-\rho(n/(n+1))\right)\right)}{\overline{\gamma}\left(1-\rho(n/(n+1))\right)}. \tag{19}$$

Note that for $\tau = 0$ ($\rho = 1$) this expression reduces to (6), as expected. When τ approaches infinity ($\rho = 0$) (19) reduces to the Rayleigh pdf for one user. This is logical since for large τs, the scheduler will have completely outdated and as such useless feedback information, and will end up selecting users independent of their CNRs.

Inserting (19) into the capacity expression for optimal rate adaptation in [9, equation (2)], then using binomial expansion, integration by parts, L'Hôpital's rule, and

[8, equation (3.352.2)], it can be shown that we get the following expression for the MASSE:

$$\frac{\langle C\rangle_{\text{ora}}}{W} = \int_0^\infty \log_2\left(1+\gamma_\tau\right) p_{\gamma_\tau^*}(\gamma_\tau)\, d\gamma_\tau = \frac{1}{\ln 2}\sum_{n=0}^{N-1}\binom{N}{n+1}(-1)^n e^{1/\overline{\gamma}(1-\rho(n/(n+1)))} \times E_1\left(\frac{1}{\overline{\gamma}(1-\rho(n/(n+1)))}\right). \tag{20}$$

Using a similar derivation as for the expression above it can furthermore be shown that we get the following expression for the MASSE using both optimal power and rate adaptation:

$$\frac{\langle C\rangle_{\text{opra}}}{W} = \int_0^\infty \log_2\left(\frac{\gamma_\tau}{\gamma_0}\right) p_{\gamma_\tau^*}(\gamma_\tau)\, d\gamma_\tau = \frac{1}{\ln 2}\sum_{n=0}^{N-1}\binom{N}{n+1}(-1)^n E_1\left(\frac{\gamma_0}{\overline{\gamma}(1-\rho(n/(n+1)))}\right), \tag{21}$$

with the following power constraint:

$$\sum_{n=0}^{N-1}\binom{N}{n+1}(-1)^n\left(\frac{e^{-1/\overline{\gamma}(1-\rho(n/(n+1)))}}{\gamma_0} - \frac{E_1\left(1/\overline{\gamma}(1-\rho(n/(n+1)))\right)}{\overline{\gamma}(1-\rho(n/(n+1)))}\right) = 1. \tag{22}$$

Again, for zero time delay ($\rho = 1$), (20) reduces to (7), (21) reduces to (8), and (22) reduces to (10), as expected.

Figure 2 shows how scheduling delay affects the MASSE for 1, 2, 5, and 10 users. We see that both optimal power and rate adaptation and optimal rate adaptation are equally robust with regard to the scheduling delay. Independent of the number of users, we see that the system will be able to operate satisfactorily if the normalized delay is below the critical value of $2\cdot 10^{-2}$. For normalized time delays above this value, we see that the MASSE converges towards the MASSE for one user, as one may expect.

6.2. Impact of outdated channel estimates

We will now assume that the transmitter does not have a perfect outdated channel estimate available at time $t+\tau$, but only at time t. Consequently, both the selection of a user and the decision of the constellation size have to be done at time t. This means that the channel estimates are outdated by the same amount of time as the scheduling delay. The constellation size is thus not dependent on γ_τ, and the time delay in this case does not affect the MASSE. However, now the BER will suffer from degradation because of the delay. It is shown in [12] that the average BER, conditioned on γ, is

$$\text{BER}(\gamma) = \frac{0.2\gamma}{\gamma+\overline{\gamma}(1-\rho)K_0}\cdot e^{-\rho K_0\gamma/(\gamma+\overline{\gamma}(1-\rho)K_0)}. \tag{23}$$

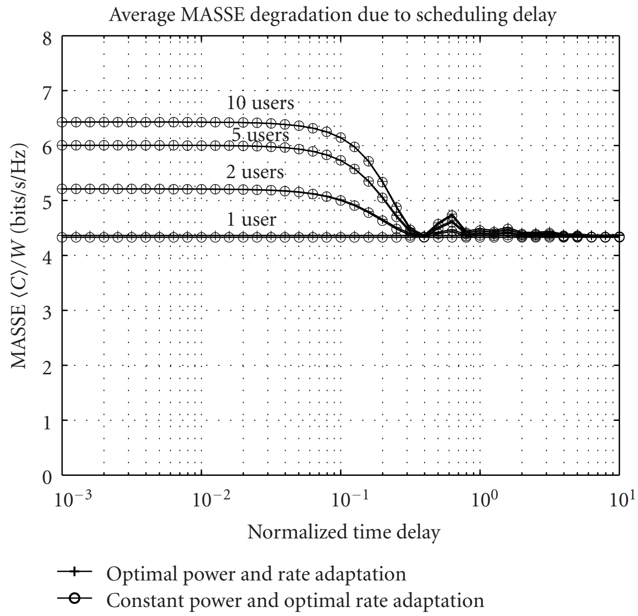

Figure 2: Average degradation in MASSE due to scheduling delay for (i) optimal power and rate adaptation and (ii) optimal rate adaptation.

The average BER can be found by using the following equation:

$$\langle\text{BER}\rangle_{\text{acr}} = \int_0^\infty \text{BER}(\gamma)p_{\gamma^*}(\gamma)\,d\gamma. \tag{24}$$

For discrete rate adaptation with constant power, the BER can be expressed by (12), replacing $\overline{\text{BER}}_k$ with $\overline{\text{BER}}_k'$, where

$$\overline{\text{BER}}_k' = \int_{\gamma_k}^{\gamma_{k+1}}\int_0^\infty \text{BER}\left(M_k,\gamma_\tau\right)p_{\gamma_\tau|\gamma}(\gamma_\tau\mid\gamma)\,d\gamma_\tau\, p_{\gamma^*}(\gamma)\,d\gamma. \tag{25}$$

Inserting (6), (11), and (18) expressed in terms of γ_τ and γ into (25), we obtain the following expression for the average BER within a fading region:

$$\overline{\text{BER}}_k' = \frac{0.2N}{\overline{\gamma}}\sum_{n=0}^{N-1}\binom{N-1}{n}(-1)^n\frac{e^{-\gamma_k c_{k,n}} - e^{-\gamma_{k+1}c_{k,n}}}{d_{k,n}}, \tag{26}$$

where $c_{k,n}$ is given by

$$c_{k,n} = \frac{1+n}{\overline{\gamma}} + \frac{3\rho}{3\overline{\gamma}(1-\rho)+2(M_k-1)}, \tag{27}$$

and $d_{k,n}$ by

$$d_{k,n} = \frac{1+n}{\overline{\gamma}} + \frac{3(1+n-\rho n)}{2(M_k-1)}. \tag{28}$$

Note that for zero delay ($\rho = 1$), $c_{k,n} = d_{k,n} = a_{k,n}$, and (26) reduces to (15), as expected.

Because we are interested in the average BER only for the CNRs for which we have transmission, the average BER for

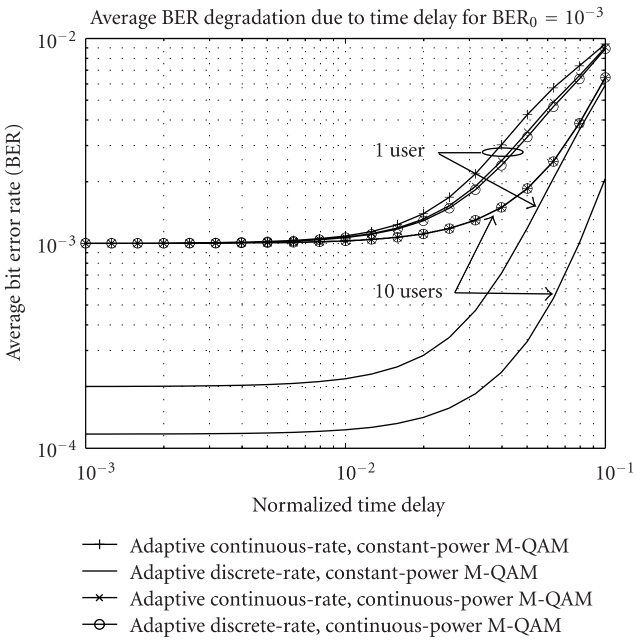

Figure 3: Average BER degradation due to time delay for M-QAM rate adaptation with $\overline{\gamma}$=15 dB, 5 fading regions, and $\text{BER}_0 = 10^{-3}$.

continuous-power, continuous-rate M-QAM is

$$\langle \text{BER} \rangle_{\text{acr,pa}} = \frac{\int_{\gamma_K}^{\infty} \text{BER}(\gamma) p_{\gamma^*}(\gamma) d\gamma}{\int_{\gamma_K}^{\infty} p_{\gamma^*}(\gamma) d\gamma}. \quad (29)$$

Correspondingly, the average BER for the continuous-power, discrete-rate M-QAM case is given by

$$\langle \text{BER} \rangle_{\text{adr,pa}} = \frac{\int_{\gamma_0^* M_1}^{\infty} \text{BER}(\gamma) p_{\gamma^*}(\gamma) d\gamma}{\int_{\gamma_0^* M_1}^{\infty} p_{\gamma^*}(\gamma) d\gamma}. \quad (30)$$

Figure 3 shows how outdated channel estimates affect the average BER for 1 and 10 users. We see that the average system BER is satisfactory as long as the normalized time delay again is below the critical value 10^{-2} for the adaptation schemes using continuous power and/or continuous rate. The constant-power, discrete-rate adaptation policy is more robust with regard to time delay.

7. CONCLUSION

We have analyzed a scheduling algorithm that has optimal spectral efficiency and reduced feedback compared with full feedback load. We obtain a closed-form expression for the CNR threshold that minimizes the feedback load for this algorithm. Both the impact of scheduling delay and outdated channel estimates are analytically and numerically described. For both delay scenarios plots show that the system will be able to operate satisfactorily with regard to BER when the normalized time delays are below certain critical values.

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EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING

Special Issue on

Trust and Digital Rights Management in Wireless Multimedia Networks and Systems

Call for Papers

With the widespread infusion of digital technologies and the ensuing ease of digital content transport over the Internet, multimedia data distribution is experiencing exponential growth. The use of emerging technologies and systems based on wireless networks has further facilitated the ubiquitous presence of multimedia data. These rapid advances are neither without cost nor without negative impact. With the increasing sophistication and ubiquity of sharing and dissemination of data over a plethora of networks, the complexity and challenges of untrustworthy behavior as well as cyber attacks may grow significantly. Moreover, the emerging unstructured, mobile, and ad hoc nature of today's heterogeneous network environment is leading to problems such as the exploitation of resources due to selfish and malicious behavior by users and their agents in the networks.

Trust and digital rights management (DRM) of data and the underlying systems and networks have therefore become of critical concern. Moreover, satisfying users' quality of service (QoS) requirements while implementing trust and DRM mechanisms may overburden the already resourceconstrained wireless networks.

The objective of this solicitation is to encourage cuttingedge research in trust and digital rights management in wireless networks and systems. Dissemination of research results in formulating the trust and DRM issues, and emerging solutions in terms of technologies, protocols, architecture, and models are expected to contribute to the advancement of this field in a significant way. Topics of interests include but are not limited to:

- DRM issues (copyright protection, tracking, tracing, fingerprinting, authentication, concealment, privacy, access control, etc.) in wireless multimedia
- Wireless multimedia traffic modeling, analysis, and management
- Tradeoff between QoS, security, dependability, and performability requirements
- Context, behavior, and reputation specification, modeling, identification, and management
- Trust and DRM models, architectures, and protocols
- Trust and DRM in applications (telemedicine, ubiquitous commerce, etc.)
- Trust and DRM in wireless ad hoc, mesh, sensor and heterogeneous networks
- Trust and DRM technologies for wireless multimedia (digital watermarking, encryption, coding, and compression, and their interplay)
- Test beds for experimental evaluation of trust and DRM models.

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EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING

Special Issue on Multimedia over Wireless Networks

Call for Papers

Scope

In recent years there has been a tremendous increase in demand for multimedia delivered over wireless networks. The design and capabilities of the mobile devices and the services being offered reflect the increase in multimedia usage in the wireless setting. Applications that are in the process of becoming essential to users include video telephony, gaming, or TV broadcasting. This trend creates great opportunities for identifying new wireless multimedia applications, and for developing advanced systems and algorithms to support these applications. Given the nature of the channel and of the mobile devices, issues such as scalability, error resiliency, and energy efficiency are of great importance in applications involving multimedia transmission over wireless networks.

The papers in this issue will focus on state-of-the-art research on all aspects of wireless multimedia communications. Papers showing significant contributions are solicited on topics including but are not limited to:

- Error resilience and error concealment algorithms
- Rate control for wireless multimedia coding
- Scalable coding and transmission
- Joint source-channel coding
- Joint optimization of power consumption and rate-distortion performance
- Wireless multimedia traffic modeling
- Wireless multimedia streaming
- Wireless multimedia coding
- QoS for wireless multimedia applications
- Distributed multimedia coding

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EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING

Special Issue on

Cognitive Radio and Dynamic Spectrum Sharing Systems

Call for Papers

Aims and Scope of the Special Issue

The ever-growing need for wireless communications which provide high data rates entails a substantial demand for new spectral resources and more flexible and efficient use of existing resources. Several measurement campaigns conducted in the recent years show that frequency spectrum in the range 30 MHz-3 GHz is most of the time unused leading to low average occupancy rates and motivating to allow more flexible spectrum use. Promising solution to exploit spectrum in a flexible way is via cognitive radio and dynamic spectrum sharing systems which use innovative spectrum management and allow different systems to share the same frequency band. Significant potential improvements offered with such approaches and also positive view from regulatory bodies have led to exploding interest in this field recently. However, such paradigm shift introduces many new design challenges that have to be solved in order to enable proper functioning of the spectrum sharing and cognitive radio systems. Recent research efforts include considerations of different physical layer technologies, spectrum sensing, coexistence mechanisms between legacy and secondary users, and shared medium access among many secondary users.

The objective of this special issue is to showcase the most recent developments and research in this field, as well as to enhance its state-of-the-art. Original and tutorial articles are solicited in all aspects of cognitive radio and spectrum sharing including system and network protocol design, enabling technologies, theoretical studies, practical applications, and experimental prototypes.

Topics of Interest:

Topics of interest include, but are not limited to:

- Spectrum measurements and current usage
- Spectrum regulations
- Spectrum sensing and awareness techniques
- Dynamic spectrum management
- Capacity and achievable data rates in cognitive radio
- Multiuser spectrum sharing:
    - Priority resource allocation
    - Cooperation and competition of users
    - Auction-based spectrum sharing
- Coexistence of spectrum sharing and legacy narrowband systems
- Physical layer design of spectrum sharing systems:
    - OFDM, OQAM, UWB, CDMA, SDR
    - MIMO component in spectrum sharing
- Applications of cognitive radio & spectrum sharing
- Standardization of cognitive radio and spectrum sharing: IEEE P1900, IEEE 802.22, ITU-R activities

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Special Issue on Radio Frequency Identification

Call for Papers

The International Journal of Antenna and Propagation (IJAP) is publishing a special issue on radio frequency identification (RFID) technologies. RFID systems are used for electronically identifying, locating, and tracking products, animals, vehicles. Passive tags (transponders) do not have a battery and have limited range, typically about one meter. Active tag systems have a power source and much longer range. Current RFID research and development include theory, antenna design, wireless communication, networking, system-on-chip IC development, database management, propagation theory, signal processing, embedded system design, and more.

This special issue is to present new RFID-related techniques to address theoretical and technical implementation challenges

Papers that reflect the current and future methods are solicited.

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

- Reader and tag antennas
- Metallic object tag antenna design
- RF- and antenna-related techniques to improve the recognition rate of RFID
- Miniaturization of tag antenna
- Reading range for different antennas
- RFID measurements and modeling
- Printable tag design and analysis
- Active and passive tag antennas
- Location technologies
- RFID near-field and far-field analyses
- RFID impedance matching and related topics
- Smart label tag antennas
- RFID and USN system (ubiquitous sensor network)

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Special Issue on Ultra-Wideband Antennas

Call for Papers

"Over the last few years much has been published about the principles and applications of electromagnetic waves with large relative bandwidth, or nonsinusoidal waves for short. The next step is the development of the technology for the implementation of these applications. It is generally agreed that the antennas pose the most difficult technological problem."

Henning F. Harmuth,
Antennas and Waveguides for Nonsinusoidal Waves,
Academic Press, New York, 1984, p. xi.

More than twenty years after Harmuth's observations on the difficulties posed by UWB antenna design and five years after the FCC authorized ultra-wideband (UWB) systems, a variety of UWB products is nearing wide-scale commercialization. Antenna designers and engineers have solved the UWB antenna problem in many ways, yielding compact antennas well-suited for a variety of applications. Unlike in previous decades when UWB antenna progress came in fits and spurts, today there is an active and growing community of UWB antenna designers sharing their insights and designs at professional conferences, trade shows, and in the pages of technical journals. The time is ripe for a special issue on UWB antennas that captures this progress and provides insight to where UWB antenna design will go in the future.

UWB systems have opened up new dimensions of antenna design. Antennas have become an organic part of RF systems, providing filtering and other custom-designed frequency-dependent properties. The wide bandwidths of UWB antennas present new challenges for design, simulation, and modeling. Optimizing UWB antennas to meet the demands of UWB propagation channels is similarly challenging. And as always, consumer applications demand compact and aesthetically pleasing designs that must nevertheless perform. Designers are meeting these challenges with novel antenna designs and novel materials. Designers are also using concepts like polarization diversity, directivity arrays, and electric-magnetic element combinations.

The goal of this special issue is to present the state of the art in UWB antenna engineering and to address the many ways in which UWB antenna designers are understanding and meeting the challenges of UWB design. Topics of interest include (but are by no means limited to):

- UWB antennas, including analysis, design, development, measurement, and testing
- Novel types of UWB antennas
- Adaptations of well-known UWB antennas that yield novel results
- Novel materials for use with UWB antennas
- Applications of UWB antennas
- Design and simulation techniques for UWB antennas and UWB propagation
- Safety and public policy related to UWB antennas and propagation
- UWB propagation channels
- Measurement methods for UWB antennas and propagation
- Challenges and anticipated needs in UWB antennas and propagation research and development
- History of UWB antennas and their development.

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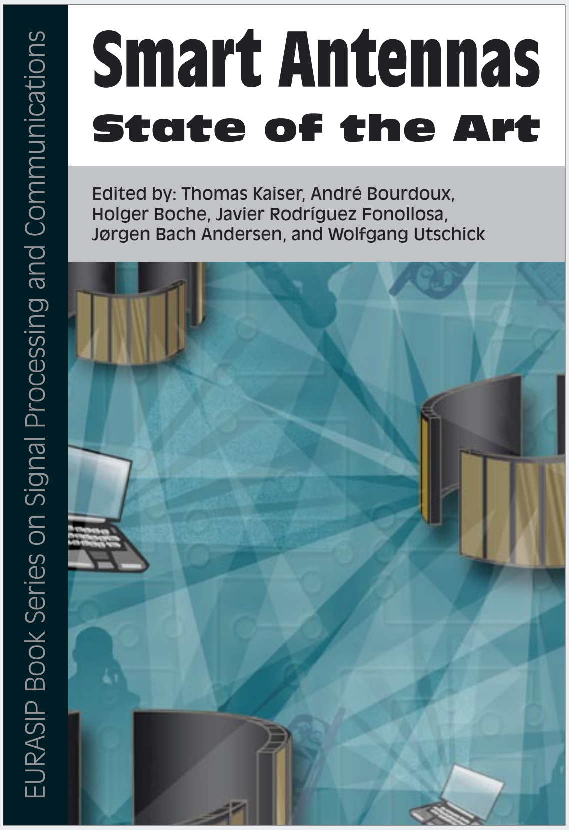
EURASIP Book Series on Signal Processing and Communications

SMART ANTENNAS—STATE OF THE ART

Edited by: Thomas Kaiser, André Bourdoux, Holger Boche,
Javier Rodríguez Fonollosa, Jørgen Bach Andersen, and Wolfgang Utschick



Smart Antennas—State of the Art brings together the broad expertise of 41 European experts in smart antennas. They provide a comprehensive review and an extensive analysis of the recent progress and new results generated during the last years in almost all fields of smart antennas and MIMO (multiple input multiple output) transmission. The following represents a summarized table of content.

Receiver: space-time processing, antenna combining, reduced rank processing, robust beamforming, subspace methods, synchronization, equalization, multiuser detection, iterative methods

Channel: propagation, measurements and sounding, modeling, channel estimation, direction-of-arrival estimation, subscriber location estimation

Transmitter: space-time block coding, channel side information, unified design of linear transceivers, ill-conditioned channels, MIMO-MAC srategies

Network Theory: channel capacity, network capacity, multihop networks

Technology: antenna design, transceivers, demonstrators and testbeds, future air interfaces

Applications and Systems: 3G system and link level aspects, MIMO HSDPA, MIMO-WLAN/UMTS implementation issues

This book serves as a reference for scientists and engineers who need to be aware of the leading edge research in multiple-antenna communications, an essential technology for emerging broadband wireless systems.

For any inquiries on how to order this title please contact books.orders@hindawi.com

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3DTV CONFERENCE 2007

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First Call For Papers

Creating exact 3D moving images as ghost-like replicas of 3D objects has been an ultimate goal in video science. Capturing 3D scenery, processing the captured data for transmission, and displaying the result for 3D viewing are the main functional components. These components encompass a wide range of disciplines: imaging and computer graphics, signal processing, telecommunications, electronics, optics and physics are needed.

The objective of the **3DTV-Conference** is to bring together researchers and developers from academia and industry with diverse experience and activity in distinct, yet complementary, areas so that full scale 3D video capabilities are seemlessly integrated.

Topics of Interest

3D Capture and Processing
- 3D time-varying scene capture technology
- Multi-camera recording
- 3D photography algorithms
- Synchronization and calibration of camera arrays
- 3D view registration
- Multi-view geometry and calibration
- Holographic camera techniques
- 3D motion analysis and tracking
- Surface modeling for 3-D scenes
- Multi-view image and 3D data processing

3D Transmission
- Systems, architecture and transmission aspects of 3D
- 3D streaming
- Error-related issues and handling of 3d video
- Hologram compression
- Multi-view video coding
- 3D mesh compression
- Multiple description coding for 3D
- Signal processing for diffraction and holographic 3DTV

3D Visualization
- 3D mesh representation
- Texture and point representation
- Object-based representation and segmentation
- Volume representation
- 3D motion animation
- Dense stereo and 3D reconstruction
- Stereoscopic display techniques
- Holographic display technology
- Reduced parallax systems and integral imaging
- Underlying optics and VLSI technology
- Projection and display technology for 3D videos
- Human factors

3D Applications
- 3D imaging in virtual heritage and virtual archaeology
- 3D Teleimmersion and remote collaboration
- Augmented reality and virtual environments
- 3D television, cinema, games and entertainment
- Medical and biomedical applications
- 3D Content-based retrieval and recognition
- 3D Watermarking

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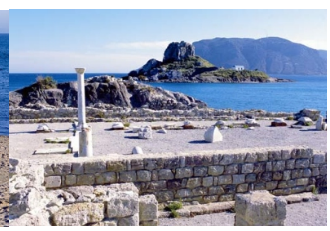
Prospective contributors are invited to submit full papers electronically using the on-line submission interface, following the instructions available at http://www.3dtv-con.org. Papers should be in Adobe PDF format, written in English, with no more than four pages including figures, using a font size of 11. Conference proceedings will be published online by the IEEE.

Important Dates

1 December 2006	Special sessions and tutorials proposals
15 December 2006	Regular Paper submission
9 February 2007	Notification of acceptance
2 March 2007	Submission of camera-ready papers

3DTV NoE — ITI-CERTH — Information Society Technologies — Institute of Electrical and Electronics Engineers — European Association for Signal and Image Processing





The International ITG / IEEE Workshop on Smart Antennas WSA 2007 February 26-27, 2007 Vienna

Call for Papers

The International ITG / IEEE Workshop on Smart Antennas WSA 2007 provides a forum for presentation of the most recent research on smart antennas. The objective is t o continue, accelerate, and broaden the momentum already gained with a series of ITG Workshops held since 1996: Munich and Zurich'96, Vienna and Kaiserslautern'97, Karlsruhe' 98, Stuttgart'99, Ilmenau'01, Munich'04, Duisburg'05, and Ulm'06. This call for papers intends to solicit contribu-tions on latest research of this key technology for wireless communication systems.

Workshop topics include, but are not limited to:

- Antennas for beamforming and diversity
- Channel measurements
- Spatial channel modeling
- Beamforming
- Diversity concepts
- Space-time processing
- Space-time codes
- MIMO Systems
- Multicarrier MIMO
- Multiuser MIMO
- Cooperative and sensor networks
- Crosslayer optimisation
- Radio resource management
- Cellular systems
- Link, system and network level simulations
- Hard- and software implementation issues

There will be oral as well as poster presentations.
The workshop will be jointly organized by the Institute of Communications and Radio Frequency at Vienna University of Technology and the ftw. Telecommunications Research Center Vienna in cooperation with the VDE, ÖVE, and the IEEE on February 26-27, 2007 in Vienna, Austria

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CALL FOR PAPERS

3rd IET/EURASIP Conference on

DSP *enabled* Radio

Glasgow, Scotland, UK

13th/14th September 2007

`http://www.DSPenabledRadio.org`

In the past decade, digital signal processing (DSP) algorithms and architectures for baseband processing have brought applications such as 3G mobile communications and wireless LAN to mass markets. Since then, further progress in DAC and ADC technology has permitted DSP to be applied at IF sampling rates up to several 100 MHz, which has opened up a large range of advanced DSP algorithms to be deployed for – potentially reconfigurable – communications system functions such as modulation, synchronisation, equalisation, coding, and many more. This development is expected to continue, and opportunities such as software defined radio (SDR) architectures forming the basis for cognitive radios for improved spectrum efficiency and reliable and ubiquitous communication are likely to become reality within the next couple of years.

This 2 day event forms a continuation of two previous conferences of identical title held in Livingston, Scotland, in 2003, and in Southampton in 2005, which were each attended by more than 120 international researchers and industrialist. Both events were co-sponsored by the Institution of Engineering and Technology (IET — formerly the Institution of Electrical Engineers, IEE) and the European Association for Signal Processing (EURASIP). This third conference IET/EURASIP will comprise of an invited keynote speaker, a number of invited contributions on key topics, oral presentations, poster sessions, and a small industrial exhibition for companies demonstrating the latest hardware and software for DSP enabled radio. Prospective authors are invited to submit original contributions on all aspects of DSP enable radio, including, but not limited to:

- hardware platforms
- mixed signal techniques
- application case studies
- sample rate conversion
- RF and IF processing
- ultra-wideband radio
- standards, IEEE802.1x
- SDR implementation
- FPGA architectures
- system-on-chip
- rapid prototyping
- cognitive radio
- power control
- RF linearisation
- Tx/Rx beamforming
- MIMO systems
- algorithms and architecture
- digital up/downconversion
- standards and inter-operability
- emerging standards: WiMAX etc
- synchronisation and equalisation
- equalisation / channel estimation
- beamforming/smart antennas
- wireless sensor / ad-hoc networks

Papers will be reviewed on the basis of a two page extended abstract of sufficient detail to permit reasonable evaluation. The deadline for submission is June 29, 2007, with notification of decision by July 20, 2007. Accepted papers will be edited into a bound digest of the event, available on CD, and be included in IEEExplore. The cover page of the summary should include paper title, names of authors and their affiliation, as well as the complete address, telephone numbers and e-mail of the corresponding author.

Detailed information on the extended abstract and paper submission, technical program, accommodation, and travel will be posted on the conference web site `http://www.DSPenabledRadio.org`.

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Stephan Weiss and Eugen Pfann, Technical Co-Chairs
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The First International
EURASIP Workshop on RFID Technology

RFID 2007

24 - 25 September 2007, Vienna, Austria

Call for Papers

The first international EURASIP workshop on RFID technology will provide a premium forum for presentation of the most recent research in this new technology. The objective is to continue, accelerate, and broaden the momentum already gained in this field. This call for papers intends to solicit contributions on the latest research of this new technology for wireless communication systems, spanning from the individual tag to entire systems based on RFIDs.

Internet page
http://rfid07.ftw.at

Important Dates

Paper submission	**31. May 2007**
Author notification	02. July 2007
Final manuscript due	19. July 2007

Organizing Committee
Markus Rupp, TU Vienna
Holger Arthaber, TU Vienna
Pavle Belanović, ftw.

Technical Program Committee
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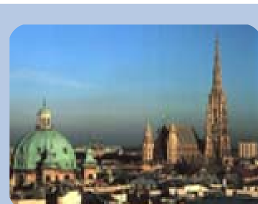
Robert Weigel, U. of Erlangen-Nuremberg
Klaus Witrisal, TU Graz
Johannes Wolkerstorfer, TU Graz
Horst Zimmerman, TU Vienna

Workshop topics include, but are not limited to:
- Electromagnetic field measurements
- Antenna design
- Multiple antenna systems
- Modulation schemes for RFID
- Security and privacy issues
- Link, system, and network level simulations
- Hardware and software implementation issues
- Inductive coupling for DC supply
- Multi-frequency and broadband tags
- Smart tags, programmable tags, and embedded systems
- Sensor tags and RFID for asset tracking and localization
- Advances in passive long range RFID technology
- Manufacturing processes for RFID tags
- Applications and industrial experience

Submission Guidelines
Authors are encouraged to submit original, unpublished work for presentation at the workshop in the form of posters and full papers. Acceptance shall be based on an extended abstract of two pages in the standard IEEE conference format.

Workshop Venue
The workshop will be held in Vienna, Austria, at the Telecommunications Research Center Vienna (ftw.).



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