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# Adaptive channel precoding for personal communications

W. Zhuang, W.A. Krzymein and P.A. Goud

A novel adaptive channel precoder is proposed to improve the bit
error rate performance of a personal wireless communication
system, without increasing the complexity of the portable unit,
over a slowly fading channel with severe intersymbol interference.

*Introduction:* In high bit rate personal communication systems, the
intersymbol interference (ISI) due to multipath can dramatically
increase the transmission bit error rate (BER). The decision-feed-
back equaliser (DFE) is the most popular equaliser for combatting
ISI. When coded modulation is used to improve the system per-
formance, the combination of coding with the DFE does not per-
form well because zero delay decisions in a coded system are not
sufficiently reliable for decision feedback. The problem can be
solved without increasing the complexity of the portable unit by
moving the equalisation function from the receiver of the portable
unit to the transmitter of the base station. Harashima-Tomlinson
(HT) precoding is a transmitter equalisation technique which is
very suitable for QAM modulation [1]. However, the precoding
technique is not very suitable for time-varying fading channels, for
which amplitude fading causes difficulty in retrieving the original
amplitude information in the receiver; in particular when an
amplitude limiter is used at the receiver with constant-envelope
phase modulation, the use of modulo-arithmetic reduction to
recover the original transmitted signal is impossible. This Letter
proposes a new adaptive channel precoding technique for phase
modulation, which predistorts both the carrier phase and ampli-
tude of the transmitted signal in such a way that the signal arriv-
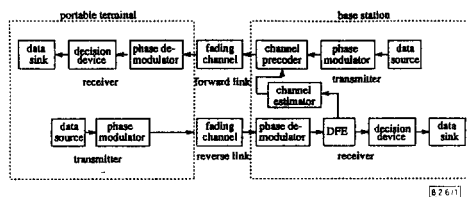ing at the receiver is ISI free.



**Fig. 1** *Functional block diagram of system model*

*System description:* Fig. 1 is a functional block diagram of the sys-
tem model. The system operates in a time-division multiple access
(TDMA) time-division duplex (TDD) scheme. An indoor radio is
characterised by Rayleigh distributed amplitude fading, uniformly
distributed carrier phase jitter, and propagation delay spread due
to multipath. In the reverse link, an adaptive DFE is used in the
base station receiver to reduce the ISI. The channel estimator esti-
mates the channel impulse response based on the tap coefficients

of the DFE, which is then used in the precoder of the base station
transmitter to predistort the signal transmitted in the forward link
so that the signal received at the portable terminal is ISI free. The
precoding is based on the fact that the indoor radio channel fades
so slowly that changes in the fading characteristics over the dura-
tion of one frame of data can be neglected. When the fading chan-
nel is not minimum-phase, a nonlinear operation is necessary to
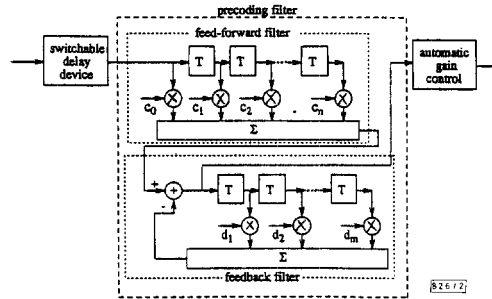achieve stability in the precoder.



**Fig. 2** *Structure of channel precoder*

*Adaptive channel precoding:* Fig. 2 shows the structure of the adap-
tive channel precoder. The switchable delay device (SDD) is con-
trolled in such a way that the precoder always introduces a
constant time delay to the received signal. The precoding filter
(PE) consists of feedforward (FF) and feedback (FB) linear filters.
Two examples are studied here: The first is a fading channel (at
time $t_1$) with a minimum-phase transfer function $H_1(z) = 0.8(1 +
0.5z^{-1})(1 + 0.3z^{-1})$. The PF transfer function $F_1(z)$ can be simply set
as the inverse of the channel transfer function, i.e. $F_1(z) = 1/H_1(z)$.
The PF filter allows only the frst path signal (ISI free) to arrive at
the receiver. The second is a fading channel (at time $t_2$) with a
non-minimum-phase transfer function $H_2(z) = 0.4(1 + 0.5z^{-1})$
$(1 + 20z^{-1})$. We use an FB filter with transfer function $F_{21}(z) = 1/
[0.4(1 + 0.5z^{-1})]$ to equalise the minimum-phase component, and a
(four-tap) FF filter with transfer function $F_{22}(z) = (-0.0625 +
0.125^{-1} - 0.25z^{-2} + 0.5z^{-3})$ to equalise the non-minimum-phase
component [2]. The PF filter $F_2(z) = F_{11}(z)F_{22}(z)$ introduces a time
delay of $4T$ to the received signal (here $T$ is the unit time interval,
which can be smaller than or equal to a symbol interval). To
reduce the diiference in time delays introduced by the filters $F_1(z)$
and $F_2(z)$, we modify the PF filter $F_1(z)$ to $F_1'(z) = z^{-3}F_1(z)$, so that
the delay introduced by $F_1'(z)$ is $3T$. As a result, the delay differ-
ence of the precoders corresponding, respectively, to $H_1(z)$ and
$H_2(z)$ is reduced to $T$. The delay of the SDD is set at $T$ for $H_1(z)$,
but is reduced to zero for $H_2(z)$; therefore, the precoder introduces
a constant time delay to the transmitted signal. Generally, for a
minimum-phase channel, the tap coefficients of the FF filter, $c_0$,
$c_1, ..., c_{n-1}$, are zero except $c_n$ of the last tap; the delay introduced
by the PF is $(n - 1)T$. For a non-minimum-phase channel, the
equivalent delay introduced by the precoder will be equal to or
larger than $nT$ depending on the non-minimum-phase component.

The precoded signal may have amplitude fluctuations depending
on the fading channel. The automatic gain control (AGC) unit is
used to suppress the fluctuations and to keep the transmitted
power constant, which may slightly degrade the performance
improvement achieved by the PF filter. All the precoding func-
tions are implemented in the transmitter only, and no additional
functions need to be performed in the receiver for equalisation
purposes, which is different from the HT precoding technique.
Consequently, using an amplitude limiter in the receiver does not
degrade the performance improvement achieved by the precoding
technique proposed here. Based on the impulse response estimated
in the reverse link over the previous data frame, an adaptive algo-
rithm should be applied to obtain the complex tap coefficient
arrays of the FF and FB filters for the current data frame, because
the channel impulse response over two adjacent data frames can
be considered as invariant for a slowly fading channel and the
radio channel is reciprocal in a TDD system. The channel precod-
ing is not subject to error propagation, which is an advantage of
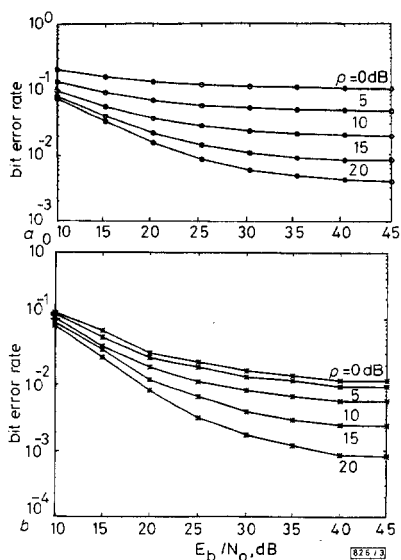the precoder over conventional DFE.

2 CLARK, A.P.: 'Equalizers for digital modems' (Pentech Press, London, 1985)

**Fig. 3** *BER performance over Rayleigh slowly fading two-path channel*

*Performance evaluation:* Fig. 3 shows the BER performance of differential QPSK (DQPSK) over a two-path time-variant Rayleigh fading channel. It is assumed that both the DFE and precoder (with a 15 tap FF filter) have perfect channel information. The propagation delay between the two paths is one symbol interval $T$. The normalised fading rate is $10^{-4}$. $E_b$ is the ensemble average of received signal energy per bit from all multiple paths. $\rho$ is the ratio of the average power of the first path to that of the second path. For a low value of $\rho$, DQPSK with DFE has a high BER error floor due to the severe ISI and its inherent error propagation. DQPSK with the channel precoder achieves significantly lower BER because the precoder is not subject to error propagation. It should be mentioned that even with $\rho = 20$dB, non-minimum-phase channel impulse responses occur from time to time during the simulation because it is possible that the instantaneous power of the second path is larger than that of the first path (when the first path signal experiences deep fading). When the amplitude of the second-path signal is approximately equal to that of the first-path signal, a large number of taps should be used in the FF filter of the precoder in order to equalise the channel completely; otherwise, no perfect precoding can be obtained (which limits the BER performance improvement obtained by the precoder). The BER performance with a channel precoder can be improved further if the number of taps in the FE filter is increased.

*Conclusions:* The newly proposed channel precoder can improve the system BER performance significantly. The precoder uses a linear filter with complex tap coefficients to predistort both the amplitude and phase of the transmitted signal carrier, a switchable delay device to achieve a constant time delay introduced by the precoder, and an AGC unit to eliminate the possibility of an instantaneous transmitted power increase due to the signal predistortion.

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## Analysis and dimensioning of a unidirectional WDM optically amplified open ring network using channel tap-and-add devices

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*Indexing terms: Mobile radio systems, Code division multiple access*

A unidirectional, WDM optically amplified open ring network is analysed using a commercial software package. Optimisation of the ring configuration is performed under the constraint of high and nearly equal SNRs for all channels. For eight nodes, the maximum ring length is shown to be greater than 500km.

*Introduction:* Recently, many WDM ring architectures have been proposed for implementing uni- and bidirectional self-healing SDH rings [2, 3]. The WDM rings use an optical amplifier and a wavelength add drop multiplexer (ADM) at each node which perform dynamic wavelength routing and allow the network to be transparent to the signal format and the bit rate. We analyse a unidirectional open WDM ring network linking a main station to a small number of secondary nodes (eight) suited for the junction or regional network layer. This configuration (Fig. 1) permits wavelength sharing between different stations because the wavelengths circulating along the open ring are not removed. The bit rates under consideration are 155Mbit/s, 622Mbit/s and 2.5Gbit/s. The number of wavelengths sent by the main station is equal to the number $N$ of secondary stations. The main station receives $2N$ wavelengths.
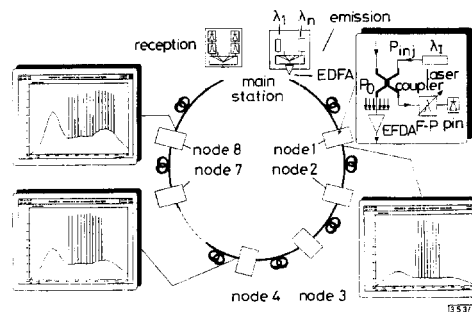


**Fig. 1** *Configuration of unidirectional open ring network*

Optical signal spectra at the output of the first, fourth and eighth stations are shown

Our simulation package [1] is able to determine the optimal values of the link loss between amplifiers, input power at the nodes, wavelength arrangement, and unsaturated small signal gain of the EDFA, that are needed to maintain a high and nearly equal SNR for all channels [4].

*Simulation description:* The signal and ASE power accumulation along the EDFA chain are computed using a spectrally resolved model [5]. We use the Er:Al:Ge:silicate fibre described in [6]. The erbium-fibre length is chosen to provide 24dB small signal gain with a 30mW, 1.48μm pump. The link losses between the amplifiers include fibre and passive coupler attenuations. The optical booster amplifier of the main station allows us to obtain an optical power of +6dBm for each channel. The link loss between this amplifier and the input to the first in-line amplifier (at station 1) is 21dB (17dB fibre attenuation 0.2dB/km × 85km, and 4dB insertion loss in the coupler). The power per channel at the input to the