

Channel Modeling and Adaptive Equalization of Indoor Radio Channels

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Abstract—This paper analyzes the benefits of using a decision feedback equalizer (DFE) in the indoor radio environment and examines the results of performance predictions for different channel modelings. It is found that a QPSK/DFE modem with second-order diversity can operate at a data rate which is an order of magnitude higher than a QPSK modem without equalization. A given set of measured profiles of the channel impulse response is interpreted using continuous and discrete channel models. The continuous channel model is represented by the delay power spectrum and the discrete channel model by the envelope delay power spectrum and the arrival rate of the paths. The sensitivity of the performance to the shape of the delay power spectrum, the shape of the envelope delay power spectrum, and the arrival rate of the paths is analyzed.

INTRODUCTION

THIS paper investigates high speed (wideband) data transmission over the indoor radio channel using adaptive equalization and compares the results to those obtained over an unequalized channel. The existing performance predictions for various communication techniques are either based on a continuous or a discrete channel model. This paper compares performance predictions for both channel models and justifies the differences.

To avoid expensive installation and relocation costs and to provide portability to various pieces of equipment, the concept of wireless indoor communication networks suggests itself as a replacement for wired data communication networks. Recently, both infrared and radio frequency communications have been examined for this purpose [1], [2]. Research in radio frequency communications is concentrated on channel measurements [3], [4] and transmission problems both for spread spectrum [5], [6] and standard modulation techniques [7].

Communication network applications demand very high data rates, but the data rate in indoor channels is bounded due to multipath and fading [7], [8]. To improve the data rate, performance enhancement techniques such as external diversity, coding, and spread spectrum have been studied [5]–[7]. Another method of improving the data rate is to use adaptive equalization. The advantage of adaptive equalization over coding and spread spectrum is

that a modem with adaptive equalization provides high data rates without any loss in bandwidth efficiency. The decision feedback equalizer (DFE) has been shown to improve the performance of digital communication systems over various fading multipath channels such as troposcatter [9], HF [10], and microwave line-of-sight [11], [12]. This paper shows that the use of an adaptive DFE in the receiver in indoor channels can result in high-speed transmission in which the bandwidth of the transmitted signal is about the same as the coherent bandwidth of the channel. This data rate is an order of magnitude higher than similar systems with no equalizer.

The existing performance predictions for narrowband and wideband spread spectrum data communication systems either use a continuous [7], [8] or a discrete model [5], [6] to represent the channel. In the continuous model, the channel is represented by a unique correlation function referred to as the delay power spectrum. This type of modeling has been adopted for performance prediction over troposcatter [9], urban mobile radio [13], and indoor radio [7], [8] channels. In the discrete channel model, first suggested for urban mobile radio [14], the received power is assumed to be at discrete delay values and existence of the paths at various delays forms a Poisson process. The discrete channel model is represented by the envelope delay power spectrum and the mean arrival rate of the paths. Recent wideband indoor radio measurements are based on the discrete channel model [3], and it has been adopted for performance prediction of wideband indoor spread spectrum systems [5], [6].

Section I describes the modeling of the channel in a continuous or a discrete form. Using both models, the performance of a QPSK modem with diversity is found in Section II. Finally, in Section III, the usefulness of channel equalization is shown by examining the performance of a QPSK/DFE modem. The influence of the arrival rate of the paths and the shape of the delay power spectrum on the performance of QPSK and QPSK/DFE modems is demonstrated in both Sections II and III. Section IV provides the conclusions.

I. CHANNEL MODELING

In indoor communications, frequencies around 1 GHz are attractive for the establishment of a transmission band [2], [3], [15]. At lower frequencies, available bands are restricted, longer antennas are required, and antenna separation for diversity is large. Higher frequencies suffer

Manuscript received January 20, 1988; revised September 15, 1988. This paper was presented in part at the 1988 IEEE Milcom Conference, San Diego, CA, October 1988.

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IEEE Log Number 8824958.

severe attenuation, design difficulties, and a possible health threat.

Deterministic analysis of radio propagation in indoor channels is not possible, and one must resort to statistical analysis. The statistics of the channel variables are determined by studying the structure of the arriving paths for various locations of the transmitter and the receiver in an indoor environment. For a fixed transmitter and receiver, with no moving objects close to the transmitter or receiver, the indoor environment for radio propagation is a pure multipath channel. This can be observed by transmitting a narrow pulse (the pulse should be much more narrow than the multipath spread of the channel) and observing the received pulses which constitute a multipath profile [3]. As the location of the transmitter or the receiver is changed or as a moving object passes near them, the multipath profile changes. A collection of these profiles from various locations within a building can be used for statistical channel modeling.

There are both continuous and discrete methods available for interpretation of a collection of profiles for mathematical channel modeling. Discrete channel modeling is more convenient and natural for channel measurement and computer simulation [16], but mathematical analysis using continuous channel modeling is more tractable [7]–[9]. An important difference between the two models is the assumption made about how many paths are present in the channel and when they occur (in delay). Continuous channel modeling uses the average received power at every delay of interest. Discrete time models specify a random number of paths at random delays arising from a Poisson process. This random element is averaged out in the formation of a continuous channel model.

In continuous channel modeling, the channel is assumed to be wide sense stationary uncorrelated scattering (WSSUS) and characterized by its delay power spectrum $Q(\tau)$ defined as

$$\overline{h(\tau) h^*(\tau + x)} = Q(\tau) \delta(x) \quad (1)$$

where $h(\tau)$ is the equivalent low-pass impulse response of the channel, δ is the Dirac delta function, and the averaging is done over the profiles. Each impulse response is a sample of the channel between a particular location of the transmitter and the receiver at the time of measurement. The stationarity of the channel is assumed in neglecting the time and location at which the impulse response is measured.

There is a difference between our interpretation of a WSSUS channel and that of the original definition of these channels employed for troposcatter channels [17]. In troposcatter, the cause of multipath fading is motion of microscopic scatterers in the medium and fading occurs for fixed transmitter and receiver. For indoor channels, however, the multipath fading is caused by relocating the transmitter (or receiver) or having people or objects moving about in the vicinity of either of them.

For an indoor channel represented by a unique continuous delay power spectrum $Q(\tau)$, the rms multipath

spread is defined as

$$\tau_{\text{rms}} = \left(\frac{\int_0^\infty [\tau - W]^2 Q(\tau) d\tau}{\int_0^\infty Q(\tau) d\tau} \right)^{1/2} \quad (2.a)$$

where

$$W = \int_0^\infty \tau Q(\tau) d\tau. \quad (2.b)$$

Measured values of τ_{rms} of around 50 ns have been reported for indoor radio channels [3].

In the discrete channel model, the complex envelope of the channel impulse response at a given time is represented by [14]

$$h(\tau) = \sum_{k=0}^L \alpha_k \delta(\tau - \tau_k) \exp(-j\theta_k). \quad (3)$$

The transmitted impulse $\delta(\tau)$ is received as the sum of $L + 1$ paths. The existing indoor radio channel measurements [3], [4] suggest that the amplitudes α_k are Rayleigh distributed, the phases θ_k are uniformly distributed, and the arrival times τ_k form a Poisson process with average arrival rate λ . The constant parameter λ can be interpreted as the average number of paths per second [18]. Path strength is a random variable whose variance $E(\alpha_k^2)$ is determined by evaluating the envelope delay power spectrum $C(\tau)$ at τ_k . The model is specified by assigning a value to the mean arrival rate λ and determining an envelope delay power spectrum $C(\tau)$. In comparison, the continuous time model is represented with a unique delay power spectrum $Q(\tau)$.

For a given set of measured channel profiles in an office environment, there are two methods to relate the delay power spectrum $Q(\tau)$ and the envelope delay power spectrum $C(\tau)$. One is to divide all profiles into subclasses where in each subclass the presence or absence of a path at a given delay is the same. The profiles in each subclass represent a continuous channel which is modeled with a discrete delay power spectrum and an associated rms multipath spread. To relate the entire set of profiles, the rms multipath spread of each subset of profiles is treated as a random variable and its probability density function is determined. The density of the rms multipath spread is then a function of the arrival rate of the paths λ . In this case, to relate the delay power spectrum $Q(\tau)$ and the envelope delay power spectrum $C(\tau)$, one can claim that, as λ approaches infinity, power exists at all delays in all profiles and there is only one class with one delay power spectrum $Q(\tau)$ which is the same as $C(\tau)$. The second method is to treat the channel as continuous, take the average received power over all profiles for all delay values of interest, and use the result as the delay power spectrum $Q(\tau)$. In this case, regardless of the arrival rate, the delay power spectrum is the same as the envelope delay power spectrum.

For a discrete channel model represented by $C(\tau)$ and λ , the rms multipath spread for a subclass of profiles is determined from

$$\tau_{\text{rms}}^\lambda = \left(\frac{\sum_{k=0}^L (\tau_k - \bar{\tau})^2 C(\tau_k)}{\sum_{k=0}^L C(\tau_k)} \right)^{1/2} \quad (4a)$$

$$\bar{\tau} = \sum_{k=0}^L \tau_k C(\tau_k) \quad (4b)$$

where τ_k is a random variable representing Poisson arrivals with mean rate λ . The $\tau_{\text{rms}}^\lambda$ is also a random variable whose measured values in indoor channels range from 20 to 250 ns [3], [4]. The direct calculation of the probability density function of this variable is difficult. In general, calculation of these density functions requires computer simulation.

Figs. 1 and 2 represent the probability density function of $\tau_{\text{rms}}^\lambda$ for a decaying exponential envelope delay power spectrum, for various values of the normalized arrival rate $\lambda\tau_{\text{rms}}$. The normalized arrival rate is the average number of paths received in a delay span equal to the rms multipath spread. The value of $\lambda\tau_{\text{rms}}$ depends on the building architecture, the material used in its construction, the type of furniture in the building, and the motion of people in the building. For typical rms multipath spreads of 20–50 ns and an average of one peak every 5 ns in the multipath profiles [$\lambda = 1/(5 \text{ ns})$], $\lambda\tau_{\text{rms}}$ has a value of 4–10 paths per unit rms multipath spread. For very large normalized arrival rates, the density of $\tau_{\text{rms}}^\lambda$ is close to an impulse located at a delay equivalent to the rms multipath spread ($E\{\tau_{\text{rms}}^\infty\} = \tau_{\text{rms}}$, where $E\{\cdot\}$ is the expectation operator). In this case, power is received at every delay almost surely, and the probability density function of $\tau_{\text{rms}}^\lambda$ is characterized by a single number. For very small values, each profile is frequently comprised of only one path, and the density is an impulse at the origin ($E\{\tau_{\text{rms}}^0\} = 0$). For intermediate values ($\lambda\tau_{\text{rms}}$ around 2 paths per unit rms multipath spread), the density takes on a bell shape; see Fig. 1. For $\lambda\tau_{\text{rms}}$ on the order of 0.2, the density contains two peaks; see Fig. 2. Although the envelope of the received power is the same for all values of $\lambda\tau_{\text{rms}}$, the average of $\tau_{\text{rms}}^\lambda$ over all profiles is different. As a result, the performance of a system will depend on $\lambda\tau_{\text{rms}}$.

II. PERFORMANCE PREDICTION FOR A QPSK MODEM

This section discusses the performance of a QPSK system with an overall 50 percent rolloff raised cosine spectrum for various data rates. The receiver uses maximal ratio combining and external diversity of order 2. First, the channel is represented with a continuous channel model, and the sensitivity of the analysis to the shape of the delay power spectrum is examined. Then, the sensitivity of the analysis to the rate of arrival of the paths in the discrete modeling of the channel is determined. For the calculation of P_e , similar to [13], [19], the average ISI

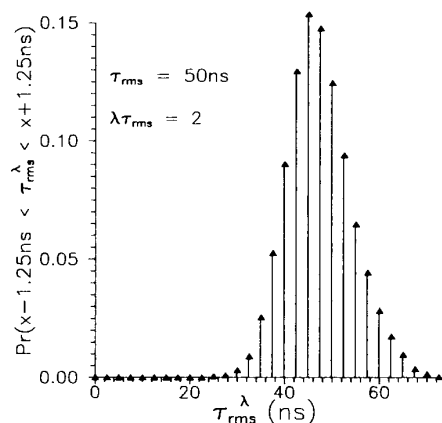


Fig. 1. Density of $\tau_{\text{rms}}^\lambda$ in discrete channel modeling of the indoor radio channel for the arrival rate of the paths of $\lambda\tau_{\text{rms}} = 2$.

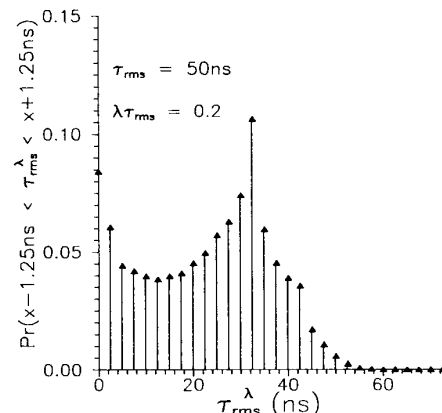


Fig. 2. Density of $\tau_{\text{rms}}^\lambda$ in discrete channel modeling of the indoor radio channel for the arrival rate of the paths of $\lambda\tau_{\text{rms}} = 0.2$.

power is treated as a source of additive Gaussian noise and the result is substituted in standard equations for the probability of error in a Rayleigh fading channel [20]. The sample timing is determined by using the average delay of the channel as in [7]

$$t_0 = \int_0^\infty \tau Q(\tau) d\tau. \quad (5)$$

Fig. 3 represents the average probability of error P_e versus energy per bit over the two sided spectral height of the noise E_b/N_0 . The curves are for normalized data rates of $\tau_{\text{rms}}R_b = 0.1$ and 0.01 with exponential and uniform delay power spectrums. For a typical value of $\tau_{\text{rms}} = 50 \text{ ns}$, these data rates are $R_b = 2 \text{ Mbits/s}$ and $R_b = 200 \text{ kbits/s}$. The data rate of 2 Mbits/s results in unacceptable error rates while the 200 kbits/s provides an error rate of 10^{-6} at $E_b/N_0 = 30 \text{ dB}$. Fig. 4 represents P_e versus normalized data for $E_b/N_0 = 20$ and 30 dB. Figs. 3 and 4 show that, for the meaningful probabilities of error, performance of the QPSK modem calculated for a continuous channel model is essentially independent of the shape of the delay power spectrum. This is in agree-

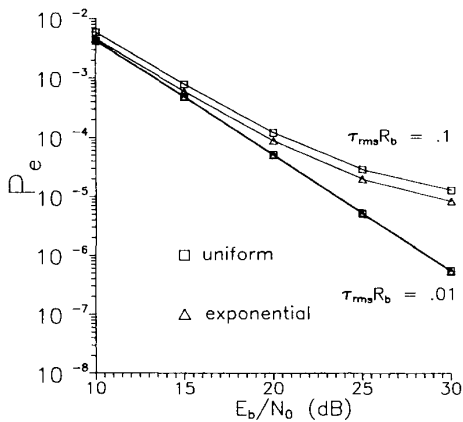


Fig. 3. Average probability of error versus E_b/N_0 for a QPSK modem using a continuous channel model. The delay power spectrum is assumed to be either exponential or uniform. The curves are for normalized data rates of $\tau_{rms}R_b = 0.01, 0.1$.

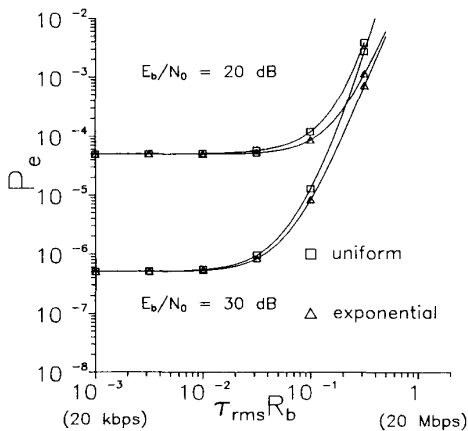


Fig. 4. Average probability of error versus normalized data rate for a QPSK modem, and $E_b/N_0 = 20$ dB, 30 dB. The channel is represented by a continuous model with either an exponential or uniform delay power spectrum.

ment with earlier work in [7] and [8] on the probability of outage.

A discrete channel model can be viewed as a combination of communication channel models with discrete delay power spectrums. As discussed in the last section, τ_{rms}^λ forms a random variable whose density function is given in Figs. 1 and 2. The density of the rms multipath spread is a function of the arrival rate of the paths λ . For a given channel identified with an arrival rate λ and envelope delay power spectrum $C(\tau)$, the average probability of error is the average of the Rayleigh averaged probability of errors over all subclasses of the discrete channel model. The probability of error for a given subclass of the profiles depends on the delay power spectrum of that particular subclass, and it is only a function of rms multipath spread of that subclass. Therefore, the average Rayleigh-averaged probability of error for a discrete channel model is determined from

$$\bar{P}_e = \int_0^\infty P_e(x) p_{\tau_{rms}^\lambda}(x) dx \quad (6)$$

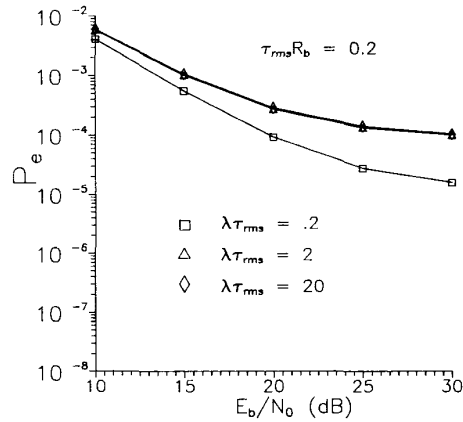


Fig. 5. Average Rayleigh-averaged probability of error versus E_b/N_0 for a QPSK modem and different arrival rates in a discrete channel model. The envelope of the delay power spectrum is exponential and the normalized data rate is $\tau_{rms}R_b = 0.2$.

where P_e is the average probability of error for a given value of rms multipath spread, and $p_{\tau_{rms}^\lambda}$ is the probability density function of the rms multipath spread for a particular arrival rate λ . Fig. 5 represents the average Rayleigh-averaged probability of error \bar{P}_e versus E_b/N_0 for the discrete channel model and different arrival rates of the paths. The data rate is normalized by τ_{rms} , and the envelope delay power spectrum $C(\tau)$ is assumed to be exponential. The rms multipath density functions given in Figs. 1 and 2 are used in the calculation of \bar{P}_e .

As shown in Fig. 5, for $\lambda\tau_{rms} > 2$, the performance does not change with the increase in the arrival rate. The difference among performances for $\lambda\tau_{rms} = 2, 20$, and ∞ are indistinguishable. As discussed in the last section, the case of $\lambda\tau_{rms} \rightarrow \infty$ associates with one delay power spectrum which is equivalent to continuous channel modeling. In summary, for a given set of profiles in a building, if the normalized arrival rate is more than 2, the envelope delay power spectrum can be used as the delay power spectrum for calculation of the probability of error of the QPSK modems. Otherwise, calculation of the error rate is affected by the arrival rate of the paths. For these arrival rates, the number of arriving paths are fewer, resulting in less ISI, a smaller rms multipath spread, and a better performance.

III. PERFORMANCE PREDICTION FOR QPSK/DFE MODEMS

This section examines the effectiveness of adaptive equalization in counteracting the multipath and fading of the indoor radio channel. The fading channel in indoor radio is frequency selective [21] and the performance degradation is due to the occasional deep nulls in the pass-band of the channel. Decision feedback equalizers have shown a performance superior to linear equalizers over frequency selective fading channels [9]–[12]. As a result, the discussions in this section are devoted to decision feedback equalization. The objective is to determine the data rate limitation for the channel when the QPSK re-

ceiver is equipped with an adaptive DFE equalizer, and the channel is represented by different channel models.

In fading multipath channels represented by a delay power spectrum $Q(\tau)$, a lower bound on the average probability of error of a QPSK/DFE modem is given by [9]

$$p_d = \frac{1}{2} \prod_{k=-k_1}^{k_2} \left(1 + \frac{E_b}{N_0} \lambda_k \right)^{-D} \quad (7.a)$$

where $k_1 + k_2 + 1$ is the number of forward filter taps, D is the external diversity, and the λ_k are the eigenvalues of the matrix $G^{-1}C(t_0)$. The elements of the matrix $C(t_0)$ are given by

$$C_{kl}(t_0) = \int_{u=-\infty}^{\infty} g(t_0 - k\tau_s - u) \cdot g(t_0 - l\tau_s - u) Q(u) du \quad (7.b)$$

where τ_s is the equalizer tap spacing, and g is the overall impulse response of the pulse shaping filters. The elements of G are given by

$$G_{kl} = g(k\tau_s - l\tau_s) + \frac{E_b}{N_0} \gamma^2 \sum_{i=1}^I C_{kl}(t_0 - iT) \quad (7.c)$$

where γ^2 is the estimated equivalent variance of the intersymbol interference (ISI), I is the number of significant future ISI pulses, t_0 is the sampling instant, and T is the symbol period. Low error rates when using the DFE with a slow fading channel can be expected for rms multipath spreads which are around the equalizer span [9]. Past decision errors do not have significant effect on the operation of the DFE, if the error rate is below 10^{-2} [23]. These conditions are met by the application under consideration. The implementation of the DFE may suffer slightly higher error rates due to errors in coefficient estimation, timing, and propagation of decision errors by the DFE. However, these calculations have shown close agreement with simulation results in [9], as well as actual field measurements [22]. The minimum number of feedback taps necessary to eliminate the past ISI for data rates of interest is three [9].

Fig. 6 represents the performance of the DFE with $E_b/N_0 = 30$ dB, 50 percent rolloff cosine spectrum, for 1, 3, 5, and 7 forward taps versus normalized data rate ($\tau_{rms}R_b$). The sampling instant is determined from (5). The delay power spectrum is a decaying exponential and $\tau_{rms} = 50$ ns. The left-most curve represents the performance of a QPSK modem using a maximal ratio combiner. The next four curves are the performances of QPSK/DFE modems for 1, 3, 5, and 7 forward taps. The performance improvement due to the increase in the number of taps is reduced as the number of taps increases. The approximate bandwidth available for indoor local area networks is around 10 MHz [15]. The maximum data rate for a QPSK modem with 50 percent rolloff pulses and a 10 MHz bandwidth is 13.3 Mbits/s. As shown in Fig. 6, in indoor fading multipath channels with $\tau_{rms} = 50$ ns, a DFE with three forward taps is adequate to support trans-

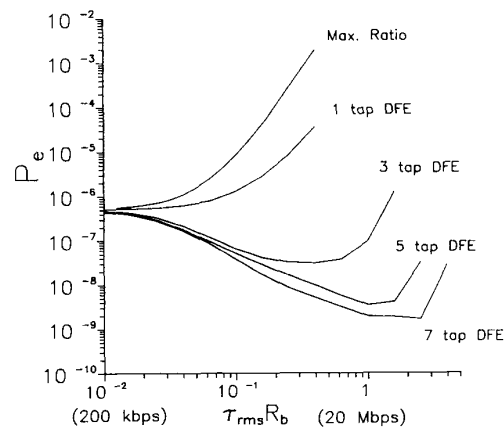


Fig. 6. Average probability of error for QPSK/DFE modem versus data rate. Forward taps are assumed to be 1, 3, 5, and 7. As a reference, the performance of a QPSK modem with a maximal ratio combiner is also given.

mission at 13.3 Mbits/s. Therefore, in the rest of the investigation, the number of forward taps is set at three.

Fig. 7 shows the average probability of bit error versus E_b/N_0 of a QPSK/DFE modem for various normalized data rates $\tau_{rms}R_b$ and a uniform delay power spectrum. Increasing the data rate increases the impact of the multipath channel on the received pulses, tending toward performance degradation due to ISI. At the same time, this increase in the multipath provides more internal diversity which tends toward performance improvement. Initially, performance improves with increasing data rate. This is due to the equalizer exploiting the increasing internal diversity of the received signal while ISI is negligible. At high data rates, however, performance begins to degrade as the harmful effects of ISI become significant with respect to the gains due to the internal diversity. As $\tau_{rms}R_b$ increases from 0.01 to 0.1 (equivalent to an increase of R_b from 200 kbits/s to 2 Mbits/s for $\tau_{rms} = 50$ ns), the performance improves. For higher values of $\tau_{rms}R_b$, performance falls off, while for $\tau_{rms}R_b = 1$, a significant performance degradation is observed. Higher values of $\tau_{rms}R_b$ result in unacceptable error rates.

Fig. 8 gives the average probability of error versus E_b/N_0 for a channel having a decaying exponential delay power spectrum. Fig. 9 compares average probability of error for a continuous channel model represented by exponential and uniform delay power spectrums to the abscissa being the normalized data rate $\tau_{rms}R_b$. For low data rates ($\tau_{rms}R_b < 0.1$), the result is similar to that of the channel with uniform delay power spectrum. For higher data rates, the performance is slightly better than that for the channel with uniform delay power spectrum. In contrast to the QPSK modem, the performance of the QPSK/DFE modem is sensitive to the shape of the delay power spectrum at high data rates.

For a channel represented by a discrete channel model, the structure of the performance calculations is the same as that of the QPSK modems with the difference that the error rate calculations for QPSK/DFE modems are a func-

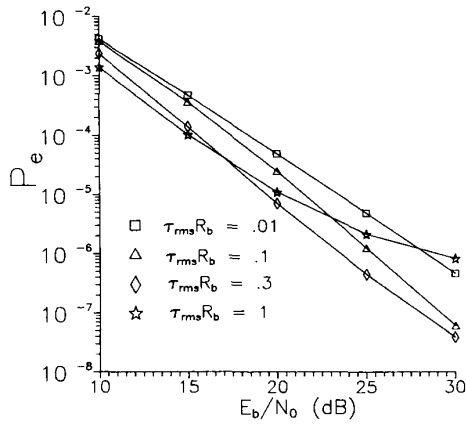


Fig. 7. Average probability of error versus E_b/N_0 for a QPSK/DFE modem using a continuous channel model. The delay power spectrum is assumed to be uniform and the equalizer uses three forward taps. The curves are for normalized data rates of $\tau_{rms}R_b = 0.01, 0.1, 0.3,$ and 1 .

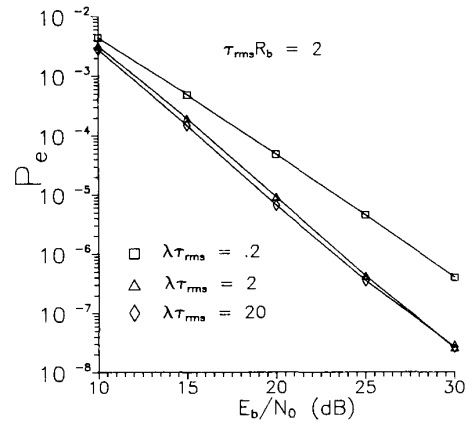


Fig. 10. Average Rayleigh-averaged probability of error versus E_b/N_0 for a QPSK/DFE modem with normalized arrival rates of $\lambda\tau_{rms} = 0.2, 2,$ and 20 for a discrete channel model. The envelope of the delay power spectrum is exponential and the normalized data rate is 2 .

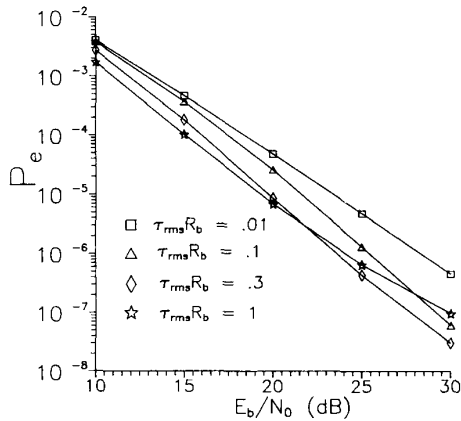


Fig. 8. Average probability of error versus E_b/N_0 for a QPSK/DFE modem using a continuous channel model. The delay power spectrum is assumed to be exponential. The curves are for normalized data rates of $\tau_{rms}R_b = 0.01, 0.1, 0.3,$ and 1 .

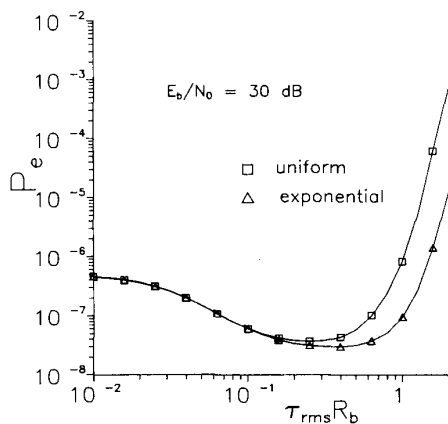


Fig. 9. Average probability of error versus normalized symbol rate for a QPSK/DFE modem, and $E_b/N_0 = 30$ dB. The channel is represented by a continuous model with exponential and uniform delay power spectra.

tion of the delay power spectrum shape; the value of the rms multipath spread alone is not sufficient for performance predictions. To calculate the performance of QPSK modems for channels represented with a discrete channel model, the profiles are divided into a collection of subclasses, each assumed to be a continuous channel represented by a discrete delay power spectrum. The performance of a QPSK modem over each of the subclasses is dependent on the rms multipath spread of that subclass, and it is not sensitive to the shape of the delay power spectrum. Therefore, one set of plots of P_e versus $\tau_{rms}R_b$ and the probability density of τ_{rms}^λ can be used in (6) to determine the average Rayleigh averaged error rate over all possible subclasses of the discrete channel model. The QPSK/DFE modem is sensitive to the shape of the delay power spectrum and the calculation for each subclass of profiles should be done separately. The average Rayleigh averaged error rate is then the average over all subclasses of profiles.

Computer simulation is run to generate a set of representative profiles with discrete delay power spectrums. Paths in the profiles are scaled by a decaying exponential envelope with time constant $E\{\tau_{rms}^\infty\} = \tau_{rms} = 50$ ns, and the profiles are normalized to unit area after generation. For each profile, Rayleigh-averaged probability of error is determined from (7) and the average over all profiles is then calculated.

The result of performance prediction for the QPSK/DFE modem over the discrete channel model with normalized arrival rates of $\lambda\tau_{rms} = 0.2, 2,$ and 20 is shown in Fig. 10. In this figure the normalized data rate is $\tau_{rms}R_b = 2$, in which $E\{\tau_{rms}^\infty\} = \tau_{rms}$. As the normalized arrival rate increases from $\lambda\tau_{rms} = 0.2$ to 2 , the performance increases. For $\lambda\tau_{rms} > 2$, the performance remains the same as the performance over the continuous channel model with $\tau_{rms}\lambda$ approaching infinity, $C(\tau) = Q(\tau)$. An interesting observation is that the performance for the lower arrival rates of the paths is worse than that of higher ar-

rival rates. This behavior of QPSK/DFE modems is in contrast with that of the QPSK modem performance shown in Fig. 5. A QPSK modem performs better for low values of normalized arrival rate of the paths. For a higher number of paths in a profile, the QPSK/DFE modem takes advantage of the inband (internal) diversity provided by multiple paths; for a QPSK modem multiple arriving paths result in additional ISI and consequently performance degradation.

IV. CONCLUSION

The relation between discrete and continuous channel modeling for indoor radio channels was discussed. The probability densities of the rms multipath spread of the channel for various arrival rates of the paths were determined. The performance of QPSK and QPSK/DFE modems for both discrete and continuous channel models was calculated. It was shown that the QPSK/DFE modem can provide data rates of an order of magnitude higher than the QPSK modem. For a typical indoor environment with rms multipath spread of 50 ns and channel bandwidth of 10 MHz, a QPSK/DFE modem with a minimum of three forward taps can provide data rates as high as 13.3 Mbits/s. The performance of QPSK/DFE modems has a small dependence on the shape of the delay power spectrum, unlike the situation encountered when using QPSK modems. Performance predictions based on discrete or continuous channel models are the same for normalized arrival rates of $\lambda\tau_{\text{rms}} > 2$. For lower arrival rates, the channel model employed will result in different expected error rates. Therefore, for a given set of measured profiles with normalized path arrival rates of more than 2, the performance predictions are the same as those of the continuous channel models represented by the delay power spectrum. For lower arrival rate of the paths, the channel model in the performance predictions should be represented with the envelope of the delay power spectrum and the arrival rate of the paths.

ACKNOWLEDGMENT

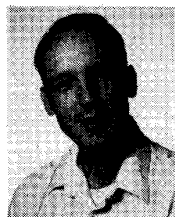
The authors thank Dr. P. Mosen for the useful discussions on the telephone, and also Dr. D. D. Falconer for helpful suggestions.

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