OPEN ACCESS

University of BRISTOL

Link to published version (if available):
10.1109/VETEC.1992.245302

Link to publication record in Explore Bristol Research
PDF-document

University of Bristol - Explore Bristol Research

General rights

ERROR RATE ANALYSIS FOR INDOOR WIRELESS NETWORKS

A.R. Nix, G.H. Norton and J.P. McGeehan
Centre for Communications Research
University of Bristol
Queens Building, University Walk
Bristol BS8 1TR, United Kingdom
Tel: +44 272 303727, Fax: +44 272 255265

Abstract:- Mobile radio research has tended to concentrate
on the difficulties associated with wireless voice transmis-
sion. These signals typically require low bandwidths and
are able to tolerate error rates in the region of 1 in 1000
bits. However, over the last few years, the decreasing size
and increasing power of portable computers has resulted
in a growing demand for a new type of wireless indoor
system. Unlike previous voice systems, wireless computer
networks will require large bandwidths and the very accu-
rate transmission of millions of bits per second. This paper
attempts to predict the maximum data rates for a typical
network operating in an indoor frequency selective envi-
ronment. To lower the error rates for high speed data
transmission we have also investigated the impact of tech-
niques such as diversity combining, frequency hopping
and pulse shaping.

1. Introduction

Current local area networks are generally wire based and
typically operate at data rates up to 10Mb/s. Replacement
networks should therefore be aiming to match, or prefer-
ably improve upon, this order of performance. Wireless
indoor networks rely very heavily on microwave radio
technology to actually transmit and receive the required
data [1]. The propagation characteristics associated with
the indoor mobile radio channel are therefore very signifi-
cant. In particular, the spread in delay times seen at the
mobile receiver tends to restrict the maximum transmis-
sion rate for a given coverage area [2,3]. This restriction
arises as a result of *intersymbol interference* which leads
to the introduction of an irreducible error floor. This paper
presents the performances obtained after modelling a num-
ber of mobile radio configurations in a typical indoor
environment. Various modulation schemes were consid-
ered, ranging from QPSK through to alternative versions
of 16QAM. To improve the validity of our simulations the
wideband propagation data was supplied using a specially
designed ray tracing algorithm [4].

To achieve the high data rates required for an indoor
network the system must be able to tolerate relatively large
values of normalised delay spread. Multi-level modulation

schemes appear particularly attractive since they combine
high bandwidth efficiency with good ISI immunity. This
tolerance to delay spread can be further improved by
employing anti-multipath pulse shapes to lower the degree
of intersymbol interference at the expense of signal band-
width. To operate in larger delay spreads techniques such
as diversity or channel equalisation were found to be
required. However, both these techniques tend to suffer to
some degree when operating in severe signal fades. This
makes it very difficult to guarantee the very low error rates
required for such a network. For example, there is always
a small probability that the receiver will find itself in, or
slowly moving through, a deep signal fade. To overcome
this problem we have proposed the use of a linear fre-
quency hopping system which effectively *randomizes* the
channel statistics. This technique, when combined with
suitable channel coding, avoids the problems of the fading
channel and thus allows very low error rates to be main-
tained at all times.

2. Propagation and Channel Modelling

The signal arriving at the mobile receiver is assumed to
consist of several multipath components, each of which
arises as a result of reflection, diffraction and scattering
from surrounding obstacles [5]. As the mobile travels
through this signal environment the dominant components
change together with the electrical path length of the
waves. The vector summation of these rays gives rise to a
phenomenon known as fading. In the worst case, assuming
no line of sight path exists, Rayleigh fading results in the
received signal envelope undergoing gross amplitude fluc-
tuations together with rapid changes in its phase. If time
delays are also present between the received paths then
echoing, or intersymbol interference, will occur. These
delays create deep notches in the frequency domain result-
ing in *frequency selective* fading.

A convenient measure for the degree of frequency selec-
tive fading is the root mean square (rms) delay spread, σ.
For digital transmissions, the rms delay spread is often
quoted normalised to the bit rate, R. This value, usually
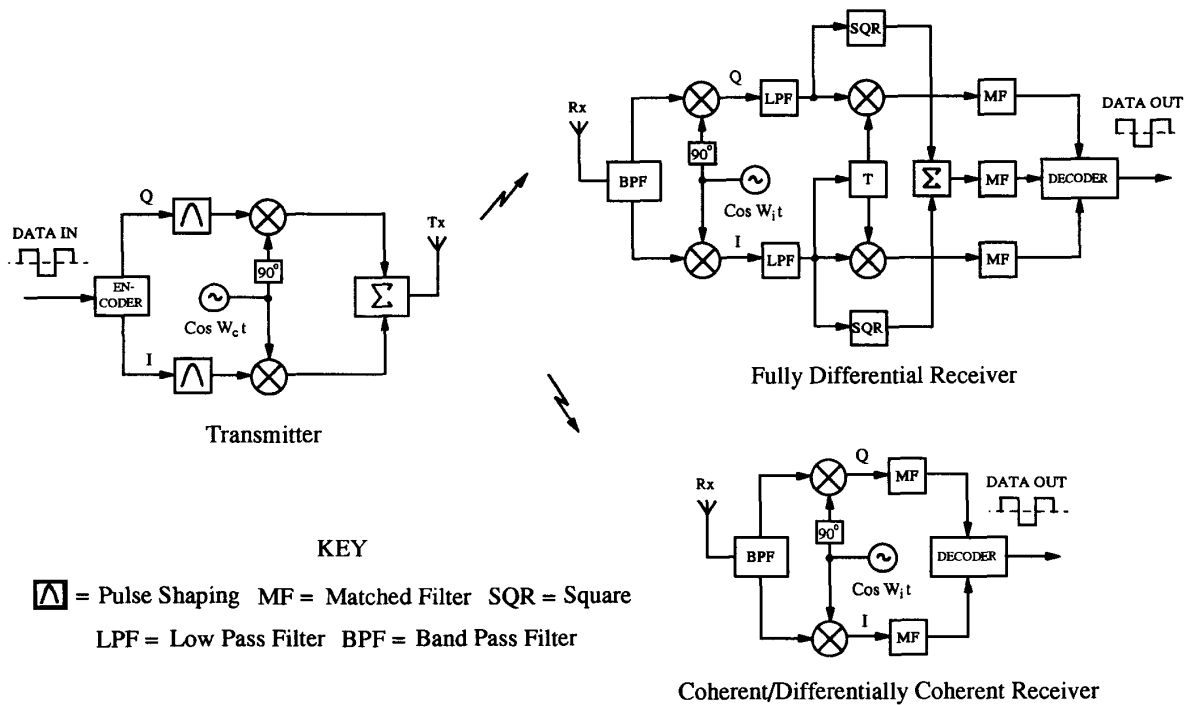denoted by the letter d, then allows direct comparisons to

KEY

$\boxed{\Lambda}$ = Pulse Shaping   MF = Matched Filter   SQR = Square

LPF = Low Pass Filter   BPF = Band Pass Filter

Figure 1 : Transmit and Receive Architechture

be made between systems operating at different symbol rates and in differing areas.

$$d = \sigma R \qquad (1)$$

To create a wideband channel model each of the multipath components can be thought of as an independent travelling plane wave whose amplitude, phase, angle of arrival and time delay are random variables. The mobile channel is described mathematically in equation 2, where B_n and θ_n represent the magnitude and phase of the nth component, t_n the corresponding time delay and L the total number of rays in the impulse response.

$$h(t) = \sum_{n=1}^{L} B_n \exp(j\theta_n) \, \delta(t - t_n) \qquad (2)$$

The parameters for each of the rays in the model were evaluated after ray tracing the room in which the simulation was to be based [4]. This technique, which has already been validated using measured results, was found to remove the uncertainty previously associated with producing realistic profiles. The accurate positioning of transmit

and receive antennas also allowed the performance to be evaluated at various positions within the room.

3. Modem Design

Figure 1 shows the block diagram for the transmit and receive architectures used throughout these simulations. The design was based on an IQ philosophy which allows various modulation schemes to be easily implemented in software. The transmitter simply maps the incoming data into I and Q impulse streams in accordance with the current modulation scheme. These impulses are then shaped, to bandlimit the signal, before passing them on to the RF upconverter. The demodulation process is slightly more complicated with different receivers being required for differential and differentially coherent reception. For constant envelope modulation schemes the received I and Q signals are simply mixed, as shown, to generate the required baseband data. However, for linear modulation schemes, we have included a separate circuit which extracts the signal amplitude when differential detection is required. This circuit not only maintains compatibility between the receivers but also helps to reduce the distortion introduced by the matched filters [6]. Once the amplitude and phase signals have been obtained they are mapped to the appropriate data bits in accordance with the
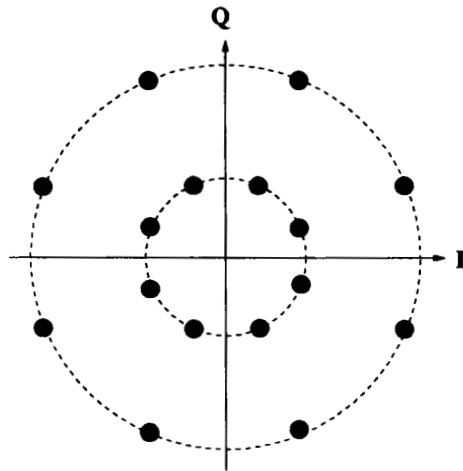
Figure 2 : 16APSK Constellation

(i) Transmit Frame

(ii) Receive Frames (Before Demodulation & De-interleaving)

(iii) Receive Frames (After Demodulation & De-interleaving)

S - Sync Symbols B - Hop Symbols F - Hop Frequencies

Figure 3 : Frequency Hopping & Coding

currently selected constellation diagram. The above is a brief description of the modems operation, a more rigourous analysis has been given in [6,7].

4. Modulation

Although traditional techniques such as GMSK and QPSK have already been simulated using this software, this paper will tend to concentrate on the advantages offered using linear multi-level modulation. It is well known that 16QAM represents an optimum constellation for the reception of data in additive white Gaussian noise. However, in a fading channel it becomes difficult to track the phase variations during deep fades. This can result in the possibility of *false locking* and hence, an unacceptably high symbol error rate. These errors can be reduced by differentially encoding the transmitted data to remove its dependency on the absolute phase of the carrier. For the square QAM configuration there are a large number of possible amplitude and phase transients when differential encoding is employed across consecutive symbols. This results in a complex differential receiver which performs inadequately in noise and fading. Many alternative constellations have been proposed over the years [8,9]. In this paper we shall concentrate on the constellation shown in figure 2. This technique, referred to as 16APSK, utilises two concentric 8-PSK rings to greatly simplify the process of differential reception. A full mathematical analysis of this technique has already been evaluated and can be found in reference [7].

5. Multiple Access & Frequency Hopping

In addition to choosing a modulation scheme, a great deal of consideration must also be given to the multiple access required. If we assume that each user, after channel coding,
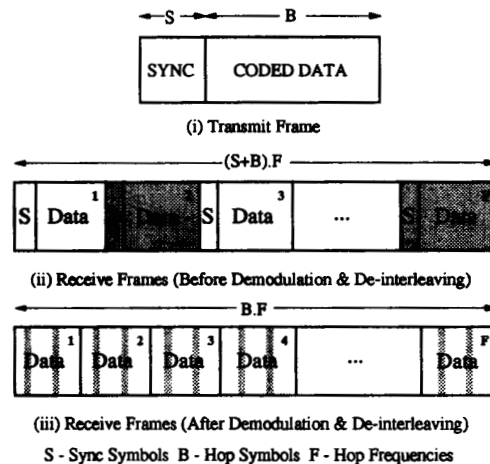
transmits at up to 10 Mb/s, a TDMA system serving 15 users would then require a data rate of 150 Mb/s. Even with channel equalisation this data rate proves very difficult and very expensive to achieve. If each user requires a high data rate it would appear more sensible to operate using FDMA. However, there is always a chance that the frequency assigned to a user will suffer from distortion or deep signal fading, when this occurs transmission may well prove impossible. Although automatic repeat request can be applied in such situations, if the user remains on this frequency repeated transmission may not necessarily help.

It would appear impossible to guarantee the low error rates required since it is always possible for the signal to fade or suffer distortion. However, if we implement our system based on the ideas of frequency hopping we can, with the correct coding, operate successfully despite this corruption of the received signal [10,11]. The basic idea is illustrated in figure 3. Firstly, the data is spread out, or *interleaved*, over a number of hopping frames, each frame containing B data symbols and S synchronisation symbols. Each of these frames is then sent using a different carrier frequency, their separation being large enough to ensure uncorrelated fading. To transmit the data we can then use any differential or non-coherent modulation scheme. Coherent modulation is difficult to achieve since it requires the system to extract the carrier after each hop. Since we intend to operate in a wideband environment the symbol timing must also be acquired for each frame. If the channel is assumed stationary during frames, the synchronisation sequence may be used to obtain this information. After receiving the data it is then quite possible, due to channel distortions, for some of the frames to be received in error, this situation is denoted by the shaded regions in figure 3(ii). De-interleaving the data bits will randomize the bursts of errors thereby allowing them to be removed by

810

the decoding process. Obviously, when too many frames arrive in error the coding scheme breaks down and is unable to correct completely the incoming data. However, by selecting the appropriate error correcting code the user can now control the error rate encountered during transmission.

To improve both the spectral efficiency and the users performance we have also assumed synchronised cyclical hopping [11]. Each user is assigned a unique pointer into a frequency look-up table, when the system is required to hop this pointer is simply incremented to obtain the next required frequency. This technique cycles through all the available frequencies in a controlled or synchronised manner thus removing any danger of data collision. This allows the overall system to fully exploit the available bandwidth.

6. Results

The following results were obtained using a wideband channel model created after ray tracing a typical 50m by 50m room. Figure 4 shows the simulated performance of a number of different modulation schemes over a range of normalised delay spreads. The GMSK simulations were loosely based on the European DECT specification which, assuming a speech error threshold of 1 in 1000 bits, indicated a tolerable normalised delay spread of approximately 0.11. The performance of root raised cosine QPSK was also simulated and seen to depend on the value of the roll-off constant, α. With this value set at 1 the system performed slightly better than that for GMSK.

The 16APSK modulation scheme offered a similar order of performance, although this was achieved with a greater spectral efficiency. Using a suitable pulse shape it becomes possible to trade off this superior efficiency for improved ISI immunity. This situation has been demonstrated for a raised sine time domain pulse shape. This had the effect of lowering the bandwidth efficiency to that expected for the previous QPSK simulation. The use of this pulse shape now allows the system to tolerate, based on the previous threshold, a normalised delay spread of 0.4. More complex, asymmetrical pulse shapes also exist and these can be used to achieve ISI immunity without necessarily expanding the signal bandwidth [12].

Diversity is one of many techniques which can be applied to a system to reduce the impact of delay spread. Figure 5 demonstrates the diversity gains expected for two of the systems described earlier. Firstly, for the GMSK simulation, two branch switched diversity allowed the receiver to operate at normalised delay spreads up to 0.22. This figure represents a doubling of the value previously expected using a single antenna. A similar situation arose for 16APSK, with two branch switched diversity it now withstands a normalised delay spread of 0.51. This value is
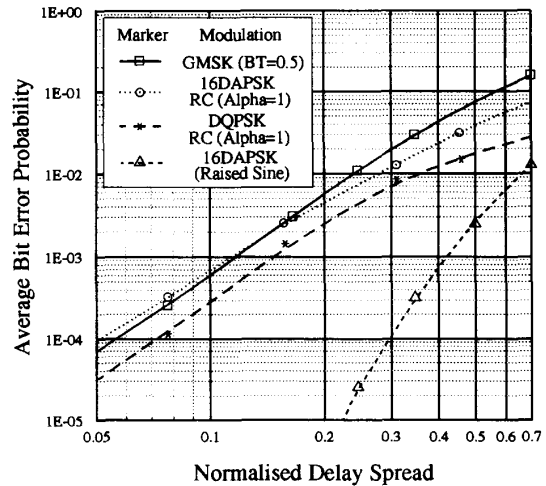

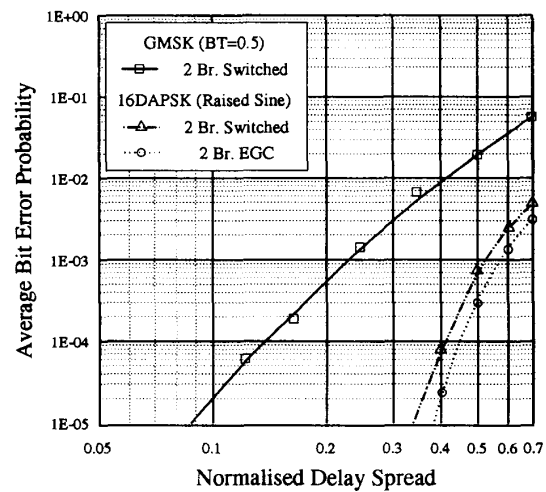Figure 4 : Delay Spread Performance

Figure 5 : Diversity Improvements in Delay Spread

further enhanced when equal gain combining (EGC) is used. However, as figure 6 shows, even with the use of diversity combining it still remains possible to encountering a signal fade. In fact, for normalised delay spreads greater than 0.7 the errors tended to occur every half a carrier wavelength. This value corresponds to the average separation distance between signal fades. For high data rates an error burst may easily last for several thousand symbol periods making forward error correction alone unable to cope. As we have already seen, applying frequency hopping to the system randomizes the channel statistics and therefore allows any coding to operate successfully. Figure 7 shows the simulated effects of adding frequency hopping in a typical wideband environment. Fifteen different frequencies were simulated with a hop rate of approximately 600 hops/sec. The data was coded
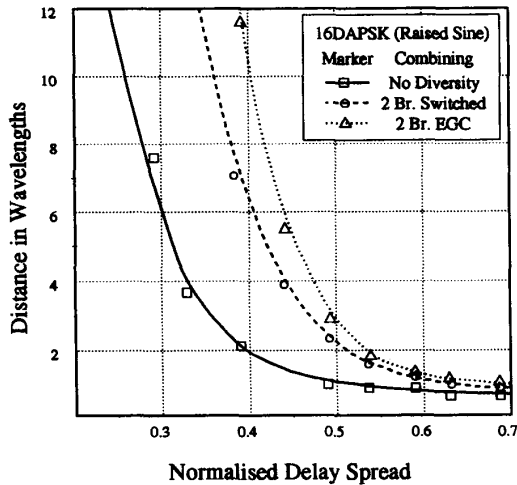
Figure 6 : Burst Error Separation Distance

Figure 7 : Frequency Hopping - Noise Reduction

using a BCH(15,7) block code which was capable of correcting two bit errors in every fifteen. Without the hopping, interleaving and coding an irreducible error rate of 4 symbols in a 1000 was seen. With the hopping system enabled this irreducible error was totally removed. A significant improvement in the noise performance was also seen, although this can be mostly attributed to the system coding. However, without the frequency hopping, the coding alone would not be able to remove the errors when the receiver moves slowly through, or remains stationary in, a signal fade.

For the hopping system, figure 8 shows the improvements in the irreducible error rate for a range of normalised delay spreads. For the previous speech threshold the unaided 16APSK receiver could tolerate a normalised delay spread of 0.41. With hopping the value is increased up to 0.65. Additional gains can also be obtained if diversity is applied to this system. Normalised delay spreads of 0.81 and 0.88 can be tolerated for switched and equal gain combining respectively.

For computer networks a more stringent error threshold needs to be defined. For the purposes of this paper we will therefore assume a data error threshold of 1 in 100000 bits. For this value, the unaided 16APSK system could tolerate a normalised delay spread of just 0.21. With frequency hopping the value increases to 0.51. Once again, diversity improves the situation with values up to 0.68 and 0.72 becoming possible for switched and equal gain combining. However, even at these low error rates additional coding or feedback error control would be needed to detect and then correct these occasional errors.

7. Conclusions

Although the results have been presented in terms of normalised delay spread, providing the rms delay spread
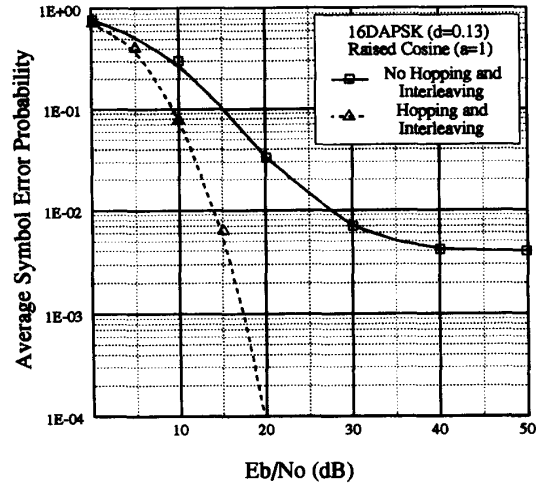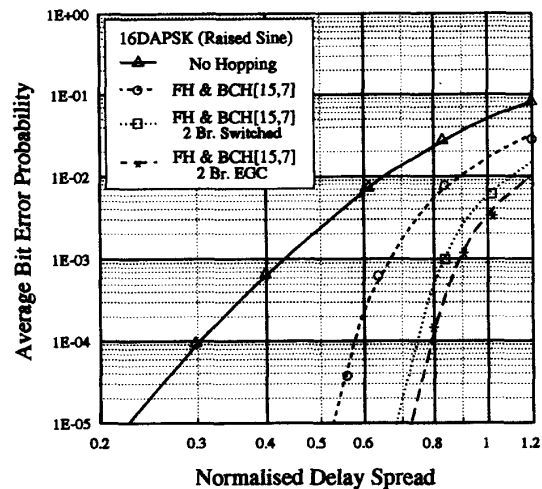

Figure 8 : Frequency Hopping in Delay Spread

is known, these can be easily converted into their corresponding data rates. The GMSK simulation was based on DECT and therefore had a data rate of approximately 1.1Mb/s. The results indicated that for speech, up to 100nS of rms delay spread would be tolerable, 220nS if switched diversity were implemented. Considering the operating range of DECT (200m), switched diversity appears very attractive for transmissions at, or near, the cell boundaries. The QPSK results suggested a performance in delay spread similar to, or slightly better than, that for GMSK. For root raised cosine 16APSK, a similar degree of delay spread could be permitted. However, for this system, a far better spectral efficiency can be achieved.

The use of a raised sine time domain pulse reduces the sensitivity of the receiver to delay spread as well as expanding the signal bandwidth. This pulse shape now per-

mits the 16APSK system to tolerate significantly higher values of delay spread whilst maintaining a bandwidth efficiency similar to that of both QPSK and GMSK. This improvement would allow, for the DECT environment, a maximum data rate of around 4.4Mb/s. Alternatively, keeping the data rate constant, we could now withstand rms delay spreads up to 400nS. This improved performance could then be translated into an increase in the overall cell size. Diversity was also seen to improve the performance of the 16APSK system. With equal gain combining the data rate was improved from 4.4Mb/s to 5.5Mb/s (Once again assuming an rms delay spread of 100nS). This relatively modest improvement arises because, for larger delay spreads, the error bursts tend to lose their correlation with the received signal envelope and therefore saturate the receiving antennas. If the frequency hopping system were applied together with diversity then speech data rates as high as 8.1Mb/s and 8.8Mb/s become achievable depending on the combining techniques employed.

For computer communications such as wireless indoor networks, frequency hopping has been shown to offer a suitable level of performance. Assuming an indoor rms delay spread of 50nS we find, for the 16APSK system, that a data rate of just over 10Mb/s can be achieved with a bit error rate less than 1 in 100000. Even after the coding redundancy has been taken into account, this leaves well over 4Mb/s. If higher rates are required equal gain combining can be added to increase the gross throughput to over 14Mb/s. This would give each of the users approximately 6Mb/s. Unlike local area networks this capacity is fixed for each user and will not be reduced as the load rises. In fact, with synchronous frequency hopping, the system can run at full load whilst still avoiding the possibility of data collision. To support higher user densities it may also be possible to split each of the frequencies into several TDMA frames. This approach would then offer more flexibility in the distribution of the overall capacity.

These simulations have shown that for indoor or short range communications relatively high date rates can be achieved without resorting to channel equalisation. The choice of modulation is also important. Schemes having good spectral efficiency can always trade off this advantage to improve their ISI immunity. Hence, for a fixed bandwidth, multi-level modulation schemes will always be capable of outperforming any spectrally less efficient techniques.

Acknowledgements

References

[1] J.E. Mitzlaff, "Radio propagation and anti-multipath techniques in the WIN environment," IEEE Network Magazine, November, 1991, pp. 21-26.

[2] A.R.Nix and J.P. McGeehan, "Modelling and simulation of frequency selective fading using switched antenna diversity," IEE Electronic Letters, Vol. 26, No. 22, 1990, pp. 1868-1869.

[3] F. Adachi and K. Ohno, "BER performance of QDPSK with postdetection diversity reception in mobile radio channels," proceedings of the 41st IEEE Vehicular Technology Conference, St Louis, USA, 1991, pp 1868-1869.

[4] M.C. Lawton, R.L. Davies and J.P. McGeehan, "An analytical model for indoor multipath propagation in the picocellular environment," proceedings of the IEE 6th International Conference on Mobile Radio and Personal Communications, Warwick, UK, 9-11 December, 1991, pp. 1-8.

[5] W.C. Jakes, Microwave mobile communications, John Wiley & Sons, New York, 1974, Chap. 1.

[6] R.J. Castle and J.P. McGeehan, "A multi-level differential modem for narrowband fading channels," proceedings of the 42nd IEEE Vehicular Technology Conference, Denver, Colorado, USA, 11-13 May, 1992.

[7] A.R. Nix, R.J. Castle and J.P. McGeehan, "The application of 16APSK to mobile fading channels," proceedings of the IEE 6th International Conference on Mobile Radio and Personal Communications, Warwick, UK, 9-11 December, 1991, pp. 233-240.

[8] W.J. Weber, "Differential encoding for multiple amplitude and phase shift keying systems," IEEE Transactions on Communications, Vol. COM-26, No. 3, pp. 385-391.

[9] W.T. Webb, L. Hanzo, R. Steele, "Bandwidth Efficient QAM Schemes for Rayleigh Fading Channels," proceedings of the IEE 5th International Conference on Radio Receivers and Associated Systems, Cambridge, UK, pp. 139-142.

[10] D.J. Purle, A.R. Nix, M.A. Beach and J.P. McGeehan, "A preliminary performance evaluation of a linear frequency hopped modem," proceedings of the 42nd IEEE Vehicular Technology Conference, Denver, Colorado, USA, 11-13 May, 1992.

[11] A.A.M. Saleh, A.J. Rustako, L.J. Cimini, G.J. Owens and R.S. Roman, "An experimental TDMA indoor radio communications system using slow frequency hopping and coding," IEEE Transactions on Communications, Vol. 39, No. 1, Jan 1991, pp 152-162.

[12] Chia-Liang Liu and K. Feher, "A new filtering strategy to combat delay spread," proceedings of the 41st IEEE Vehicular Technology Conference, St Louis, USA, 1991, pp. 776-781.