8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '97)
1–4 September 1997, Helsinki, Finland

HIPERLAN System Performance Under DCA and FCA

Brendan C. Jones and David J. Skellern

Electronics Department, School of Maths, Physics, Computing and Electronics
Macquarie University NSW 2109 Australia

email: brendan@mpce.mq.edu.au, daves@mpce.mq.edu.au

ABSTRACT

HIPERLAN is a high speed wireless LAN standard recently adopted by ETSI. It operates in 150 MHz of spectrum in the 5 GHz band, with up to five TDD channels provided for duplex data transmission at up to 23.5 Mb/s.

This paper shows that in the presence of cochannel cells and full link utilisation, HIPERLAN performs poorly when using its DCA–type Clear Channel Assessment (CCA) scheme, and that the target performance levels are only achievable under optimal FCA–type channel assignments.

Two main factors contribute to this poor performance: HIPERLAN has insufficient channels to meet C/I constraints in the presence of cochannel cells; and the CCA scheme results in poor channel distributions.

I. INTRODUCTION

The success of cellular telephony in providing wireless public voice telecommunications services has led to wireless technologies being applied to private data transmission systems in the form of Wireless Local Area Networks (Wireless LANs).

HIPERLAN (HIgh PErformance Radio Local Area Network) [1] is a Wireless LAN standard recently adopted by the European Telecommunications Standards Institute (ETSI). It operates in 150 MHz of spectrum in the 5.150 to 5.300 GHz band, with at least three and up to five TDD channels provided for duplex data transmission at speeds up to 23.5 Mb/s.

HIPERLAN uses a (31,26) BCH code to encode data to be transmitted into 31 bit segments, and Gaussian Minimum Shift Keying (GMSK) with BT=0.3 to modulate these encoded bits for transmission over the air at the high bit rate (23.5 Mb/s).

Each HIPERLAN hub or cell site may transmit on any HIPERLAN channel, however the hub and all terminals within the cell operate on only one RF channel at any given time. Only one terminal in each HIPERLAN cell may transmit a packet at any given time. Duplexing is via TDD.

Medium access control (MAC) is via a type of listen–before–talk (LBT) algorithm called Non–preemptive Priority Multiple Access (NPMA). This algorithm has three activity phases: a prioritisation phase, contention phase, and transmission phase.

II. HIPERLAN SYSTEM ASSESSMENT

The first issue to be considered is the C/I and BER performance possible for HIPERLAN in the presence of a cochannel interferer.

The probability of bit error P_b for GMSK in the presence of AGWN was derived by Murota and Hirade [2]. Expressed in terms of the Q function P_b is given by:

$$P_b = Q\left(\sqrt{\frac{d^2_{\min}}{2N_0}}\right) \qquad (1)$$

where $d_{\min}$ is the minimum value of the signal distance between mark and space in Hilbert space, and is related to BT. Murota [2] published a plot of $d^2_{\min}/2E_b$ versus BT for GMSK. For HIPERLAN, BT=0.3 and from the plot $d^2_{\min}/2E_b \approx 1.8$. Hence for HIPERLAN P_b is given by:

$$P_b \approx Q\left(1.342\sqrt{\frac{E_b}{N_0}}\right) \qquad (2)$$

The (31,26) BCH code can detect three bit errors and correct one, thus a (31,26) BCH packet is correctly received if there are only 0 or 1 bit errors. Hence the probability of packet error Pp in the 31 bit BCH encoded segment is given by:

$$P_p = 1 - (1 - P_b)^{30} \qquad (3)$$

Assume that the HIPERLAN performance target is an over the air (31,26) BCH packet error rate (PER) $Pp = 10^{-3}$. From Eq. (3), this requires a bit error $P_b = 3.33 \times 10^{-5}$. From Eq. (2) it can be found that the required $E_b/N_0 = 9.46$ dB. Assuming data transmission is at the high bit rate of 23.5 Mb/s and BT = 0.3 this equates to a C/I of 14.7 dB.

The minimum number of channels required to support performance at this level may be computed using the channel reuse ratio results of Jones [3]. A mobile terminal in a cell always meets a C/I threshold Z if the closest channel reuse ratio satisfies:

$$\Re > (\alpha Z)^{1/\gamma} \qquad (4)$$

where $\Re$ is the channel reuse ratio, α is the strength of the interferer relative to a cochannel interferer (i.e. $\alpha = 1$ for a cochannel interferer) and γ is the propagation path loss exponent.

With a regular cell layout, the minimum reuse ratio $\Re = R - 1$ where R is the distance between cochannel cell centres, related to the cluster size C by:

$$R = \sqrt{\Delta C} \tag{5}$$

where $\Delta = 2$ for 'square' cells and $\Delta = 3$ for 'hexagonal' cells. With one channel per cell the cluster size C is equal to the total number of available channels. Hence the total number of channels required to provide the target performance is given by:

$$C = \left\lceil \frac{1}{\Delta}\left[(\alpha Z)^{1/\gamma} + 1\right]^2 \right\rceil \tag{6}$$

In an indoor environment, it can be shown that a three–ray propagation model (direct ray + floor and ceiling reflected rays) gives inverse square law propagation in the limit [4]. Taking into account obstructions, the path loss exponent γ may vary between 2 and 3.5. In the worst case of $\gamma = 2$, Eq. (6) indicates that HIPERLAN requires 21 channels for a square cell layout ($\Delta = 2$) or 14 channels in a hexagonal cell layout ($\Delta = 3$). If, however, it is assumed that $\gamma = 3.5$ then HIPERLAN requires 7 channels in a square cell layout or 5 channels in a hexagonal cell layout.

The HIPERLAN standard provides for only 5 RF carriers. Thus HIPERLAN satisfies the assumed performance target (an over the air PER of 10^{-3}) with a hexagonal cell layout and a path loss exponent of 3.5 or greater. It can be argued that these are optimistic conditions, especially since is assumes channels are perfectly assigned with optimal cochannel separation.

III. HIPERLAN SYSTEM SIMULATION

A Monte Carlo simulation can be used to estimate HIPERLAN system performance. The Monte Carlo simulation used in [5] was modified to provide a clock–tick driven simulation of a HIPERLAN network of 20 cells of 50 m radius in a square cell arrangement, and 200 class A (10 dBm transmit power) mobile HIPERLAN terminals, ten per cell.

Simulations were performed under the worst case condition of full link utilisation, i.e. one of the mobile terminals in each cell and the hub transmitted a packet at alternate clock ticks. This avoids artefacts introduced by applying a particular traffic statistic, and in any event accurate traffic models for different types of data communication sessions are still being developed [6].

Mobile terminals were randomly placed with a uniform area distribution in each cell, and transmitted packets in a random sequence. Cells were assumed to be clock–tick synchronised.

The propagation model assumed was similar that used in the original development of HIPERLAN [7]. A dual slope path loss model was used with an initial path loss exponent $\gamma = 2$ out to 10 m and then $\gamma = 3.5$ at distances greater than 10 m. In addition, it was assumed that the channel exhibited Rician fading with a Rice factor $K = 10$. In all other respects it was assumed that the channel was equalised.

The PER was estimated by computing, at each clock tick, the total interference generated by all mobile terminals and hubs at the input to a particular receiver, calculating the $E_b/(N_0+I)$, and then applying Eqs. (2) and (3). Each packet therefore provides a finer PER estimate than by applying a binary success/fail threshold to each packet and considerably reduces simulation time for small PERs.

The PER was averaged over the total simulation, usually 1 million packet transmissions, to provide PER estimates for both the uplink and downlink. Unless stated otherwise, the simulation results in this paper refer to the uplink PER results. In any event, the downlink PER results tended to be very similar to the uplink PER results.

Two modes of operation were simulated. In the first mode, the HIPERLAN system chose channels dynamically in accordance with its Clear Channel Assessment (CCA) scheme [1]. These simulations were denoted 'DCA' (Dynamic Channel Assignment) simulations.

The HIPERLAN specification does not indicate under what conditions CCA should be invoked. For the purposes of the simulation, CCA was invoked whenever the PER at a hub rose above 10^{-3}. The PER applied for CCA was a moving average computed over the previous ten packet transmissions. The moving average was reset to zero after a channel reassignment.

In the second mode, channels were permanently allocated to each cell in accordance with an optimum cochannel layout. These simulations were denoted 'FCA' (Fixed Channel Assignment) simulations.

IV. HIPERLAN INTERFERENCE PERFORMANCE

The first simulation performed calculated the interference to noise ratio (INR) and cell radius distributions for the 20 cell, 200 user HIPERLAN system. The INR is the ratio of total received interference power to receiver noise at a receiver, and is a useful measure for comparing interference distributions between different wireless technologies [5].

Fig. 1 shows the resultant INR distributions for the DCA and FCA HIPERLAN simulations. The dotted lines are the lognormal lines of best fit to the simulation data. Fig. 1 shows that under the simulated FCA conditions a relatively small range of interference powers (10 dB) was experienced by HIPERLAN receivers, and that the interference distribution was close to lognormal. Under DCA, however, there was nearly a 60 dB variation in interference powers experienced at HIPERLAN receivers and that the distribution was severely skewed away from lognormal at both tails.

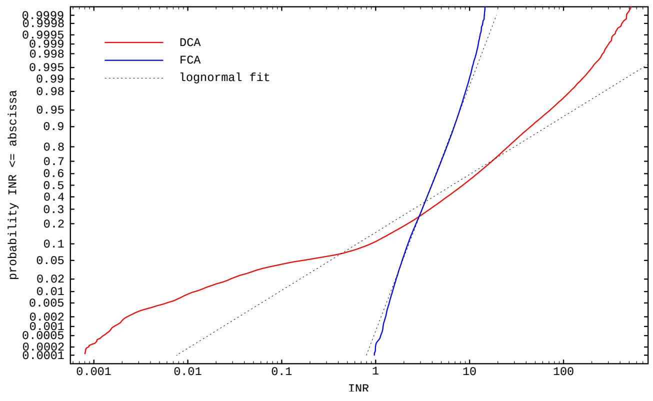

Fig. 1 – HIPERLAN INR CDF – 20 cells, 200 terminals

The cell radius distributions (Fig. 2) show the maximum hub–to–terminal range at which packets could be transmitted at the target PER for a given proportion of terminals. This provides information about the quality of the radio coverage, as ideally 100% of terminals should be able to successfully transmit a packet at the target cell radius of 50m.

Fig. 2 shows that due to the larger interference levels experienced, a much larger proportion of terminals have reduced radio range (i.e. range less than the target cell radius of 50 m) under DCA operation than under FCA operation. For example, at 30 m from the hub, only 0.04% of terminals failed to meet the PER target under FCA, whilst under DCA 37.6% failed. At 40 m, 44.7% failed under FCA and 66.8% failed under DCA. Beyond 43 m DCA outperformed FCA, but 75% of terminals at this range failed to send packets at the target PER.

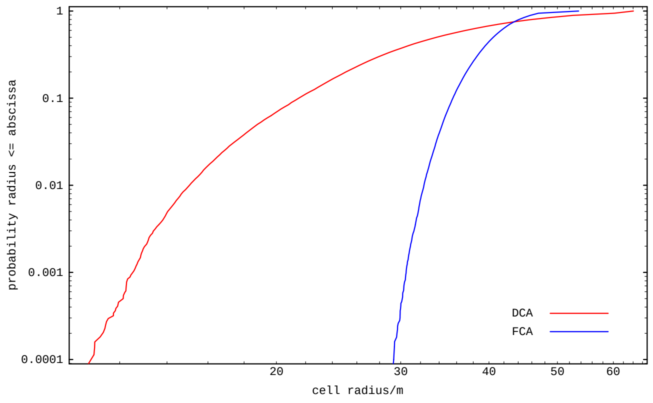

Fig. 2 – HIPERLAN Cell Radius CDF – 20 cells 200 terminals

The reduced radio range manifests itself as a higher probability of packet error in the DCA case. The uplink PER for the FCA simulation was 1.89×10^{-3} whilst for the DCA simulation the uplink PER was 1.20×10^{-1}. Clearly the increased probability of high interference levels under DCA operation led to a much higher PER. This suggests that the CCA scheme does not result in good channel assignments.

The CCA scheme flags a channel as being ‘free’ if less than –75 dBm of RF energy is detected in that channel. In a square cell layout, a potential cochannel terminal at the centre of an adjacent cell would generate –86.5 dBm of interference under the assumed propagation model. Hence it is possible that the CCA scheme could flag this channel as being ‘free’ despite this interference being sufficient to cause a large probability of packet errors. HIPERLAN has provision for the CCA threshold to be increased above –75 dBm, but not lowered.

Cell maps (Fig. 3) were created to illustrate the difference between the FCA channel assignment and a DCA assignment made under CCA. In the DCA case the map shows the final channel assignment at the end of the simulation. The assigned channel numbers are shown in each cell and also by the cell shading. A channel number of ‘0’ indicates a channel reassignment was underway. Also on the maps are shown the locations of the first 100 cochannel terminals in relation to the reference cell at the Cartesian origin. This illustrates the difference in proximity of cochannel interferers in the two schemes.

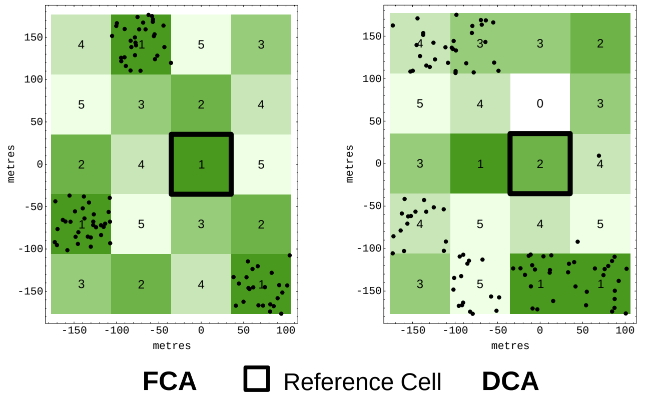

Fig. 3 – Cell maps and location of cochannel terminals

V. HIPERLAN CHANNEL REUSE

The cell maps provide a ‘snapshot’ of cochannel reuse over a small amount of simulation time. Of more interest is an assessment, over a longer period of simulation time, of the probability of small cochannel reuse ratios under the two different channel assignment schemes. While the previous simulations were being performed, whenever two terminals were found to be transmitting on the same channel the distance between that terminal and the other terminal’s hub was recorded. Dividing this distance by the cell radius gives the cochannel reuse ratio (CRR). Fig. 4 shows the resultant CRR CDF. The dotted lines show the theoretical reuse ratio lower limits as derived in [3].

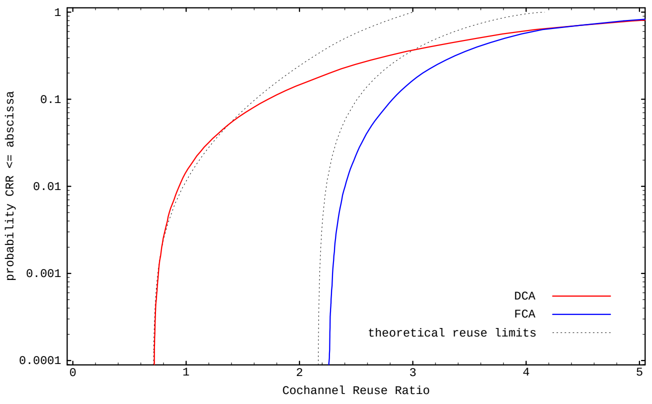

Fig. 4 – Cochannel reuse ratio CDF

Fig. 4 illustrates the degree to which close cochannel reuse is more likely under the DCA scheme than the FCA scheme, leading to much higher interference levels and much higher PERs. Under FCA the minimum CRR is constrained by the assignment geometry and is given by $\sqrt{2C}-1$, or about 2.16 in this case. As seen earlier, the CCA scheme does not necessarily prevent the establishment of adjacent cochannel cells. Thus under DCA the minimum CRR is constrained solely by the fact that cochannel interferers must necessarily be external to the reference cell. This gives a minimum CRR of $1/\sqrt{2}$ or 0.71.

In both the FCA and DCA cases the simulation CRR CDFs are reasonably close to the minimum reuse ratio limits predicted by [3]. The major source of error is that whilst hexagonal cells can be reasonably well approximated by a circle in order to simplify the theoretical calculation of reuse ratio distributions [3], the approximation is not as good for square cells.

A similar graph can be produced for adjacent channel reuse ratios (ACRR, i.e. reuse of a channel immediately above or below the reference channel). In both the FCA and DCA cases, the only constraint is that an adjacent channel interferer must be external to the reference cell, hence the two reuse ratio distributions would be expected to be very similar. This is confirmed in the ACRR CDF shown in Fig. 5, with the simulation results again being close to the theoretical ACRR distribution derived in [3]. This indicates that the prime factor for the difference in DCA and FCA performance is closer cochannel reuse, rather than any effects from adjacent channel interferers.

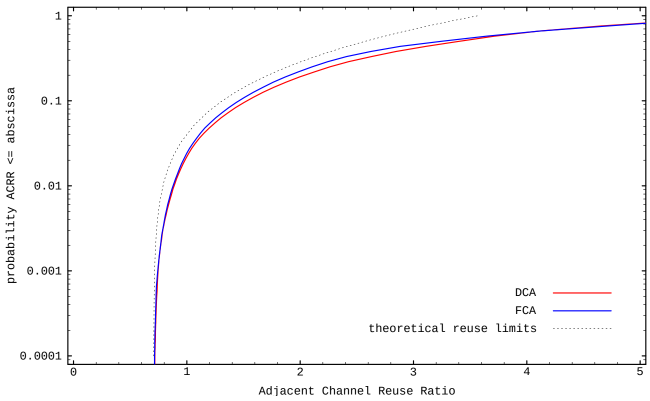

Fig. 5 – Adjacent channel reuse ratio CDF

VI. HIPERLAN SYSTEM PERFORMANCE

Given the previous results, it is useful to determine under what conditions HIPERLAN performance could be improved in a network of cells.

Three system parameters which can be varied are the total number of cells, the total number of channels, and the amount of cochannel protection (guaranteed attenuation between cochannel cells).

Firstly, HIPERLAN performance was assessed against the number of cells. Simulations were performed to estimate the PER as the number of cells in the system was increased from 1 to 20 with ten HIPERLAN terminals per cell. The propagation model was the same as in previous simulations. With more than 5 cells it is impossible to avoid cochannel cells, hence it would be expected that a significant deterioration in PER would occur once the system comprises more than 5 cells. This is confirmed in the results shown in Fig. 6.

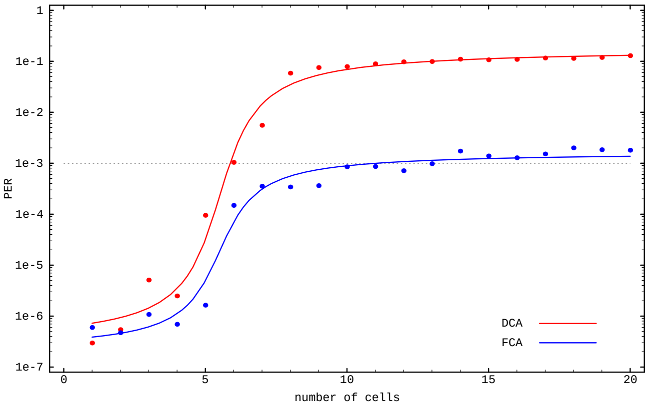

Fig. 6 – PER versus total number of cells

Fig. 6 shows the PER deteriorating between 5 and 10 cells but then levelling out once additional cells are far enough away to only marginally increase the interference levels. It is interesting to note that the DCA PER performance is approximately two orders of magnitude worse than the FCA PER performance, which levels out close to the desired PER of 10^{-3}.

Although 5 channels appear to be sufficient under optimal channel assignment, this is not a reasonable basis for practical operation. Hence it may be useful to consider whether increasing the number of RF channels allocated to HIPERLAN could solve this problem, keeping in mind that it may not be possible in practice to allocate large segments of spectrum for this purpose.

Further simulations were performed to estimate the system performance of a 20 cell, 200 user network as the number of available channels was increased from 2 to 25 for both FCA and DCA operation. The result is shown in Fig. 7.

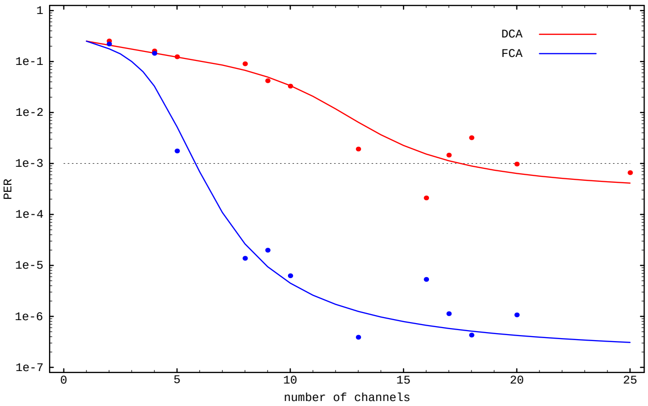

Fig. 7 – PER versus total number of channels

Fig. 7 shows that under DCA operation the PER only improves slowly with an increase in the number of available channels, and does not reach the target of 10^{-3} until around 20 channels are available – most likely an impractical proposition. The problem is that although more channels reduces the probability of close cochannel reuse, the CCA algorithm can still make poor assignment choices.

Finally, it is constructive to consider the amount of additional cochannel protection which may make a 5 channel DCA HIPERLAN system feasible. The reason for this is that it is likely that there will be bulk obstructions (walls, partitions, doors etc.) between cochannel cells in a HIPERLAN network. If a few dB of additional attenuation results in a large improvement in PER then it may be possible to develop installation methodologies which ensure potential cochannel sites are suitably protected.

A further round of simulations were performed for the 20 cell, 200 user network with the propagation model as before, except that an additional amount of attenuation was provided between *every* pair of cochannel cells (even if the CCA algorithm led to adjacent cochannel cells). The amount of cochannel protection was increased from 1 to 20 dB and the PER results are shown in Fig. 8.

Fig. 8 shows that the PER reduces approximately logarithmically with each dB of cochannel protection, with the target PER of 10^{-3} achieved with approximately 10 dB of protection. At 5 GHz, 10 dB of attenuation is likely to be provided by a concrete floor, concrete or double brick wall, or metal sheet, but not by a composite wall or office partition [8]. Thus HIPERLAN would perform to specification only if all cochannel cells were in different rooms separated by concrete walls, or on different floors. This may be an optimistic requirement and in any event undermines the principle that private wireless networks should be able to be installed with minimal RF engineering and no requirement for coordination between neighbouring systems which may be under someone else's control.

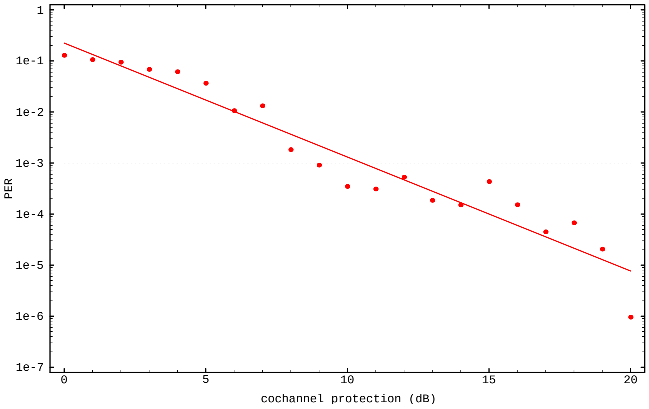

Fig. 8 – PER versus additional cochannel protection for DCA operation with 5 channels

VII. CONCLUSION

This results in this paper suggest that HIPERLAN networks may only perform well under optimistic installation and propagation conditions.

A theoretical analysis of the HIPERLAN air interface suggested that 5 channels would be insufficient to provide an over the air PER of 10^{-3} unless the propagation path loss exponent $\gamma > 3.5$ and the channels were optimally assigned. This result was confirmed using Monte Carlo simulations.

Cochannel reuse was shown to be much closer under the DCA–type Clear Channel Assessment (CCA) scheme than an optimal FCA scheme. It appears that one factor contributing towards this is that the CCA threshold is set too high. This aspect is further investigated in [9].

Increasing the number of channels allocated to HIPERLAN systems only marginally improves the PER under the CCA scheme. Introducing additional cochannel protection provides more rapid improvement in performance, but this is unlikely to be a practical proposition as the location of cochannel cells may change over time as new assignments are made.

The analysis and simulations assumed full link utilisation. The interference effects would decrease and the PER would improve if link utilisation was less than 100%.

REFERENCES

[1] ETSI, “Radio Equipment and Systems (RES); HIgh PErformance Radio Local Area Network (HIPERLAN), Type 1 Functional Specification”, ETS 300–652 (Ed.1), August 1996.

[2] K. Murota, K. Hirade, “GMSK Modulation for Digital Mobile Radio Telephony”, *IEEE Transactions on Communications*, vol 29 no 7 pp 1044–1050, July 1981.

[3] B.C. Jones, “Cochannel and Adjacent Channel Reuse Ratio Distributions in Dynamic Channel Assignment Microcellular Systems”, *IEEE Region Ten Conference (TENCON ’96)*, pp 338–347, Perth, Australia, 27–29 November 1996.

[4] S. Faruque, “A Three Ray Propagation Model for PCS and Microcellular Services”, *14th Military Communications Conference (MILCOM ’95)*, vol 3 pp 1239–1243, San Diego, USA, 5–8 Nov 1995.

[5] B.C. Jones and D.J. Skellern, “An Integrated Propagation–Mobility Interference Model for Microcellular Network Coverage Prediction”, accepted for publication in *Wireless Personal Communications* – Special Issue on Interference in Mobile Wireless Systems, to appear 1998.

[6] V. Paxson, S. Floyd, “Wide Area Traffic: The Failure of Poisson Modelling”, *IEEE/ACM Transactions on Networking*, vol 3 no 3 pp 226–244, June 1995.

[7] G.A. Halls, “HIPERLAN: The High Performance Radio Local Area Network Standard”, *Electronics and Communications Engineering Journal*, pp 289–296, December 1994.

[8] T..S. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, New Jersey, 1996, pp 123–131.

[9] B.C. Jones and D.J. Skellern, “HIPERLAN Channel Assignment Strategies”, accepted for publication in *Electronics Letters*, to appear.