

$L_{\pi} = 190 \mu\text{m}$ (Fig. 3) with 0.3 dB of insertion loss, plus 4.7 dB of current-induced loss. This $190 \mu\text{m}$ active length will also produce 21 dB extinction in a Mach-Zehnder modulator.⁹ Again at 10^{18} , Fig. 4 shows that $L(10 \text{ dB}) = 390 \mu\text{m}$ with a 0.6 dB initial loss and 10.6 dB final loss. There is incentive to reach 10^{19} injection because at 10^{18} the interaction length and insertion loss are ~ 10 times larger than at 10^{19} . The intensity modulation predictions are encouraging and show that a practical result should be feasible in a compact device. The TM_0 -mode results (not shown) are almost identical to those in Figs. 3 and 4. The modulation is also slightly less efficient at $1.3 \mu\text{m}$ than at $1.55 \mu\text{m}$.

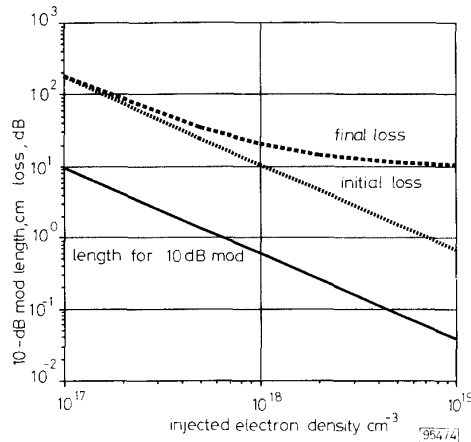


Fig. 4 Predicted performance of HBT for optical intensity modulation at $1.55 \mu\text{m}$

TE_0 mode

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R. D. LAREAU
L. FRIEDMAN

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Worcester Polytechnic Institute
Electrical Engineering Department
Worcester, MA 01609, USA

R. A. SOREF

Rome Air Development Center
Solid State Sciences Directorate
Hanscom AFB, MA 01731, USA

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CSMA LOCAL RADIO NETWORKS WITH BPSK MODULATION IN RAYLEIGH FADING CHANNELS

Indexing terms: Telecommunications, Networks, Phase-shift keying

Calculation of the throughput of a carrier sense multiple access (CSMA) packet radio network with capture over slow Rayleigh-fading channels is presented. The effects of capture on the throughput of the system are related to the modulation and coding technique of the transmission system, the general distribution of terminals in the area and the length of the transmitted packets. BPSK modulation and BCH coding are considered.

Introduction: There have been efforts to analyse the effects of capture in the packet radio systems using various assumptions. Most of these studies only consider the effects of power fluctuations caused by Rayleigh fading and neglect the details of modulation and coding techniques used for the transmission system. Among the limited studies relating the transmission issues to the capture effect, the work in Reference 1 analyses a slotted ALOHA system with BPSK modulation and BCH coding. That study uses a uniform distribution for the terminals, assumes Rayleigh fading channel and treats the interference signal from other users as a source of Gaussian noise. In Reference 2, a different approach to the capture model for BPSK modulation is considered for fast Rayleigh fading channels which affect the bits of a packet independently. The interference from other users is assumed to have a Gaussian distribution and the analysis is derived for a general distribution of the terminals. In slow fading channels it assumes that the packet error rate is approximately the same as the bit error rate. A more realistic approach to this problem is considered in Reference 3 for a slow Rayleigh fading channel. An exact calculation of the throughput which includes the correlation between the bits of a packet, length of a packet, signal to noise ratio of the received signal and modulation and coding of the transmission system is provided in this work. It also provides several bounds to the performance of the system. Other recent works relate the performance of the CSMA packet radio networks to the capture parameter⁵ using the power based capture model suggested in Reference 4.

This letter extends the capture model used in Reference 3 for the exact calculation of throughput in nonpersistent CSMA packet radio networks. The calculations are determined for various packet lengths, BPSK modulation and BCH coding.

Throughput of a CSMA channel and the capture model: The system is assumed to be an ideal nonpersistent CSMA with base station located in the centre and terminals distributed around it with a given distribution.

Define $P_{pN}(C)$ as the probability that the test packet is captured with N interfering packets. The throughput of the non-persistent CSMA system with perfect acknowledgments in the channels with capture is given by⁵

$$S = \frac{\sum_{N=0}^{\infty} P_{pN}(C) \exp(-\alpha G)(\alpha G)^N / N!}{1 + 2\alpha + \frac{e^{-\alpha G}}{G}} \quad (1)$$

where G is the average attempted traffic arriving in the duration of a packet and α is the ratio of the maximum transmission delay to the duration of a packet. This equation is valid for versions of CSMA such as ISMA⁵ or BTMA⁶ which deal with the hidden terminal problem.

Using the capture model developed in Reference 3, $P_{pN}(C)$ is obtained by taking the average value of $P_{pN}(C|a_0, G)$ which is the probability of capturing a packet given a_0 and $G_N = [g_1, \dots, g_N]$ in which a_0 and g_s are the amplitude of bits in the test packet and the interference from other packets, respectively. Given the probability density functions of a_0 and

g_i , the average probability of capture for the test packet $P_{pN}(C)$ can be obtained with an N dimension integral given by

$$P_{pN}(C) = \int_0^\infty da_0 \int_{-\infty}^\infty dg_1, \dots, \int_{-\infty}^\infty dg_N f_{a_0}(a_0) f_{g_1}(g_1), \dots, f_{g_N}(g_N) P_{pN}(C | a_0, \mathbf{G}_N) \quad (2)$$

For the BCH coding with packet length of L bits and t correctable bits in the code word (for the uncoded system, $t = 0$), $P_{pN}(C | a_0, \mathbf{G}_N)$ is given by

$$P_{pN}(C | a_0, \mathbf{G}_N) = \sum_{i=0}^L \binom{L}{i} \times (1 - E\{P_{bN}(e | a_0, a_N)\})^{L-i} (E\{P_{bN}(e | a_0, a_N)\})^i \quad (3)$$

where $E\{P_{bN}(e | a_0, a_N)\}$ is given by

$$E\{P_{bN}(e | a_0, a_N)\} = \frac{1}{2^N} \sum_{a_1=\pm 1} \dots \sum_{a_N=\pm 1} \frac{1}{2} \operatorname{erfc} \left(\frac{a_0 + \sum_{i=1}^N \alpha_i g_i}{\sqrt{N_0}} \right) \quad (4)$$

where N_0 is the power of the white Gaussian noise.

Results and discussion: The averaged probability of capture $P_{pN}(C)$ is determined by Monte Carlo integration of eqn. 3 using the probability density functions $f_{a_0}(a_0)$ and $f_{g_i}(g_i)$ calculated for a bell shaped distribution function^{3,4} of the terminals.³ Fig. 1 presents the relation between the average

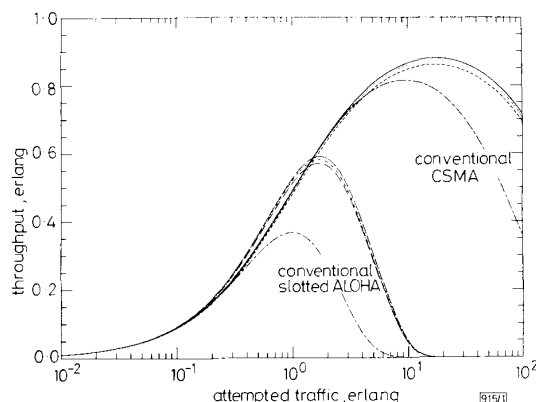


Fig. 1 Effects of packet length on throughput

SNR = 20 dB
BPSK modulation
— $L = 16$ bits/CSMA
..... $L = 64$ bits/CSMA
- - - $L = 640$ bits/CSMA
— $L = 16$ bits/slotted ALOHA
..... $L = 64$ bits/slotted ALOHA
- - - $L = 640$ bits/slotted ALOHA

throughput S and the attempted traffic G for BPSK modulation with a SNR of 20 dB and packet lengths of 16, 64 and 640 bits for both nonpersistent CSMA with $\alpha = 0.01$ and slotted ALOHA³ to show the effects of packet length on the throughput. The curves for conventional nonpersistent CSMA and slotted ALOHA without capture are also shown for comparison. With capture, the maximum throughput of the CSMA with packet length of 16 bits is 0.88 Erlang which is 0.065 Erlang more than the case without capture. The maximum throughput of the slotted ALOHA with the same packet length is 0.591 Erlang which is 0.231 Erlang more than the case without capture. In slow fading channels, if the location of a terminal generating the test packet is 'good', the interference from the other packets is small and all the bits of a packet survive the collision. In contrast, for a test packet originating from a terminal in a 'bad' location, all the bits are subject to high probability of error and the packet does not survive the collisions. As a result, the system shows minimal

sensitivity to the packet length which is in support of the assumptions made in Reference 2 for the slow fading channels.

Fig. 2 shows the effects of coding on the throughput of the CSMA in the slow fading channels for a 64 bits packet BCH

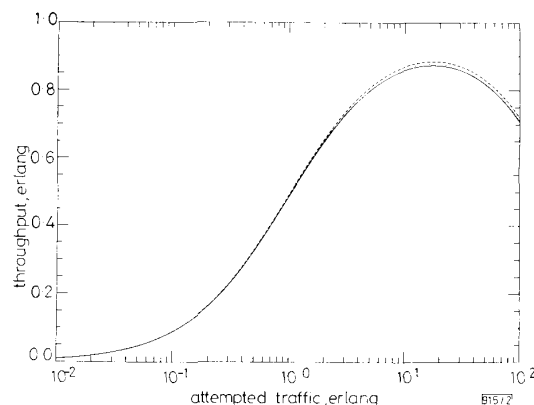


Fig. 2 Effects of coding on throughput

SNR = 20 dB
BPSK modulation
— uncoded
..... (71, 64, 1)
- - - (127, 64, 10)

coded into 71 bits and 127 bits packets. Coding significantly reduces the required transmission power in the absence of packet interference. In the presence of interference, the assumption is that the average power is high enough to provide a close to optimum throughput in the absence of interference signal. When the effects of interference from other users are considered under these circumstances, for the same reason explained for the sensitivity to the length of the packet, the average throughput shows minimal sensitivity to the strength of the coding.

Conclusions: An exact analysis of the throughput of the local packet radio networks using nonpersistent CSMA was presented. It was shown that the capture effect results in approximately 0.06 Erlang improvement in the performance of the CSMA packet radio networks in slow fading channels. This improvement is considerably less than the improvement of approximately 0.2 Erlang for the slotted ALOHA. The throughput was shown to have minimal sensitivity to the length of the packet and the complexity of the coding technique.

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K. ZHANG
K. PAHLAVAN

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Electrical Engineering Department
Worcester Polytechnic Institute
Worcester, MA 01609, USA

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