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SLOTTED ALOHA RADIO NETWORKS WITH PSK MODULATION IN RAYLEIGH FADING CHANNELS

Indexing terms: Telecommunications, Radiocommunication, PSK, Networks

The throughput of a local slotted ALOHA radio network using PSK modulation over Rayleigh fading channels is analysed. The capture effect is related to the modulation technique, signal/noise ratio of the received signal, distribution of terminals in the area and the length of the transmitted packets. Owing to the capture effect a maximum throughput of 0.75, rather than 0.36 with no capture, is predicted. This improved performance is observed in the slow fading channels with a very high signal/noise ratio.

Introduction: Recently there have been efforts to analyse the effects of capture using various approaches. The approaches used in References 1-4 isolate the collision mechanism from the modulation technique used in the system, by defining a capture parameter based on the ratio of the received powers from various terminals. The received power is a function of distribution of the terminals and the channel characteristics between the central station and the terminals. In reality, survival of a packet is a random process which is a function of the modulation technique used for transmission, received signal/noise ratio and the length of the packet. An analysis for a particular distribution in indoor radio channels, in which the modulation is DPSK and the channel is slow Rayleigh fading, is given in Reference 5.

The analysis in this letter presents another approach to relate the capture effects in slotted ALOHA and the modulation technique used for transmission. The analysis is derived for any distribution of the terminals, PSK modulation, and both slow and fast fading channels. The throughput is related to the length of the packets and signal/noise ratio of the channel.

Probability of error in Rayleigh fading channel with packet interference: For ideal coherent binary phase shift keying (PSK), assuming the receiver is phase-locked to the test packet, the receiver decision variable for a bit is⁵

$$r = \alpha_0 a_0 + \sum_{i=1}^N \alpha_i \cos \theta_i a_i + \eta_r \quad (1)$$

where a_i (the transmitted bit for packet i) is ± 1 , α_0 (the amplitude of the received bit for the test packet) is Rayleigh, θ_i is uniform, and η_r and $\alpha_i \cos \theta_i$ as well as $\sum_{i=1}^N \alpha_i \cos \theta_i + \eta_r$ are Gaussian.

Define $\gamma_n = p_0/(p_n + N_0)$ to be the ratio of instantaneous signal power to instantaneous interference plus noise power in the presence of n interfering packets, where p_0 is the received energy per bit for the test packet, p_n is the received energy per bit from the other n packets involved in collision, and N_0 is the variance of the received noise. Then, assuming $w = p_n + N_0$, we have

$$f_{\gamma_n, w}(\gamma_n, w | \bar{p}_0) = f_{p_0}(\gamma_n w | \bar{p}_0) f_{p_n}(w - N_0) w \quad (2)$$

where f_{p_0} and f_{p_n} are the probability distribution functions (PDF) of received power from the test terminal and interference from other terminals, respectively, and $\bar{p}_0$ is the averaged received power from the test terminal. Therefore

$$f_{\gamma_n}(\gamma_n | \bar{p}_0) = \int_{N_0}^{\infty} f_{p_0}(\gamma_n w | \bar{p}_0) f_{p_n}(w - N_0) w dw \quad (3)$$

For the distribution of the form $\rho(r) = 2r \exp[-(\pi/4)r^4]$, where r is the normalised distance between the transmitter and the receiver, and using a fourth-power law for the received signal $\bar{p}_0 = r^{-4}$, the PDFs of $\bar{p}_0$, $\bar{p}_n$, p_0 and p_n are given in Reference 3.

The probability of error for a given γ_n and coherent binary PSK modulation is $p(\gamma_n) = \frac{1}{2} \operatorname{erfc}[\sqrt{(\gamma_n/2)}]$.⁶ The average probability of bit error with n interfering packets for a test terminal with averaged received power of $\bar{p}_0$ is then given by

$$p_{bn}(\bar{p}_0) = \int_0^{\infty} \frac{1}{2} \operatorname{erfc}[\sqrt{(\gamma_n/2)}] \int_{N_0}^{\infty} f_{p_0}(\gamma_n w | \bar{p}_0) f_{p_n}(w - N_0) w dw d\gamma_n \\ = \frac{1}{2} \left[1 - \frac{\bar{p}_0^{1/2}}{(\bar{p}_0 + N_0)^{1/2} + n\pi^{1/2}/2} \right] \quad (4)$$

In fast fading channels, bit errors are assumed to be independent of each other. Therefore, the probability of correct reception of a packet is $p_{cn} = [1 - p_{bn}]^L$, where L is the length of the packet. In slow fading channels, the probability of correct packet reception can be approximated to the probability of correct bit reception.⁵

Throughput of slotted ALOHA system: If the packet generation rate for all terminals is λ , then the average number of packets arriving in a slot is $G = \lambda T$, where T is the slot size. For a Poisson process, the probability that n packets arrive in a slot is

$$R_n = G^n \exp(-G)/n! \quad (5)$$

where $G = \lambda \tau$.

We define $S(\bar{p}_0)$ as the number of packets per time slot successfully received with averaged received power of $\bar{p}_0$. Then

$$S(\bar{p}_0) = \sum_{n=0}^{\infty} R_{n+1} p_{cn}(\bar{p}_0) \quad (6)$$

The total throughput for the system averaged over all locations for the test terminals is then given by

$$S = \int_0^{\infty} f_{\bar{p}_0}(\bar{p}_0) S(\bar{p}_0) d\bar{p}_0 \quad (7)$$

Results and discussion: Fig. 1 shows the relation between throughput S and the attempted traffic G for a 30 dB signal/noise ratio (SNR), with packet sizes of $L = 1$ to 100 bits. The SNR is defined for a terminal located at the median of distribution of the terminals. For slow fading ($L = 1$ bit) the maximum throughput of 0.75 is observed. In fast fading, the error for each bit occurs independently of the other bits. As a result, the effect of capture on throughput is related to the length of the packet; as the length of the packet increases, the maximum throughput decreases. For large values of the

packet size (of the order of 100 bits) the performance is close to slotted ALOHA without capture; while for short packets (of the order of 10 bits) the performance is significantly

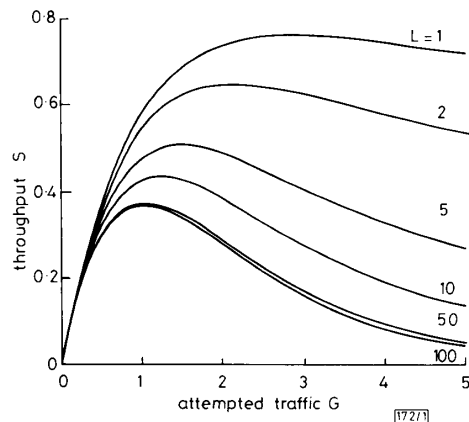


Fig. 1 Effect of packet length on throughput for SNR = 30 dB

improved. Fig. 2 shows the effects of SNR on the throughput of the slow ($L = 1$ bit) and fast ($L = 1, 5, 10$ bits) fading channels. Three different SNRs of 5, 10 and 30 dB are shown. The performance in slow fading shows minimal sensitivity to the level of the noise. For a packet of 10 bits, a maximum reduction of 9% in the throughput is observed over fast fading channels, for a reduction of 25 dB in the SNR. In slow fading, the throughput decreases much more slowly after the peak. As a result, higher stability than conventional ALOHA without capture is predicted.

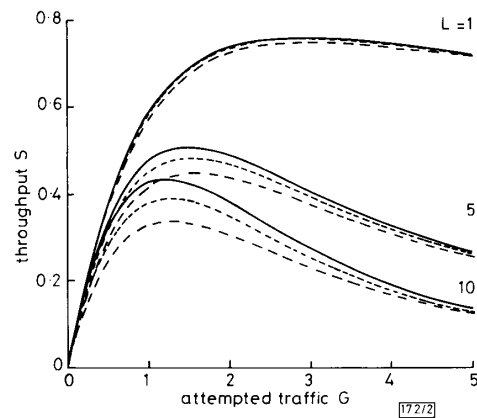


Fig. 2 Effect of white noise on throughput
— 30 dB - - - - 10 dB 5 dB

Conclusions: An analysis for the throughput of a BPSK packet radio network using slotted ALOHA was presented. It was shown that for a system with Poisson-distributed arrivals, a throughput as high as 0.75 is expected for slow fading channels. The throughput of the system over fast fading channels is dependent on the packet size, and is lower than the throughput over slow fading channels. In addition, the slotted ALOHA system in slow fading channels is more stable in high traffic and more robust in noise than in fast fading channels.

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K. ZHANG
K. PAHLAVAN
R. GANESH

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

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ZINC-DOPING OF (511)A LAYERS OF $(\text{Al}_{0.6}\text{Ga}_{0.4})_{0.5}\text{In}_{0.5}\text{P}$ GROWN BY ATMOSPHERIC METALORGANIC VAPOUR PHASE EPITAXY

Indexing terms: Semiconductor devices and materials, Semiconductor lasers, Epitaxy, Semiconductor doping

Zinc-doping into (511)A $(\text{Al}_{0.6}\text{Ga}_{0.4})_{0.5}\text{In}_{0.5}\text{P}$ layers using atmospheric metalorganic vapour phase epitaxy is investigated and compared to that into (100) layers. The doping efficiency is an order of magnitude higher for (511)A layers. Saturation in hole concentration begins at around $1.5 \times 10^{18} \text{ cm}^{-3}$ in (511)A crystals, but at $4 \times 10^{17} \text{ cm}^{-3}$ in (100) crystals.

Quaternary AlGaInP is a material used for the clad layers of visible light-emitting laser diodes which have recently come into commercial use. A problem with this mixed phosphide crystal, however, is the high electric resistivity of the p -type material. Research has shown that the hole concentration for practical laser diodes is limited to the moderate value of around $4 \times 10^{17} \text{ cm}^{-3}$ in (100) epilayers if Zn is used.¹⁻⁴ In an attempt to maximise the performance of laser diodes, the p -clad layer must be minimised, while not spoiling the waveguiding effect. In addition, the hole concentration must be maximised. In this way the series resistance of laser diodes can be lowered to enable CW operation up to $80 \sim 90^\circ\text{C}$. This is a necessary condition to enable the lasers to be used commercially. In addition to low hole concentration, the (100) crystal has another problem. The bandgap of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ grown on the (100) substrate by metalorganic vapour phase epitaxy (MOVPE) is lower by tens of meV than that grown by liquid phase epitaxy (LPE).⁵ The outcome is that the wavelength of the light emitted from lasers with a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ active layer falls into the 670-680 nm range. If the bandgap of the active layer is normal or equal to that of the LPE-grown crystal, the wavelength should be 650-660 nm. We have previously shown that the bandgap was restored if (111)B-oriented substrates were used instead of the (100) substrates currently in use.⁶ A recent letter reported a short-wavelength laser utilising this effect.⁷ We choose (511)A substrates rather than (111)B substrates because they can produce rectangular chips by cleaving. On this plane, as well as on the (111)B plane,* the bandgap shrinkage of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ observed for the (100) crystal completely disappears. This letter, however, deals only with Zn-doping into the (511)A $(\text{Al}_{0.6}\text{Ga}_{0.4})_{0.5}\text{In}_{0.5}\text{P}$ layers.

The phosphide layers were grown by atmospheric-pressure MOVPE using a conventional horizontal quartz reactor and an SiC-coated graphite susceptor. The reactants were triethylaluminium, triethylgallium, trimethylindium, phosphine

* To be published elsewhere