Jyh-Horng Wen and Jin-Fu Chang +
Electrical Engineering Department
National Taiwan University
Taipei, Taiwan, R.O.C.

Abstract

The effect of multipath interference on the performance of packet radios is investigated in this paper. The protocols considered include pure ALOHA and slotted ALOHA. Signal reception with and without capture effect are both considered in the analysis. Mathematical expressions of system throughput and packet delay have been successfully obtained for each protocol. Numerical calculations are used to demonstrate when the multipath interference can be ignored and when it can be disastrous.

I. Introduction

Since the introduction of ALOHA protocol by Abramson[1] numerous papers have appeared to address various aspects of random access techniques. Some of these works treat problems in ground-based packet radio networks. For examples [2] - [3]. Multipath interference resulting from signal reflections is unavoidable in both urban and suburban areas in radio communications. Before packet radios can be deployed in these areas, the effect of multipath interference on the performance of a packet radio network needs to be understood.

Multipath interference is a problem of historical interest and importance. It results from reflections and refractions during signal propagation. In urban areas, the main contributors to multipath interference are buildings. Modeling and analysis of multipath interference can at least be found in [4] - [8]. A multipath channel is usually characterized by number of signal paths, path strengths, and path delays. In general the signal $r(t)$ received at the receiver can be written as follows

$$r(t) = \sum_{i=0}^{\infty} \beta_i s(t-t_i) + n(t) \quad (1)$$

where $s(t)$ denotes the signal transmitted by the transmitter and $n(t)$ the channel noise. In (1), β_i and t_i are used to denote the "signal strength" and the "propagation time from transmitter to receiver" of the i th path. The direct or line-of-sight path is

represented in particular by $i=0$. $\{\beta_i\}_{i=0}^{\infty}$ and

$\{t_i - t_0\}_{i=1}^{\infty}$ are usually modeled as random variables.

For mathematical convenience we shall in this paper assume the following:

- 1) $\beta_0, \beta_1, \dots$ form an independent Rayleigh sequence;
- 2) $t_1 - t_0, t_2 - t_0, \dots$ form a homogeneous Poisson sequence with mean arrival rate λ , i.e., the interarrival times between consecutive paths form an independent and identically distributed sequence with mean interarrival time $1/\lambda$;
- 3) $\{t_i - t_0\}_{i=1}^{\infty}$ and $\{\beta_i\}_{i=0}^{\infty}$ are independent.

In this paper we shall further assume that we have a noise free channel to work with, i.e. $n(t)$ in (1) is set to zero, since so far in most of the studies on random access techniques collision is considered to be the only source of destruction to packets.

In most of the studies on random access techniques, the input process which consists of the newly generated and retransmitted packets is usually assumed to be a Poisson process. Such model of Poisson input will again be used in this study. Let the mean input rate be G packets per T seconds where T is the packet transmission time.

In random access techniques one usually assume that collision between packets yields irrecoverable destruction to the parties involved in the collision. Possible improvement provided by signal capture effect in random accessing has been studied in [9] - [13]. A related study is also done in [14]. In this paper the effect of multipath interference with and without capture effect will both be studied. Two types of capture effect will be considered. Type I is the case where among the signals involved in a collision the signal with the strongest power dominates. Type II is the case where a packet succeeds only when its power is stronger than the sum of the rest packets involved in the collision.

In this study we consider only pure and slotted ALOHA protocols. Other protocols such as CSMA and CSMA/CD are for further investigation. We further assume only the success of line-of-sight packets contributes to the calculation of channel throughput. Possible improvement due to delayed versions of

*This work is supported by the National Science Council, R.O.C. under Grant NSC76-0404-E002-26.

+Senior Member, IEEE; Also with Institute of Information Science, Academia Sinica, Taipei, R.O.C..

the direct packet is also a topic for future research.

II. Results of an N-delay-path channel

In this section we use S and D to denote channel throughput and mean packet delay, respectively. Once S is obtained, $D = R + 1/(G/S - 1)(R + 1 + (K - 1)/2)$, where R denotes the round-trip propagation delay between transmitter and receiver and $(K - 1)/2$ the average rescheduling delay in retransmitting a packet. Both R and K are measured in number of slots.

A. No capture effect

For pure ALOHA we have

$$S = G e^{-2(N+1)G} e^{-\lambda T} \quad (2)$$

while for slotted ALOHA

$$S = G e^{-(2N+1)G} e^{-\lambda T} \quad (3)$$

As a check, if multipath interference does not exist, i.e. $N=0$ and $\lambda=0$, (2) and (3) reduce to $G e^{-2G}$ and $G e^{-G}$ which are simply the throughput results of conventional pure and slotted ALOHA system, respectively.

B. Type I capture effect

In the following we further assume:

- 1) The strength of a received packet maintains at a constant level during its T-sec packet transmission time. In other words, a slow fading channel is implicitly assumed;
- 2) Power levels of different packets are statistically independent.

For pure ALOHA we obtain

$$S = G \int_0^1 e^{-G f_p(u)} \left(\sum_{i=0}^N T_i g_i(u) \right) \rho u^{\rho-1} du \quad (4)$$

where

$$T_i = \frac{(\lambda T)^i e^{-\lambda T}}{i!}, \quad 0 \leq i \leq N-1$$

$$T_N = 1 - \sum_{i=0}^{N-1} T_i, \quad f_p(u) = 2 \sum_{i=0}^N u^{\frac{\mu_i}{\mu_1}}$$

$$g_i(u) = \frac{1}{\pi} (1 - u^{\frac{\mu_i}{\mu_1}})$$

In (4) μ_i represents the mean power level of the i th path and ρ the capture ratio. Next for slotted ALOHA we obtain

$$S = G \int_0^1 e^{-G f_s(u)} \left(\sum_{i=0}^N T_i g_i(u) \right) \rho u^{\rho-1} du \quad (5)$$

where

$$f_s(u) = u^{\frac{\mu_0}{\mu_1}} + 2 \sum_{i=1}^N u^{\frac{\mu_i}{\mu_1}}$$

C. Type II capture effect

For pure ALOHA we have

$$S = G e^{-2G \left[\sum_{i=0}^N \frac{\mu_i}{\mu_0} \right] \sum_{i=0}^N \left[\left(\frac{1}{\pi} \frac{1}{1 + \frac{\mu_i}{\mu_0}} \right) T_i \right]} \quad (6)$$

while for slotted ALOHA

$$S = G e^{-G \left[\frac{\rho}{1+\rho} \sum_{i=1}^N \frac{\mu_i}{\mu_0} \right] \sum_{i=0}^N \left[\left(\frac{1}{\pi} \frac{1}{1 + \frac{\mu_i}{\mu_0}} \right) T_i \right]} \quad (7)$$

III. Numerical examples and discussions

In the following examples, we assume $R=1$ and $K=5$. Figs. 1 and 2 are done when capture effect is not considered. Fig. 1(a) shows the effect of multipath interference, i.e. N, on the performance of pure ALOHA. In this figure we assume $\lambda T=0$ and plot delay versus throughput. Here $\lambda T=0$ means $\lambda=0$ or equivalently $1/\lambda=\infty$ in other words, two consecutive delay paths are separated by an interval which is infinitely long on the average. This does not at all say that the multipath interference does not exist. On the contrary, a packet will be affected by the delay packets of those which were transmitted infinitely long time ago. Fig. 1(b) shows similar result for slotted ALOHA. From these two figures we observe the severe degradation caused by multipath interference. The degradation is even worse for slotted ALOHA.

Figs. 2(a) and 2(b) show the effect of λT on pure ALOHA and slotted ALOHA, respectively. Since with constant T larger λT implies shorter inter-arrival times of delay paths. We observe that the degradation is more severe. The tendency of course is reasonable. In both Figs. 1 and 2, we observe that larger N or larger λT will bring slotted ALOHA close to pure ALOHA.

Figs. 3 and 4 are plotted for type I capture effect. In these two examples we assume $\rho=\sqrt{2}$, $\lambda T=50$, $R=1$ and $K=5$. Fig. 3 is done for $\mu_0=\mu_1=\dots=\mu_N$ while Fig. 4 is done for $\mu_i/\mu_{i-1}=0.5$. Figs. 3(a) and 4(a) show D vs S for pure ALOHA while fig. 3(b) and 4(b) are done for slotted ALOHA. We observe from Fig. 3 the effect of multipath interference is still disastrous when $\mu_0=\mu_1=\dots=\mu_N$. However when $\mu_i/\mu_{i-1}=0.5$ both protocols seems operational in the presence of multipath interference if signal capture can be realized in the receiver.

Figs. 5 and 6 are plotted for type II capture effect. In these two examples, we use the same set

of parameters as in Figs. 3 and 4. Fig. 5 is done for $\mu_0 = \mu_1 = \dots = \mu_N$ while Fig. 6 is done for $\mu_1/\mu_{i-1} = 0.5$. Figs. 5(a) and 6(a) show D vs S for pure ALOHA while Figs. 5(b) and 6(b) are done for slotted ALOHA. Again we observe that multipath interference can be disastrous when $\mu_0 = \mu_1 = \dots = \mu_N$ and when $\mu_1/\mu_{i-1} = 0.5$ both protocols are operational if capture can be realized in the receiver. Comparing Figs. 5 and 6 with Figs. 3 and 4 we observe that type I capture shows better performance which is reasonable.

References

- [1] N. Abramson, "The ALOHA system—Another alternative for computer communications," in Proc. 1970 Fall Joint Computer Conference, AFIPS Press, vol. 37, 1970, pp. 281-285.
- [2] F. A. Tobagi, "Analysis of a two-hop centralized packet radio network—Part I: Slotted ALOHA," IEEE Trans. Commun., vol. COM-28, pp. 196-207, Feb. 1980.
- [3] H. Takagi and L. Kleinrock, "Throughput-delay characteristics of some slotted-ALOHA multihop packet radio networks," IEEE Trans. Commun., vol. COM-33, pp. 1200-1207, Nov. 1985.
- [4] R. E. Ziener and W. H. Tranter, Principles of Communication: Systems, Modulation, and Noise. Boston: Houghton Mifflin, 1976, pp. 415-423.
- [5] G. L. Turin, "Communication through noisy, random-multipath channels," in IRE National Convention Record, Part V, 1956, pp. 154-166.
- [6] G. L. Turin, "Simulation of urban locator systems—a preliminary report," in Proc. 3rd Hawaiian International Conference on System Sciences, Part 2, 1970, pp. 809-812.
- [7] G. L. Turin et al., "A statistical model of urban multipath propagation," IEEE Trans. Veh. Technol., vol. VT-21, pp. 1-9, Feb. 1972.
- [8] J. F. Chang, "The effect of multipath interference on the performance of a digital matched filter," IEEE Trans. Commun., vol. COM-27, pp. 737-745, April 1979.
- [9] D. J. Goodman and A. A. M. Saleh, "Local ALOHA radio communication with capture and packet buffers," in Proc. IEEE Globecom, 32.4, New Orleans, Dec. 1985, pp. 984-990.
- [10] J. J. Metzner, "On improving utilization in ALOHA network," IEEE Trans. Commun., vol. COM-24, pp. 447-448, April 1976.
- [11] N. Abramson, "The throughput of packet broadcasting channel," IEEE Trans. Commun., vol. COM-25, pp. 117-118, Jan. 1977.
- [12] F. Kuperus and J. Arnbak, "Packet radio in a Rayleigh channel," Electronics Letters, vol. 18, pp. 506-507, June 1982.
- [13] C. Namislo, "Analysis of mobile radio slotted ALOHA networks," IEEE J. Selected Areas in Commun. vol. SAC-2, pp. 583-588, July 1984.
- [14] R. Nelson and L. Kleinrock, "The spatial capacity of a slotted ALOHA multihop packet radio network with capture," IEEE Trans. Commun., vol. COM-32, pp. 684-694, June 1984.

51.1.4.

Fig. 4 (a)

Fig. 5 (a)

Fig. 6 (a)

Fig. 4 (b)

Fig. 5 (b)

Fig. 6 (b)

51.1.5.