Packet Radio and the Factory of the Future

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Abstract

Spread-spectrum packet radio networks are currently being considered for use in the factory of the future. These networks have the resistance to fading and the inherent multiple access capability that are necessary to interconnect the Autonomous Guided Vehicles (AGVs) and other mobile machines and personnel that will be used in the future factory.

This paper reports on progress in the design and analysis of spread-spectrum packet radio networks for the factory. This progress includes the accurate analysis of the probability of packet success in a direct sequence spread spectrum communication channel and analytical results on the transient behavior of packet radio networks. The first use of these networks will be to provide communications between a transport system controller and a fleet of AGVs.

1. Introduction

Increased efficiency, fast turnaround, flexibility, reliability, reduced in-process inventory, and more intelligent use of available machines and materials are some of the fundamental goals that have been set for the factory of the future. In research conducted at Purdue's Engineering Research Center for Intelligent Manufacturing Systems, it has become clear that these goals cannot be achieved without the use of sophisticated communication networks.

The goal of the research reported here is to develop the networks that will be needed. This involves not only finding the solution to the communication problems that are already present in the factory, but establishing a reasonable course of evolution toward the best solution for interconnecting the mobile machines of the future factory.

We have thus pursued a dual course of research. We have established a strong effort in the modeling and analysis of current communication networks to determine their suitability for the factory environment and have also begun the conceptualization, design, and analysis of the packet radio networks we believe will be necessary for the interconnection of mobile machines in the future.

The question of immediate interest is how to develop a reliable communication network for the the factory's transport system. This network should ideally link not only the wire-guided vehicles, but also the free-ranging vehicles that have been developed over the last few years at Caterpillar and at Purdue, and any other workstations, mobile machines, or factory personnel that might need direct interaction with the transport system.

Wire, coax, and optical fiber based networks are not appropriate for interconnecting such an inhomogeneous and possibly mobile group of transmitters and receivers. The only possibility is some type of radio or optical communication channel. We have focused on the development of the radio channel.

Another reason for focusing on the radio channel is that radio communication schemes are already in use with some factory transport systems. Interlake Corp. has developed a simple polling scheme over a radio channel for communicating with its wire-guided vehicles. Thus, we can concentrate immediately on solving the problems they have encountered and on designing the next generation of radio network for them to use. This can provide the evolutionary approach that is necessary to ensure that our research effort is not expended on developing a communication system that will never be used.

The first step taken at Purdue toward the development of a packet radio network for the factory was an experiment to characterize the radio channel inside the factory [1]. This was especially important for determining the best frequencies at which to transmit and for determining why Interlake was encountering situations in which they were within sight of a vehicle but could not communicate with it over the radio. This experimental effort clearly identified the problem to be one of fading, and also helped to characterize the noise environment inside the factory.

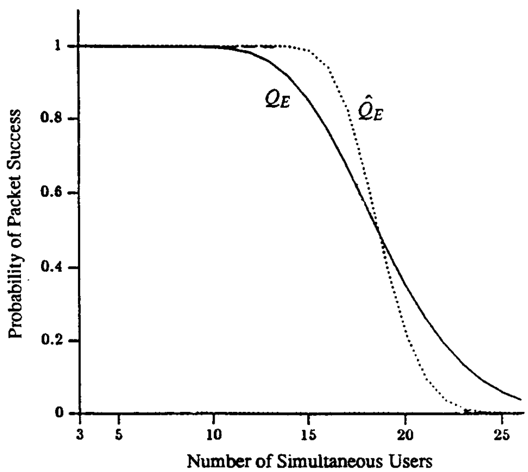
To combat the fading problem and to provide multiple-access capability, we have decided to use spread-spectrum random multiple-access networks. In the following two sections, we report briefly on our efforts to determine whether these networks can provide the real-time communication capability required in the factory.

2. Analysis of Packet Error Probability [2-4]

This effort focuses on determining the key quantity needed to determine the delay performance of the spread-spectrum network: the probability that a packet which is transmitted by any user or machine will be successfully received.

Obtaining these results required the development of new techniques for the analysis of spread spectrum systems. These new techniques allow precise analytical determination of the packet error probability. They also allow the effect of coding to be studied.

In the figure appearing below, we show some of the results we have obtained. The left axis is the probability of success for a given packet when it is one of a given number of packets that are transmitted simultaneously. The plot compares the previous results, denoted $\hat{Q}_E$, which are based on a standard Gaussian approximation and do not account for bit-to-bit error dependence, with new results, denoted Q_E, which are based on an improved Gaussian approximation and account



for bit-to-bit error dependence.

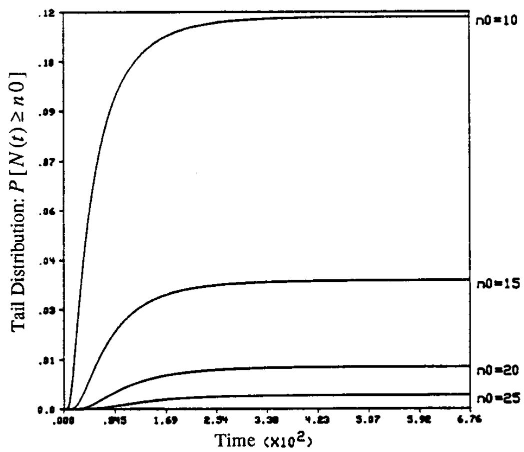
3. Analysis of Transient Behavior of the Network [5-6]

Once the probability of packet success has been determined it is possible to perform delay analysis of the network. The goal here is to determine how long it takes to transmit a packet across the network. Such an analysis is usually carried out under the assumption that the network is operating in equilibrium and that all the packet arrival processes for the network are jointly stationary. This is, unfortunately, almost never the case in a real factory environment. Thus, in addition to the usual efforts to determine the delay performance in equilibrium, we have addressed the problem of characterizing the performance these networks when they are not operating in equilibrium.

We have shown that if $\pi_n(t)$ is the probability vector of length m specifying the likelihood that the communication channel is in one of m states when there are n packets awaiting transmission on the network, then

$$\pi_{n+1}(s) = \pi_n(s) W(s) \qquad n = 1, 2, \cdots$$

where $\pi_n(s)$ is the Laplace transform of $\pi_n(t)$ and $W(s)$ is an $m \times m$ matrix. This result has allowed to obtain analytical results like those shown in the graph below. This graph shows the probability, as a function of time, that $N(t)$, the number of packets awaiting transmission at time t, is *greater than* 10, 15, 20, or 25. In the case shown here, it was assumed that at time 0 there were no packets awaiting transmission. This plot thus shows how the network will behave immediately after it has been



switched on.

4. Acknowledgement

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5. References

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