Performance of a DS/CDMA Packet Network in an Indoor Wireless Infrared Channel

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ABSTRACT

In this paper, performance of a CDMA-based packet transmission system is analyzed and simulated in a wireless infrared channel. The indoor wireless infrared channel is modeled as a non-directed diffuse link. The pulse position modulation (PPM) is used as a modulation scheme. From the simulation results, it is shown that the RS coding is very effective in improving the packet-delay characteristics of the CDMA-based packet transmission system. The performance improvement is more significant especially when the infrared channel is in a worse condition.

Ⅰ. INTRODUCTION

Recently, there has been an increasing demand for indoor wireless communication systems. An idea of using infrared as a medium for indoor wireless systems was first proposed by Gfeller in 1979 [1]. Afterwards, many researchers such as Barry and Kahn have proposed an infrared wireless communications for applications to the indoor LANs in the 1990's [2,3]. The infrared medium has many advantageous characteristics compared to radio waves. The advantages include: 1) robustness to eavesdropping, 2) short wavelength leading to spatial diversity which makes an infrared channel immune to multipath fading, 3) unlimited communication resources due to unregulation by law, and 4) coexistence with other radio systems which comes from the fact that the radio and infrared systems do not interfere each other.

To accommodate many users in the indoor infrared wireless environment, an efficient multiple access scheme is required [4]. The CDMA (code division multiple access) has been considered as a promising multiple access technique because it the CDMA system does not need frame synchronization as in TDMA (time division multiple access) system. So far, most of research on the CDMA system in the infrared channel has focused on the analysis and design in the bit level. However, there has not been yet any paper that deals with packet transmission aspects in the wireless infrared channel. The infrared CDMA network allows us to deploy flexible network design in the sense that bit error rate (BER) depends on the number of active users in the infrared CDMA network.

In this paper, the performance of a CDMA-based packet transmission system with RS (Reed-Solomon) coding is analyzed and simulated in a wireless infrared channel. The indoor wireless infrared channel is modeled as a non-directed diffuse link. The pulse position modulation (PPM) is used as a modulation scheme. The performance of the network is evaluated in terms of packet throughput and delay that are derived from queueing theory. To decode the RS codeword, BDD (bounded distance decoding) algorithm is used. We consider a slotted network where time is divided into discrete slots synchronized across the network. The packets are allowed to transmit only at the beginning of each time slot. The basic motivation of this research comes from an idea that the performance assessed through analytic approach for an infrared CDMA network can be closer to the actual network performance by bridging a physical layer and a data link layer. Therefore, the FEC coding scheme is chosen as a kind of physical layer issues while packet throughput and delay are derived as characteristics of the data link layer.

The paper is organized as follows: In Section II, the configuration of an infrared CDMA network and the RS coding scheme are described. And, the indoor infrared wireless channel is modeled. In Section III, packet throughput is derived. Simulation results are presented in Section IV, and conclusions are drawn in Section V.

II. SYSTEM MODEL

II. 1. Infrared CDMA Network

The configuration of an infrared CDMA network is shown in Fig. 1. The physical configuration of the network is a kind of star network. In a slotted network, the time is divided into discrete slots which are synchronized across the network. The packets are allowed to transmit only at the beginning of each time slot.

Block diagrams of transmitter and receiver for the infrared CDMA system are shown in Fig. 2. (a) and Fig. 2. (b). As shown in Fig. 2. (a), the information data bits are first encoded in the RS encoder, and then modulated by M-ary PPM modulator. In the RS encoder, the data bit sequence is converted into a sequence of channel symbols.

In an M-ary PPM, an M-ary symbol is transmitted in a symbol interval which is divided into M equally spaced slots. Each symbol in the M-ary alphabet is assigned to one of the M slots. A symbol is transmitted by sending a pulse in only one slot. The encoded and modulated data bits are transmitted through the pulse transmitter. The transmitted signals from each user go through indoor infrared wireless channel. In Fig. 2. (b), the received signal is correlated with its own signature sequence at the correlator. The correlator output passes through photodetector and is then PPM demodulated. The PPM demodulator output is processed to recover the transmitted symbols. The RS decoder converts the recovered symbols back to the data bits by inverse mapping of the RS encoder.

II. 2. Indoor Infrared Channel Model

There have been three kinds of models for an indoor infrared wireless channel: 1) directed ling-of-sight (LOS) link, 2) non-directed LOS link, and 3) non-directed diffuse link. In the directed or non-directed LOS links, the LOS path is essential for reliable communications. However, in an indoor infrared wireless channel, various kinds of obstacles such as walls, ceiling, and furniture typically exist between transmitter and receiver. Therefore, non-directed diffuse link becomes a more appropriate channel model because communications depend mainly on diffusive reflections from surrounding obstacles in an indoor infrared wireless channel. In this paper, we adopt ceiling bounce model whose impulse response is given by

$$h_l(t) = \gamma_l \frac{6a_l^2}{(t+a_l)^7} u(t), \tag{1}$$

where γ_l is path-loss of the *lth* user and $a_l = 12D_l\sqrt{11/13}$ for delay spread D_l of the *lth* user. The ceiling bounce model is known to be an accurate and simple model for an indoor infrared wireless channel.

III. PERFORMANCE ANALYSIS

The uncoded symbol error probability for the *lth* user is given by

$$P_{us} = 1 - \Pr\{Z_{l,1} > Z_{l,2}, \cdots, Z_{l,1} > Z_{l,M}\}, \tag{2a}$$

$$= 1 - \Pr\{Z_{l,1} > Z_{l,2}\} \cdots \Pr\{Z_{l,1} > Z_{l,M}\}, \tag{2b}$$

$$= 1 - \prod_{i=2}^{M}\left(1 - Q\left(\frac{Y_{l,1} - Y_{l,i}}{\sqrt{2\sigma^2}}\right)\right), \tag{2c}$$

where $\sigma^2 = WN_0/T_c$ is noise variance of $N_{l,i}$. The RS-coded symbol error probability is upper bounded by

$$P_s \le \frac{1}{N}\sum_{i=t+1}^{N} i \binom{N}{i} P_{us}^{\,i} (1-P_{us})^{N-i}. \tag{3}$$

Then, the RS-coded bit error probability is given by

$$P_b \le \frac{2^{J-1}}{2^J - 1} P_{es}, \tag{4}$$

where J is the number of bits in a symbol.

For the performance analysis, the followings are assumed: 1) optical characteristics of receiver components for each user are identical, 2) synchronization between the transmitters and the intended receiver is perfect in a chip and a bit levels. 3) infrared CDMA network is modeled as a slotted CDMA network, and 4) intensity of each transmitter is the same ($A_l = A (1 \le l \le L)$).

In the slotted infrared CDMA network, at the beginning of each slot, each terminal is either blocked or unblocked, depending on whether its previous packet was successfully transmitted or not. Only the unblocked terminal can generate a new packet with probability p_n and the blocked terminal retransmit its backlogged packet with probability p_r in each slot. At the end of each slot, the central receiver broadcasts feedback messages to all the terminals simultaneously.

The dynamics of this network can be modeled by a multidimensional Markov chain. The number of blocked terminals can be modeled by a Markov chain where a state represents the number of blocked terminals. The state space of this Markov chain is $\{0,1,\cdots,L\}$ where L is the number of terminals in the network. The transition from one state to another is determined by the difference between the number of new unsuccessful transmissions and successful retransmissions. The successful new transmissions and the unsuccessful retransmissions have no influence on the system state.

In a given slot, there are $N_t = N_n + N_r$ packets where N_n and N_r are the number of new and backlogged packets, respectively.

Packet throughput in a steady state is defined as the average number of successfully transmitted packets per slot, and given by

$$T_p = \sum_{l=1}^{L} l \cdot S(l)[\sum_{m=0}^{l} \pi(m)\xi(l \mid m)], \qquad (5)$$

where $S(l)$ is the packet success probability at the state l and given by

$$S(l) = \sum_{i=0}^{t} \binom{N}{i} P_b(l)^i (1 - P_b(l))^{N-i}, \qquad (6)$$

t is error correcting capability in a block of length N, and $\xi(l \mid m)$ is composite (newly generated and retransmitted) packet arrival distribution function (newly and retransmitted) and given by

$$\xi(l \mid m) = \sum_{i=\max(l-m,0)}^{\min(l,L-m)} B(i, L-m, p_n) \cdot B(l-i, m, p_r), \qquad (7)$$

for binomial distribution

$$B(i, j, \rho) = \binom{j}{i} \rho^i (1-\rho)^{j-i}. \qquad (8)$$

IV. SIMULATION RESULTS

The simulations are performed with the following parameters: 1) photodetector responsivity $\mu = 0.5$, 2) concentrator gain $G = 2.5$, 3) photodetector area $B = 1$, 4) chip duration $T_c = 10^{-8}$, 5) (15,8) RS coded 16-ary PPM, 6) packet length = 1024 bits, 7) packet generation probability $p_n = 0.02$, and 8) OOC (optical orthogonal code) with length $F = 500$ and weight $W = 5$.

In Fig. 3, packet success probability vs. channel BER is shown for varying error correction capability. It is shown that the packet success probability drastically increases as the error correction capability, t, becomes higher. The $t = 0$ represents the uncoded case. As is seen from the figure, the RS coding is effective especially when the channel BER is very high, that is, the channel is in a harsh condition.

In Fig. 4, packet throughput vs. SNR is shown for varying error correction capability. It is shown that the effectiveness of the RS coding becomes more distinct when the SNR is low. It is also confirmed that the RS coded system achieves improved performance over the uncoded system.

V. CONCLUSIONS

We have examined the implications between the physical layer and data link layer issues. From the simulation results, it is confirmed that the RS coding is very effective to improve the throughput-delay performance of the infrared CDMA network. The performance improvement was very distinct when the channel BER is low or the SNR is low. The results in this paper can be applied to the design of CDMA-based infrared indoor wireless LANs.

REFERENCE

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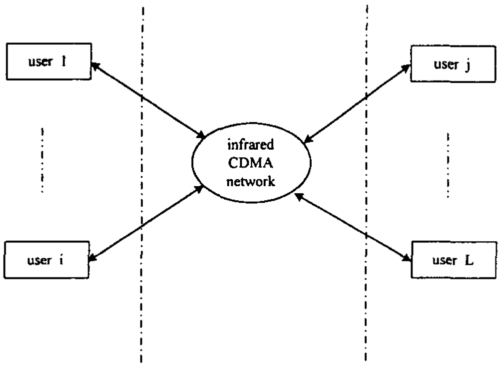


Fig. 1. Configuration of an infrared CDMA network.

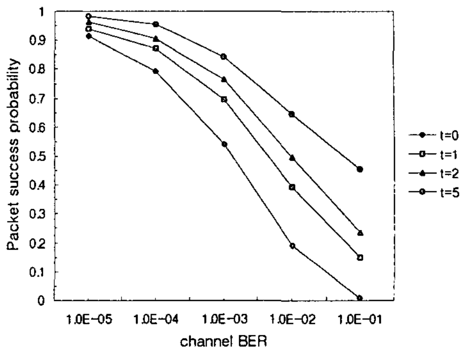
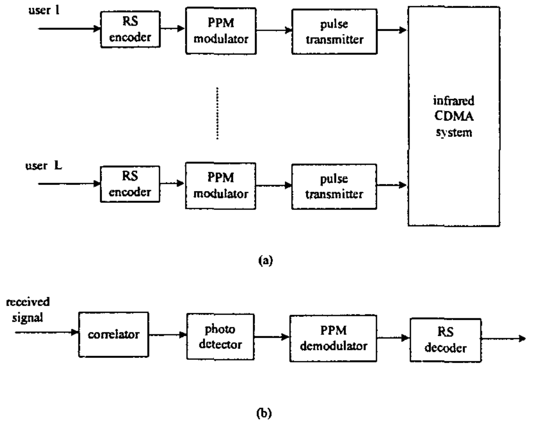


Fig. 3. Packet success probability vs. channel BER for varying error correction capability.



(a)

(b)

Fig. 2. Block diagram of transmitter and receiver of an infrared CDMA system. Transmitter. (b) Receiver.

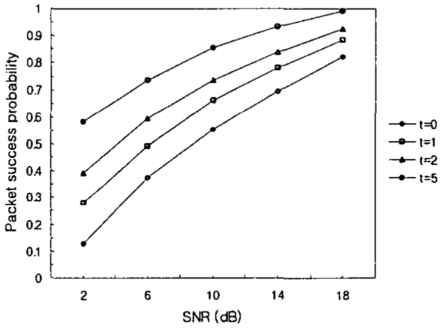


Fig. 4. Packet success probability vs. SNR for varying error correction capability.