PACKET THROUGHPUT IN HYBRID DS/SFH CDMA SLOTTED
ALOHA SYSTEMS FOR WIRELESS COMMUNICATIONS

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ABSTRACT

The hybrid direct-sequence/slow frequency hopping code division multiple-access (DS/SFH CDMA) technique is proposed for wireless packet transmission channel. We consider that the channel is hybrid DS/SFH CDMA slotted ALOHA (H-CDMA) channel. The probability of packet success and channel throughput are derived. The numerical analysis will be performed with several level of processing gain and forward error correction (FEC) capability. The numerical results show that an increase in H-CDMA processing gain and FEC capability produces an increase in maximum peak of channel throughput and offered load. The throughput of this channel is compared to the multichannel narrow-band slotted ALOHA (M-ALOHA) channel that occupies approximately the same bandwidth. At

offered load level below and slightly above the point that achieve maximum peak throughput, the H-CDMA produces throughput better than the M-ALOHA.

Keywords: DS/SFH, CDMA, throughput, multiple-access, Nakagami fading, wireless

1. INTRODUCTION

The hybrid DS/SFH CDMA is developed for wireless communication channel because it can combine the effectiveness of anti-multipath of DS, with the good anti-partial-band-jamming and the good anti-near-far problem of FH [1]. In previous paper we proposed the performance analysis of multi-processing gain hybrid DS/SFH CDMA for multirate wireless communications. We now propose the hybrid DS/SFH CDMA technique for the

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wireless packet transmission channel. The system is considered as the large number of independent users sharing a common communication channel. This communication channel employs the hybrid DS/SFH CDMA technique for transmit data packets. We can thus consider that the system is H-CDMA channel. We will derive the throughput of this channel and compare to the M-ALOHA channel that occupies approximately the same bandwidth.
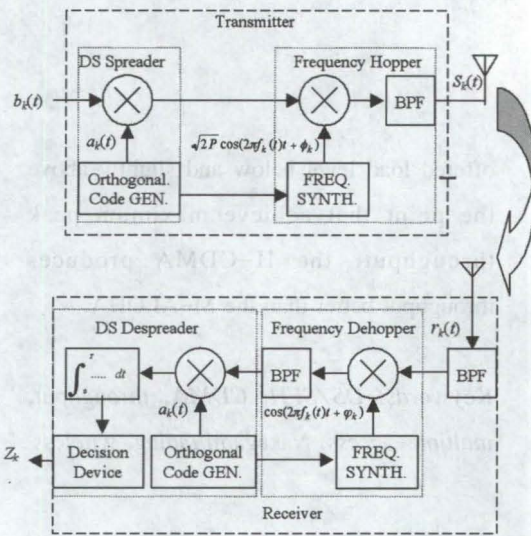

Fig.1 Hybrid DS/SFH CDMA transmission system.

2. SYSTEM MODEL

The transmission system that used in this paper is shown in Fig.1. The system consists of transmitter, channel, and receiver. The definition of each part is described below.

2.1 Transmitter

The data bit is spreaded by N chips of orthogonal spreading sequences in the DS spreader section, and sent in one carrier that selected from q available frequencies in the hopper section. The next data bit is spreaded by the new N chips and sent in another one carrier that hops to the new one in q

available frequencies too. Spreading sequence controls the hopping carrier to produces the randomly hopping pattern with a rate equal to data rate. From the first part in Fig.1, the transmitted signal of kth user at time t can be derived as [2]

$$s_k(t) = \sqrt{2P}b_k(t)a_k(t)\cos\left[2\pi f_k(t)t + \phi_k\right] \quad (1)$$

where P, $b_k(t)$, $a_k(t)$, $f_k(t)$, and ϕ_k are ,respectively, the signal power, data sequence, spreading sequence, hopping frequency, and phase of transmitted signal of kth th user.

2.2 Channel

Transmission channel is the wireless medium with transfer function [1,2]

$$h(t) = \sum_{l=1}^{L} \beta_l \delta(t - \tau_l) \exp(j\gamma_l) \quad (2)$$

where δ, β_l, τ_l and γ_l are, respectively, the delta function, gain, delay, and phase of lth path. And L is the total number of path in the network.

The channel is assumed to be a Nakagami fading channel with probability density function of the path gain β, as shown below

$$p(\beta) = 2/\Gamma(m)(m/\Omega)^m \beta^{(2m-1)} e^{-(m/\Omega)/\beta^2} \\ , \beta \geq 0, m \geq 1/2 \quad (3)$$

where β is the path gain value, $\Gamma(m)$ is Gamma function, $\Omega = E[\beta^2]$ and $m = \Omega^2 / E[(\beta^2 - \Omega)^2]$. Here, the symbol $E[X]$ means the expected value of X.

2.3 Receiver

We assume that the transmission path between any user and base station (reference receiver) has only one. Thus the received signal of

the reference receiver at time t can be derived below [1-3]

$$r(t) = \sqrt{2P} \sum_{k=1}^{K} \beta_k b_k(t-\tau_k) a_k(t-\tau_k)$$
$$\cos[2\pi f_k(t)t + \varphi_k] + n(t) \qquad (4)$$

where β_k, τ_k, and $\varphi_k = \phi_k - 2\pi f_k(t)\tau_k$ are, respectively, the gain, the delay, and the phase of the path that associated with k^{th} user. And K is the total active users in the system. And $(n)t$ is a noise function at time t.

In the third part of Fig.1, the received signal, i.e. $(r)t$, will be processed in five orderly steps in order to retrieve the original data signal as described in [2]. The output signal of the receiver for the 1st user can be expressed below [2]

$$Z_1 = \int_0^T r(t)a_1(t)\cos[2\pi f_1(t)t + \varphi_1]dt = D + I + \eta \qquad (5)$$

where D, I, and η are ,respectively, the desired signal, interference signal from other users with same frequency (calls "*hit*"), and the additive white Gaussian noise (AWGN) that passed through the receiver. And T is the data bit duration.

By assuming that the transmission path equal to one and the transmission method is an asynchro nize. Then, $\tau_1 = 0$ and $\beta_1 = \beta$. Let a current trans mitted data bit of 1st user described by b_1^0 for 0<t<T. The desired signal is given from (4) and (5) by setting K=1 and $(n)t = 0$ as follows [2]

$$D = \sqrt{\frac{P}{2}}\beta b_1^0 T \qquad (6)$$

The interference signal, I, is given from (4) and (5) by setting $k > 1$, $f_k(t) = f_1(t)$, and $n(t) = 0$ as follows [2]

$$I = \sqrt{\frac{P}{2}} \sum_{k=2}^{K} \beta_k \cos(\varphi_k - \varphi_1)\left[b_k^{-1}R_{k,1}(\tau_k) + b_k^0\hat{R}_{k,1}(\tau_k)\right] \qquad (7)$$

where $R_{k,1}(\tau_k)$ and $\hat{R}_{k,1}(\tau_k)$ are the continuous-time partial cross-correlation functions [1-3]. Here, b_k^{-1} and b_k^0 are the successive previous and current transmitted data bit of kth user, respectively.The variance of I is given by [2,3], as below

$$\sigma_I^2 = E[I^2] = \frac{PT^2}{6N}(K-1)\Omega \qquad (8)$$

Finally, the variance of AWGN term that passed through the receiver is given by [2], as below

$$\sigma_\eta^2 = \frac{N_0 T}{4}\Omega \qquad (9)$$

3. PERFORMANCE ANALYSIS

The signal-to-noise ratio is proportional to the number of users that used the same carrier in the same time. It can be derived as follow

$$SNR(K) = \frac{E[D^2]}{E[I^2] + E[\eta^2]} = \frac{D^2}{\sigma_I^2 + \sigma_\eta^2} \qquad (10)$$

Here, K is the number of the active users that access the system. The probability of bit error obtains by using the improved Gaussian approximation method as follow [2,3]

$$P_e(K) = \int_0^\infty Q[SNR(K)]p(\beta)d\beta \qquad (11)$$

where $Q[x]$ is the Q function of variable x, [1,4]. But, now the system has q carrier frequencies. The using of any one carrier can be considered as Binomial distribution. Then, it has cumulative density function as follow [1]

$$P_h(K) = \sum_{k=0}^{K}\binom{K}{k}\left(\frac{1}{q}\right)^k\left(1-\frac{1}{q}\right)^{K-k} \qquad (12)$$

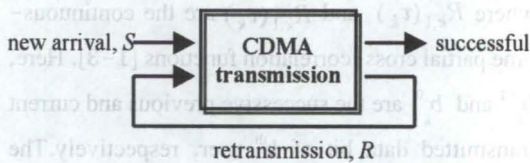new arrival, S → [CDMA transmission] → successful

retransmission, R

Fig. 2   Packet data trasmission channel that uses the hybird DS/SHF CDMA technique.

The number of users that use any one carrier to transmit a data bit is an integer value between 0 and K. We denote it as k = 0, 1, 2,...K. Thus the probability of bit error in this system, $P_E(K)$, is the summation of probability that k uses employ reference carrier ,$P_h(K)$, multiplied the probability of error when active user of reference carrier equal to k,$P_e(K)$, as shown below [2]

$$P_E(K) = \sum_{k=0}^{K} P_e(k)\binom{K}{k}\left(\frac{1}{q}\right)^k\left(1-\frac{1}{q}\right)^{K-k} \quad (13)$$

Let consider the packet data transmission with L-bit lengths and employed FEC with j-bit capabilities. The probability of packet transmission success, $Q_E(K)$, can be expressed as [4]

$$Q_E(K) = \sum_{i=0}^{j}\binom{L}{i}\left(P_E(K)\right)^i\left(1-P_E(K)\right)^{L-i} \quad (14)$$

Let the wireless communication channel uses the hybrid DS/SFH CDMA technique to transmit the data packet as shown in Fig.2. The system is considered as the large number of independent users sharing a common communication channel. The channel receives the new arrival packet with rate S and the previous unsuccessful transmitted packet with rate R. Both are assumed to be Poisson distribution. The offered channel load is also Poisson distribution

with rate $G = S + R$. When the channel is assumed to be stationary, throughput rate of the channel will be S. And every packet will be transmitted until success under finished-time interval. From [5], the throughput of DS/CDMA slotted ALOHA channel can be expressed as

$$S = Ge^{-G} + Ge^{-G}\sum_{k=1}^{\infty}\frac{G^k}{k!}Q_E(k+1) \quad (15)$$

The term Ge^{-G} represents the throughput given that there are at least one user can access the channel. The remaining term represents the additional throughput realized by using CDMA technique. Here, we replace the quantity of Q_E of DS by the quantity of Q_E of DS/SFH.

The H-CDMA channel occupies approximately the same bandwidth as the $N \cdot q$ parallel M-ALOHA channel. The quantity $N \cdot q$ is overall processing gain (spreading factor) of the hybrid DS/ S F H technique. From [5], the throughput of M-ALOHA channel can be expressed as

$$S = Ge^{-(G/N \cdot q)} \quad (16)$$

We can now perform the numerical analysis and compare the results.

4. NUMERICAL RESULTS

In Fig. 3, the actual and effective throughput increases proportional to the processing gain $N \cdot q$. An increase in number of $N \cdot q$ improve both actual and effective throughput. The number G that obtains maximum peak throughput, denoted by G^*, closes to the number of $N \cdot q$. At the offered load levels below G^* the channel is considered stable, since an increase in the offered load produces an increase

in the throughput. At offered load levels above G^* the channel is considered saturated, an increase in the offered load produces a decrease in the throughput. These because the number of transmitted packet exceeds the multiple-access capability of the system.

In Fig.4, an increase in number of j makes the number of G^* close to the number of $N \cdot q$. At offered load levels above G^* the slope of an effective throughput decreases proportional to the increase in the number of j. These result because the number of data in the packet decreases since the number of error control code in the packet increases. Such as $G = 20$, using $j = 5$ produces the throughput greater than using $j = 20$, whereas $G = 25$, using $j = 5$ produces the throughput less than using $j = 20$.

Fig. 5 and 6 show the comparison of effective throughput between H-CDMA and M-ALOHA system that occupy approximately the same bandwidth. The figures show that the H-CDMA system produces maximum throughput greater than the M-ALOHA system. The increase in the number of $N \cdot q$. and j produce an increase in the difference of their throughput. The throughput of H-CDMA reaches to the maximum peak rapidly, whereas the throughput of M-ALOHA reaches very slowly. At region of offered load around G^* the H-CDMA produces throughput better than the M-ALOHA. But at offered load levels above G^* the throughput of H-CDMA decrease rapidly. At one point of G the throughput of both become the same value. After this point, the H-CDMA's throughput is less than the M-ALOHA's throughput. But, this point occurs above the maximum peak point of M-ALOHA's throughput. If we consider that the channel offered load is less than this point, we thus conclude that

the H-CDMA channel produces the throughput better than the M-ALOHA channel.
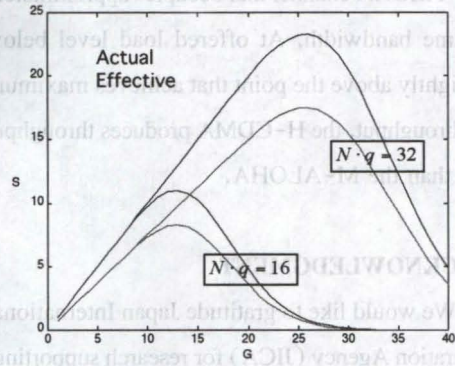

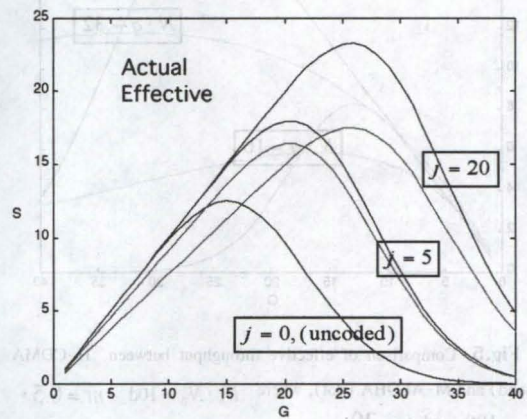**Fig. 3** Throughput of H-CDMA at $m = 0.5$, $E_b / N_0 = 10$dB, $L = 1000$, and $j = 20$

Fig. 4 Throughput of H-CDMA at $m = 0.5$, $E_b / N_0 = 10$dB, $N \cdot q = 32$, and $L = 1000$.

5. CONCLUSIONS

The hybrid DS/SFH CDMA technique is proposed for wireless packet transmission channel. The channel is considered as H-CDMA channel. The data and FEC code are packaged before transmission. The probability of packet transmission success and channel throughput are derived. The numerical analysis is performed with several level of processing gain and FEC capability. The numerical results show that an increase in H-CDMA processing gain and FEC capability produces an increase in

maximum peak of channel throughput and offered load. The throughput of this channel is compared to the M-ALOHA channel that occupies approximately the same bandwidth. At offered load level below and slightly above the point that achieves maximum peak throughput, the H-CDMA produces throughput better than the M-ALOHA.

6. ACKNOWLEDGMENT

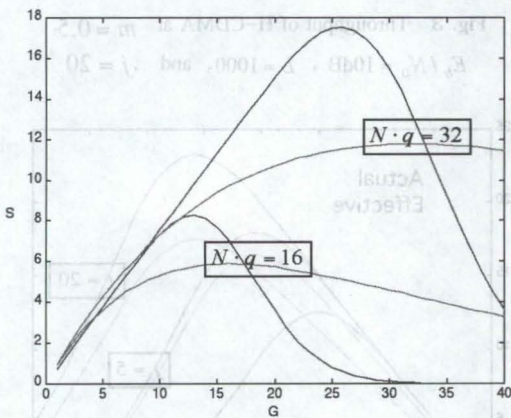We would like to gratitude Japan International Cooperation Agency (JICA) for research supporting.

Fig.5. Comparison of effective throughput between H-CDMA (solid) and M-ALOHA (dot), where $E_b/N_0 = 10d$, $m = 0.5$, $L = 100$ and . $j = 20$.
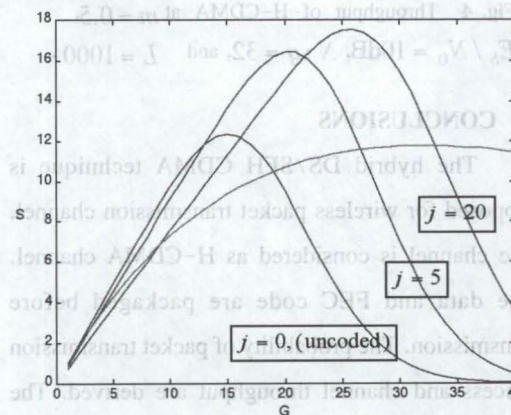

Fig.6. Comparison of effective throughput between H-CDMA (solid) and M-ALOHA (dot), where $m = 0.5, E_b/N_0 = 10dB, N \cdot q = 20$ and . $L = 100$

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