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동기식 버스트 통신시스템 적용을 위한 새로운 반송파 동기 기법에 관한 연구

A Study on a New Carrier Recovery Algorithm for Coherent Burst-mode Communication Systems

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Abstract

In this paper, a newsynchronization technique applied to burst-mode communication is proposed. A synchronization technique is to estimate carrier frequency and phase offsets in a noisy channel environment. A fundamental problem for estimating the parameters(carrier phase and frequency offsets) in burst-mode transmission is that the ways of pursuing estimation accuracy and transmission efficiency are always trade-off. To solve this problem, a new carrier recovery technique is proposed to improve the transmission efficiency with reliable performance especially at low S/N. In the proposed technique, the synchronization parameters are first estimated based on a data-aided feed-forward estimation scheme. Then, a phase tracker using decision-directed DPLL estimates the phase offset for the data portion of the burst data. From simulation results, it shows fast synchronization with shorter preamble maintaining reasonable BER performance at low S/N.

Keywords : Carrier Recovery, MLE, DPLL, Burst-mode Communication

1. Introduction

While burst-mode communication time such as time division multiple access offers lots of advantages such as one carrier at a time, simplified radio hardware, variable user data rates, etc, it requires rapid carrier synchronization during the limited burst epochs. Synchronization plays a critical role for a more accurate replica of the transmitted symbol sequence in a receiver design. A synchronization technique is to estimate carrier frequency and phase offsets in a noisy channel environment. Conventional methods of digital communication system synchronization such as feedback schemes(PLLs) have demonstrated reduced performance when operated in burst-mode communication systems due to hang-up phenomena. On the other hand, feed-forward approaches does not suffer from the hang-up problem associated feedback loops and are better suited for burst

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mode transmissions because of their shorter acquisition time.

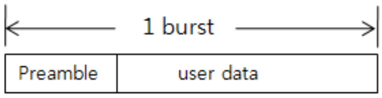

Fig. 1. Typical burst format

As is shown in Fig. 1, the burst format for typical data packet includes preamble for carrier and symbol timing recovery. A fundamental problem for estimating the parameters(carrier phase and frequency offsets) in burst-mode transmission is that the ways of pursuing estimation accuracy and transmission efficiency are always trade-off. The longer preamble, the more accurate the estimate is but reduces the transmission throughput because the preamble consumes communication resources such as bandwidth and power that are not used to convey information.

To solve this problem, a new carrier recovery technique is proposed to improve the transmission efficiency with reliable performance especially at low S/N. In the proposed technique, the synchronization parameters are first estimated based on a data-aided feed-forward estimation scheme. Then, a phase tracker using decision-directed DPLL estimates the phase offset for the data portion of the burst data. After overall description of the proposed system model, the algorithms are described and its performance is evaluated using Matlab software.

2. System Design

A. System Model Based on the Proposed Scheme

The overall baseband equivalent carrier recovery system block diagram based on the proposed synchronization scheme is given in Fig. 2.

In the receiver above, the incoming signal corrupted by AWGN is first coherently demodulated to a baseband signal, which may have the frequency offset Ω and the phase offset ϕ due to the frequency instability in either transmitter or receiver oscillator, and the Doppler effect when the terminal is in motion relative to each other. The estimation of Ω and ϕ($\hat{\Omega}$ and $\hat{\phi}$) in acquisition is based on feed-forward scheme over oversampled the matched filter outputs, which are at sampling rate of 1 *Ts*, a rate higher than the symbol rate. The oversampling reduces preamble symbols needed in Maximum Likelyhood estimation described in following sections. After the offsets(Ω and ϕ) are compensated by multiplying the baseband samples by complex numbers, exp(-jk$Ts\hat{\Omega}$) and exp(-j $\hat{\phi}$), the sampling rate is converted down to the symbol rate of 1 *T* before the phase tracking begins. Then, a phase tracking based on feedback scheme(DPLL) estimates the phase offset($\hat{\Theta}$) caused by inaccurate frequency offset estimate($\Delta\Omega = \Omega - \hat{\Omega}$) and inaccurate phase offset estimate($\Delta\phi = \phi - \hat{\phi}$) in the acquisition stage for the data portion of the burst data.

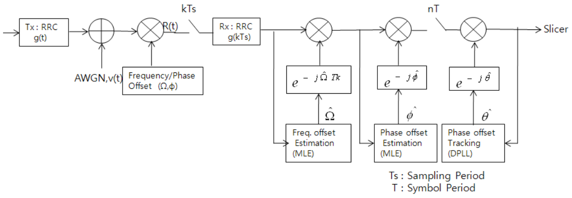

Fig. 2. The proposed carrier synchronization scheme block diagram

The demodulated baseband signal can be represented as

$$r(t) = u(t)e^{j(2\pi ft+\phi)} + v(t) \tag{1}$$

where u(t) is the baseband equivalent signal of QPSK, f is the carrier frequency offset in Herts to be estimated, ϕ is the unknown phase offset to be estimated, and v(t) is an AWGN with PSD of No/2.

After matched filtering the oversampled signal, it yields

$$r_k = u_k e^{j(2\pi fT_s k+\phi)} + v_k \quad k = 1,2,\ldots, N \tag{2}$$

where k is the sample index, and N is the number of samples in the observation window.

B. Frequency offset Estimation

Since the parameters($\Omega = 2\pi f$, ϕ) to be estimated is unknown but deterministic, i.e., non-random parameters, Maximum Likelihood(ML) criterion is adopted. Then, ML estimate is the value of parameter that maximizes the likelihood in (3)

$$\Lambda(\Omega) = \left| \sum_{i=0}^{N-1} r_i e^{-j\Omega i} \right|^2 = \mathrm{Re}\left\{ \sum_{k=0}^{N-1}\sum_{m=0}^{N-1} r_k r_m^{*} e^{-j\Omega(k-m)} \right\} \tag{3}$$

Differentiating the likelihood function with respect to the unknown parameter(Ω) and setting the derivative to zero results in the ML estimate of Ω as follows

$$\hat{\Omega} = \frac{1}{C_d}\tan^{-1}\left\{ \frac{\mathrm{Im}\left[\frac{1}{N-C_d} \sum_{k=C_d}^{N-1} r_k r_{k-C_d}^{*} \right]}{\mathrm{Re}\left[\frac{1}{N-C_d} \sum_{k=C_d}^{N-1} r_k r_{k-C_d}^{*} \right]} \right\} \tag{4}$$

where *Cd* is autocorrelation distance($0 < Cd < N-1$) over a window of (*N*- *Cd*) samples.

The estimation range of $\hat{\Omega}$ is restricted to $\hat{\Omega} < \pi/Cd$ per sample. The autocorrelation distance(*Cd*) and the number of time average of samples(*N*-*Cd*) determines estimation accuracy. If the values of (*Cd* and *N*) increases, the estimation is more accurate. It should be noted that if *Cd* is fixed, the estimation accuracy will be raised as the value of *N* increases. This is why the proposed scheme applied ML estimator over oversampled data instated of one sample per symbol. Similarly if (*N*-*Cd*) is fixed, the estimation accuracy will increase as Cd increases, however, the estimation range decreases with increasing *Cd*.

C. Phase offset Estimation

If we assume that we observe *Np* frequency compensated samples in the preamble portion(the number of total preamble = N + Np), then the *k* th complex sample can be expressed as

$$\tilde{r}_k = a_k e^{j(\Delta\Omega k + \phi)} + \nu_k \quad k = 1,2,\ldots,N_p \tag{5}$$

where $\Delta\Omega = \Omega - \hat{\Omega}$ is the residual frequency error carried forward by the inaccurate frequency offset estimate in frequency offset estimation and a_k is the preamble symbols.

As afore mentioned, the phase offset($\hat{\phi}$) to be estimated is unknown and deterministic. So like frequency offset estimation, Maximum Likelihood(ML) criterion can be adopted. Then, phase offset($\hat{\phi}$) is the value which maximizes the likelihood in (6)

$$\Lambda(\phi) = \mathrm{Re}\left\{ \sum_{k=0}^{N_p-1} a_k^{*} r_k r_k^{*} e^{-j(\Delta\Omega k + \phi)} \right\} \tag{6}$$

Based on the ergodic theory, the phase offset estimate is the total phase offset estimate at the middle of the observation window of *Np* samples, where *Np* is odd-valued, by (7)

$$\hat{\phi} = \tan^{-1}\left\{ \frac{\mathrm{Im}\left[\frac{1}{N_P} \sum_{k=0}^{N_P-1} \tilde{r}_k \right]}{\mathrm{Re}\left[\frac{1}{N_P} \sum_{k=0}^{N_P-1} \tilde{r}_k \right]} \right\} \tag{7}$$

It should be noted that the residual frequency error($\Delta\Omega$) may result in a significant phase estimate variation over the averaging length *Np* because the phase estimate will change linearly with time due to the $\Delta\Omega$. Since the phase offset estimate is from the middle sample in the observation window *Np*, the correction of the phase error due to the $\Delta\Omega$ at the end of the preamble can be compensated by starting the tracking atthe middle sample in the observation window *Np*.

D. Phase Tracking

When a short burst mode is considered, it may be sufficient to make a single estimate of the synchronization parameters for each individual burst because the carrier phase can be considered as constant over the entire burst epoch. However in the case of longer burst mode, the fluctuation of the synchronization parameters over the burst cannot be ignored because the inaccurate parameter estimates will accumulate phase error with time and cause a loss of phase synchronization. So residual phase error tracking is necessary after estimating the parameters a longer burst mode. In the phase tracking process, estimates are extracted from random user data instead of a preamble. Traditionally, Viterbi and Viterbi(V&V) NDA feedforward phase estimator which uses complex non linear function (8) has been an excellent choice for phase tracking in burst mode communication.

$$x_n' + iy_n' = F(\rho_n)e^{jm\phi_n}$$
$$where \quad \rho_n = \sqrt{x_n^2 + y_n^2} \quad and \quad \phi_n = \tan^{-1}(y_n / x_n) \tag{8}$$

But the performance of the V&Vtracking algorithm is mainly dependent upon the residual offset errors(ΔΩ and Δϕ) especially at low signal-to-noise ratio because of ISI effect, and the residual offset must be very small for the ISI to be ignored.

$$r_n'' = u_n e^{j(\Delta\Omega n + \Delta\phi)} + v_n \quad n = 1,2,..., \tag{9}$$

So, to have good performance with the V&V approach, it is necessary to reduce and maintain the residual frequency and phase errors within a small tolerable range, which compels to increase the preamble length to minimize the frequency error in burst mode operation. This is a trade-off between estimation accuracy and transmission efficiency. Contrary to the feed-forward approach, the performance of feedback phase tracker is not affected by the frequency error because of the loop filter with perfect integrator. So, to solve the trade-off problem, a phase tracker using decision-directed DPLL with a 2nd loop filter shown in Fig. 3. estimates the phase offset for the data portion of the burst data in the proposed technique.

The transfer function of the DPLL is

$$H(z) = \frac{K_1(z-1) + K_2 z}{(z-1)^2 + K_1(z-1) + K_2 z} \tag{10}$$

The DPLL in the proposed scheme inherently may suffer the hang-up phenomena as well but thepossibility of hang-up in the proposed scheme can be ignored because the frequency error delivering from inaccurate frequencyoffset and phase offset estimation due to the shorter preamble length would not be too large to cause the tracker to start phase tracking at unstable equilibrium point, which is the key idea for combining feed-forward and feedback in the proposed hy scheme.

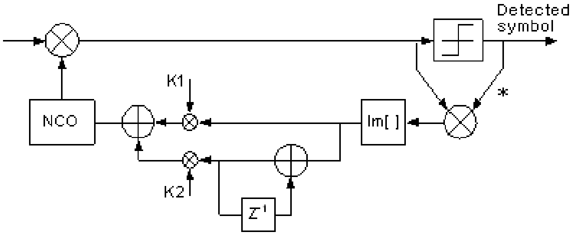

Fig. 3. Decision directed DPLL block diagram

3. Simulation Results

Computer simulations using Matlab software have been carried out to evaluate the performance of the proposed scheme. The following assumptions have been made : i) modulation is QPSK with roll-off factor of 0.5 ; ii) frequency offset based on IEEE 802.16 MAN system, f = 1.00e-1% of symbol rate R, phase offset, ϕ = π/4 ; and iii) w.r.t. DPLL, K1 = 0.05, K2 = 0.001.

Table 1 shows the performance of parameter estimator in terms of the estimate bias according to various signal-to-noise ratio when the correlation distance *Cd* = 640(40 symbols), the number of averaging sample *N- Cd* = 640(40 symbols), *Np* = 336(21 symbols), and a total of 101 preamble symbols.

Table 1. Average frequency estimates according to various S/N

Eb/No	Ω(rad/sample)
	IEEE 802.16(3.93e-4)
0	0.00038863
2	0.00039281
4	0.00039262
6	0.00039254
8	0.00039227
10	0.00039375

From the table, we can see that the parameter estimator is unbiased w.r.t. frequency offset Ω = 3.93e-4 under the AWGN channel environment.

Fig. 4. Shows that the BER performance of the frequency estimator is best around the preamble size of 100～200.

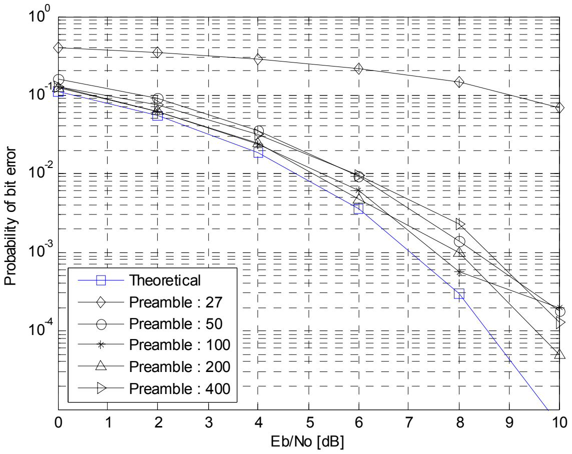

Fig. 4. BER performance of frequency estimator according to various preamble size

Strange to say at first, the performance is not improved any more as the preamble length increases beyond some point(around 100～200 symbols) as shown in the graph. This is because the phase offset estimate is from the middle sample in the observation window. As a result, the phase estimate changed linearly with time due to the residual frequency error delivered form frequency estimator. And the longer the preamble length, the more time that contributes more the change of the phase estimate.

The residual frequency error can not be ignored when a long burst operation is needed. Fig 5. Shows that in case of the long burst operation, a single estimate of the synchronization parameters for each individual burst is no longer sufficient.

The BER performance of the proposed scheme for different user data length is shown in Fig. 6 where the frequency offset assumes worst, i.e. Ω = 3.93e-4.

From the graph, we can see that contrary to feed-forward approach such as the V&V tracking algorithm, the performance of the proposed scheme is not dependent on the residual frequency error due to the inaccurate parameter estimates in the previous stage, which means that we can improve the transmission efficiency with reliable performance especially at low S/N.

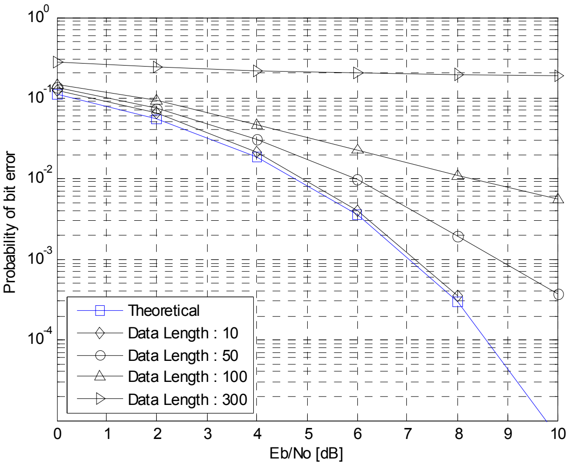

Fig. 5. BER performance of frequency estimator according to short and long bursts

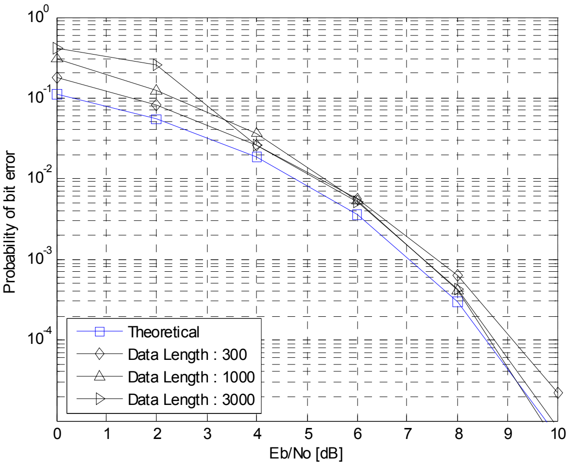

Fig. 6. BER performance of the proposed parameter estimator for short and long bursts

4. Conclusion

A new carrier synchronization technique presented in this thesis proved to be applicable to the burst mode communication system. In the proposed technique, the synchronization parameters are first estimated based on a data-aided feed-forward estimation scheme. Then, a phase tracker using decision-directed DPLL estimates the phase offset for the data portion of the burst data.

The simulation demonstrated that the proposed scheme provide a fast carrier acquisition using a shorter preamble (about 100 symbols) maintaining reasonable BER performance at low S/N.

References

[1] B. Sklar, Digital Communications : Fundamentals and Applications, Prentice Hall Inc., Englewood Cliffs, NJ, 1998.

[2] F. M. Gardner, “Hangup in Phase-lock Loops”, IEEE Transactions on Communications, Vol. COM-25, No. 10, pp. 1210～1214, 1977.

[3] M. Luise and R. Reggiannini, “Carrier Frequency Recovery in All-digitalmodems for Burst-mode Transmissions”, IEEE Transactions on Communications, Vol. 43, No. 2/3/4, pp. 1169～1178, Feb./Mar./Apr., 1995.

[4] S. Kay, “A Fast and Accurate Single Frequency Estimator”, IEEE Trans. Acoust., Speech, Signal Processing, Vol. ASSP-37, pp. 1987～1990, Dec. 1989.

[5] N. Caouras, R. Morawski, and T. Le-Ngoc, “Fast Carrier Recovery for Burstmodecoherent Demodulation using Feedforward Phase and Frequency Estimationtechniques”, Proceedings of the 1999 IEEE CCECE, Edmonton, Alberta, Canada, pp. 79～83, May 9～12 1999.

[6] A. J. Viterbi and A. M. Viterbi, “Nonlinear Estimation of PSK-modulated Carrier Phase with Application to Burst Digital Transmission”, IEEE Transactions on Information Theory, Vol. IT-29, No. 4, pp. 543～551, 1983.