International Global Navigation Satellite Systems Society
IGNSS Symposium 2007

The University of New South Wales, Sydney, Australia
4 – 6 December, 2007

Performance Evaluation of Acquisition Scheme Based on Timing-synchronized Network for AGPS High-sensitivity Receiver

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ABSTRACT

A function of automatic location identification from an emergency call is required in Japan and many other countries. How to give a reliable position promptly is a problem in places where the GPS signal is extremely weak. We propose an acquisition scheme for the Assisted GPS (AGPS) architecture based on a timing-synchronized mobile network. With this method, the C/A code search and frequency search range are significantly reduced and long-time coherent correlation becomes possible. Simulations prove that the method is efficient, fast and power saving for the user handset. Furthermore, the AGPS receiver can begin with hot start even in a cold start condition. An important measure of GPS receiver performance TTFF (Time To First Fix) is shortened.

KEYWORDS: Acquisition, high-sensitivity receiver, Assisted GPS, timing-synchronized network

1. INTRODUCTION

Enhanced 911 (E911), imposed by the United States FCC (Federal Communications Commission), is crucial in times of fires, break-ins, kidnappings, and other events where communicating one's location is difficult or impossible. To comply with the E911 government mandate, Assisted GPS and high-sensitivity GPS technology have received much attention. The function of automatic location identification from an emergency call has also been made a requirement for cellular phones by the Japanese Ministry of Internal Affairs and Communications (April, 2007) [1]. Such mandates in turn require integrated positioning services in cellular communication networks. Location-based services (LBS) have begun to be considered tightly coupled to cellular networks. Furthermore, assisted GPS and high-sensitivity solutions have opened the door to new applications for devices.

Together with increasing market needs, there is also a variety of technical challenges that have stimulated research on signal processing techniques for receivers that can operate under poor signal propagation conditions. The most challenging technical problem that needs to be solved is how to improve the sensitivity of a receiver in complicated indoor and dense urban environments, because people are likely to carry their cell phones indoors or in urban canyons where the GPS signal is attenuated and extremely weak. The signal processing performed by the receiver, especially during the signal acquisition stage, is critical to achieving the sensitivity needed for reliable positioning. This has given rise to high-sensitivity GPS architectures that process extended periods of the signal by means of long coherent and non-coherent integration. However, there are two essential factors that limit the long correlation time and impose large amounts of computation. One is navigation data bit transitions, and the other is the Doppler effect (Tsui, 2005). Moreover, the sensitivity that can be achieved in the acquisition stage is essential to a receiver because the sensitivity of tracking process is higher. For the sake of achieving high sensitivity in the acquisition process, we focus on how to deal with these two problems in a mobile telecommunications network.

The cellular mobile telecommunications networks around the world are being updated to use new 3G (third-generation) technologies. Japan was the first country to introduce 3G, and the transition to 3G was largely completed during 2005/2006. There are two 3G standards used in Japan: W-CDMA by NTT DoCoMo and Softbank; and cdma2000 which is very successfully used by KDDI. Moreover, there is a Chinese 3G standard: TD-SCDMA, which is also approved by the ITU (International Telecommunications Union). On January 20, 2006, Ministry of Information Industry of the People's Republic of China formally announced that TD-SCDMA is the country's standard of 3G mobile telecommunications. CDMA2000 and TD-SCDMA are both timing-synchronized networks in which the clock differences between the base station and user handset are no more than 10 microseconds and 1 microsecond, respectively [2][3]. We think having a precise synchronized time can assist acquisition for assisted GPS (AGPS) receivers in this kind of timing-synchronized network.

We propose a novel and efficient scheme for fast, high-sensitivity acquisition in the context of an AGPS architecture based on a timing-synchronized network. In the proposed system, there is an assisting server and a user handset (a cell phone with an embedded GPS chip). Our contributions are as follows: First, we present a method of using information from the server and time synchronization network to enable a fast C/A code phase search and long-time coherent correlation. Second, we discuss a method for minimizing the range of the Doppler frequency search during acquisition by using an efficient combination of the Doppler information provided by the server and an analysis of the local oscillator frequency uncertainty range. These methods save hardware resources, mitigate the computational load and reduce power consumption of the user handset. Third, the system's main errors are analysed and its performance is evaluated.

The rest of this paper is organized as follows. Our proposal is explained and the system errors are described in detail at first. Simulation results, an error analysis, and a performance evaluation are then presented. The paper ends with a conclusion.

2. FAST ACQUISITION METHOD FOR AGPS RECEIVER

A fast high-sensitivity acquisition method for an AGPS receiver is composed according to the timing-synchronized mobile network application assumed above. The synchronization information is used when a navigation message is forwarded from the server to the user handset. The effects of system errors on the C/A code phase search and the Doppler frequency bin search are discussed.

2.1 Quick C/A Code Search

2.1.1 System Structure

The system is composed of an assisting server, user handset, and network communication link, as shown in Figure 1. The user is in the service area of the base station. The navigation message is sent by the satellite at time T_s and is received by the server and user handset at times T_r and $\tilde{T}_u$, respectively. $\tilde{T}_u$ is an estimated value that includes a time error as shown in the figure. d_{ss} is the distance from the satellite to the server. The approximate distance between the satellite and the user is $\tilde{d}_{us}$.

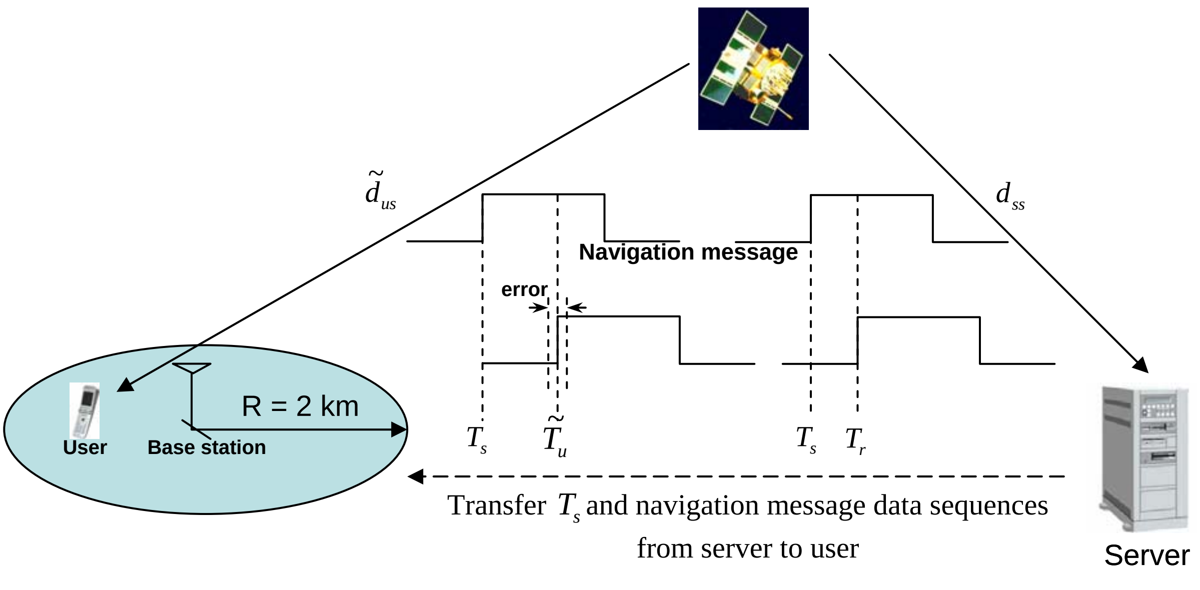

Figure 1. System structure

The C/A code search process is as follows. First, the assisting server collects the information that includes the navigation message data arrival times T_r and the navigation message data stream itself. Because the server and satellite positions are known at the server side, the distance d_{ss} from satellite to server can be calculated. Thus we get T_s from equation (1), where c means the speed of the light.

$$T_s = T_r - \frac{d_{ss}}{c} \tag{1}$$

The T_s information and navigation message data sequences are then sent to the user. Here, remember that the user handset and server are timing-synchronized. The user uses the position of base station as his approximate position; thus, the approximate distance $\tilde{d}_{us}$ between satellite and user is known. The approximate arrival time of the navigation message $\tilde{T}_u$ is estimated by using this distance and the transmission times of the navigation message data from the satellite provided by the server. $\tilde{T}_u$ is calculated as follows.

$$\tilde{T}_u = T_s + \frac{\tilde{d}_{su}}{c} \tag{2}$$

Finally, by referring to the estimated time $\tilde{T}_u$ and the navigation message data stream, the polarity changes due to the navigation message can be removed from the C/A-coded GPS signals.

The navigation message data bit is 20 ms long and includes 20 pieces of 1 ms C/A code. The start times of navigation message data and C/A code are simultaneous. Thus, the estimated navigation message data arrival time $\tilde{T}_u$ at the user side can be considered a reference time for C/A code initial phase search. Thus, the code search can be carried out only near the estimated arrival time $\tilde{T}_u$. Hence, the C/A code search should be as quick as possible.

The ultimate receiver sensitivity that can be achieved is affected by the length of signal correlation time and the presence of navigation message data modulation on the GPS signal. The navigation message data bit transition decreases the correlation processing gain, which means, the sensitivity of receiver is decreased. Thus, the user's receiver can perform the long-time correlations necessary for high acquisition sensitivity without the navigation message modulation.

2.1.2 Error Analysis

There are two major error sources that affect the estimated navigation message data arrival time $\tilde{T}_u$. One is the timing error whose components are the estimated navigation message data arrival time error caused by using the approximate distance from the satellite to the user, and the clock difference between the user and the server which comes from the mobile network synchronization error.

The first source is analysed to get the time error caused by taking the base station's position to be the user's approximate position. We assume the base station coverage area has a 2 km radius, which is a reasonable value for base stations in urban areas. The maximum distance between the user and the base station is 2 km. Thus, the maximum signal transmission time difference from satellite to base station and user is

$$\frac{2000}{c} = 6.7 \times 10^{-6} s \tag{3}$$

which is much less than 1 bit of the navigation message data length, i.e. 20 ms. This error is endurable, and hence our proposal is at least feasible.

We assume that the acquisition scheme for the AGPS receiver works on timing-synchronized cellular mobile telecommunications networks such as CDMA2000 and TD-SCDMA. Hence another error source that affects the wiping off navigation message is the synchronization error of the network. The typical timing synchronization accuracy in this kind of network is on the order of 10 microseconds or less. Thus, even with both errors, an error range within 20 microseconds is acceptable.

2.2 Quick Frequency Search

2.2.1 Method Description

During the acquisition process, searches are done in two directions to get the right C/A code initial phase and Doppler frequency shift, which also includes a local clock error. Striping off the navigation message data accelerates the C/A code phase search, but we also have to deal with the Doppler frequency shift.

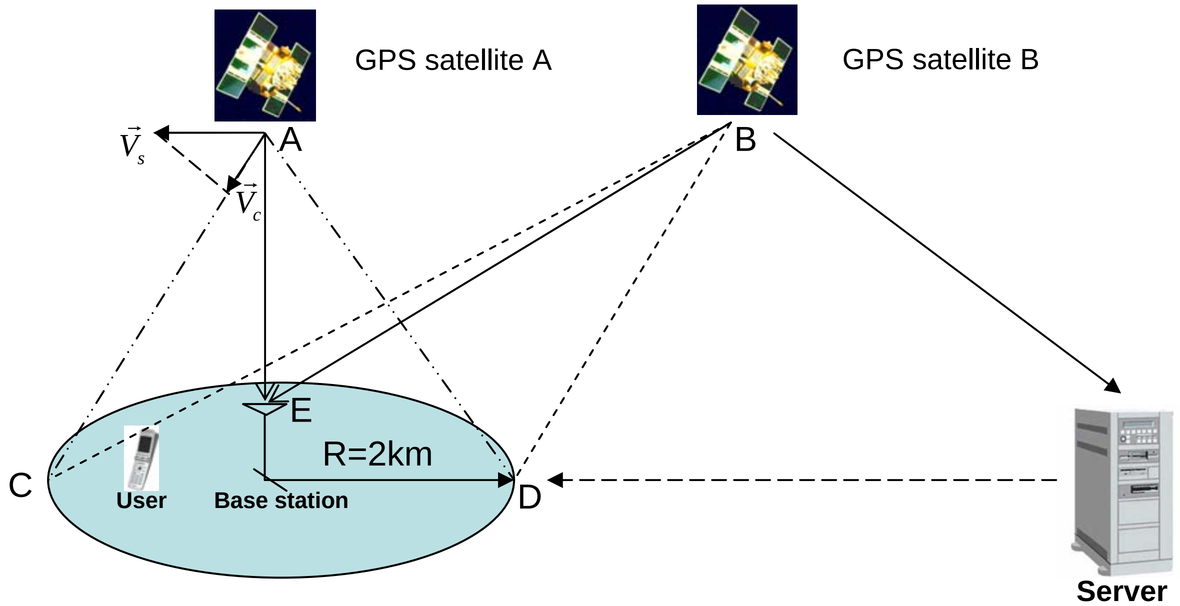

Figure 2. Doppler frequency shift caused by motion of the satellite

The position of the base station is taken as the approximate user position to calculate the Doppler frequency shift caused by the motion of the satellite (Fig. 2). The Doppler frequency shift information is calculated by the server and then is transmitted from the server to the user handset. In the figure, satellite A is at the zenith of the base station and $\vec{V}_s$ is its speed vector. $\vec{V}_c$ represents the projection of vector $\vec{V}_s$ in the direction AC. A is the position of satellite A, and C and D are the positions at the edge of the base station's service area. E is the position of the base station. Points A, C, D, and E are on the same plane.

2.2.2 Error Analysis

The error is added using the base station's position as the user's position. The error is highest when the satellite is at the zenith. GPS satellites orbit at about 20192 km above the earth's surface, and their average velocity $\vec{V}_s$ is 3874 m/s (Tsui, 2005). In Figure 2, angle CAE is equal to angle DAE and can be calculated from equation 4.

$$\angle CAE = \angle DAE = arctg\frac{R}{AE} \approx 9.9\times10^{-5} \text{ rad} \tag{4}$$

The Doppler frequency shift in the direction AC is:

$$f_d = f_{L1}\times\frac{V_c}{c} = f_{L1}\times\frac{V_s\times\sin(\angle CAE)}{c} = 1575.42\times10^6\times\frac{3874\times9.9\times10^{-5}}{3\times10^8} \approx 2Hz \tag{5}$$

Because there is not any Doppler frequency shift when the satellite is at the zenith of the base station, the maximum frequency difference caused by using of base station's position as the user's approximate position is less than 5 Hz.

The frequency difference between the received signals and locally generated signals is caused by the motion of the satellite and local reference oscillator error, and the latter affects the frequency search range as well. The reference oscillator has a frequency uncertainty of ± 1part per million, that is about 1600 Hz for a 1575.42 MHz L1 band signal [Lawrence R. Weill, 2004]. The frequency search is centred on the Doppler frequency shift value sent by the server, and the search range is the oscillator uncertainty frequency. Although it takes some time to transmit the Doppler information from the server to the user, this time is less than 1 second in a mobile network. As the maximum rate of change of the Doppler frequency is 0.936 Hz/s relative to a static user (Tsui, 2005), the Doppler frequency change during transmission can be ignored.

3 SIMULATIONS AND PERFORMANCE EVALUATION

Two simulations were carried out to verify the effect of the estimated navigation message data arrival time errors and the Doppler frequency search range. One simulated the method of wiping off the navigation message by using the time information and navigation message data stream from the server. The other simulated the Doppler effect observed from a certain position.

3.1 Simulation of Time Error Effect on Acquisition Correlating Gain

A C/A code was modulated with a navigation message and carrier. Additive white Gaussian noise (AWGN) was added to this signal to simulate an actual received GPS signal sent by one satellite. We used the first 50 bits of a raw navigation message data stream from Satellite PRN 1 for a certain time for one-second coherent correlation. The same navigation message data stream was then used to wipe off the navigation message data and a time shift was added as an estimated time error. Finally, the C/A code without the navigation message data was correlated with locally generated C/A code and the correlation process gain obtained.

The intermediate frequency (IF) was 16.3676 MHz and the sampling frequency was 8.1304 MHz. The corresponding correlation results – the processing gain loss in dB of the baseband signal and GPS signal at CN0 44 dB-Hz - are illustrated in Figures 3 and 4, respectively.

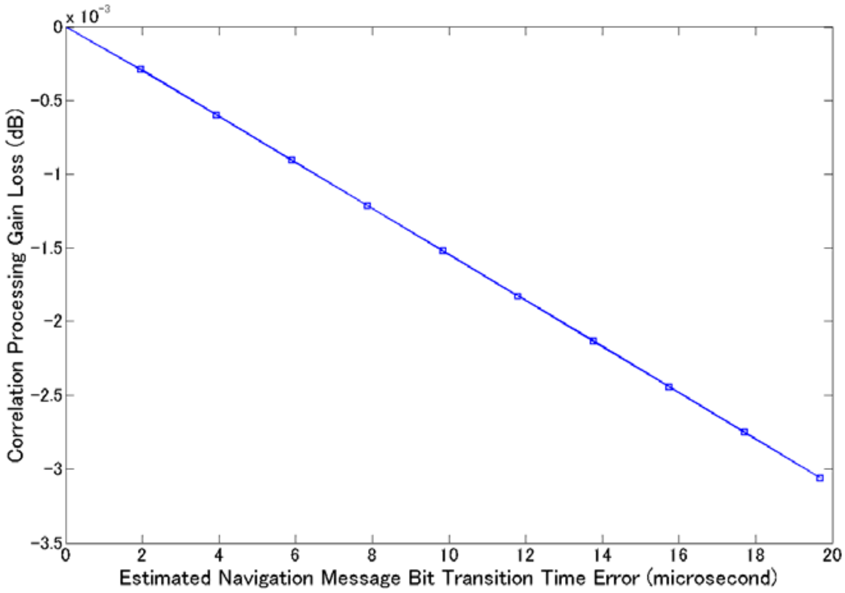

Figure 3. Baseband GPS signal correlation processing gain loss at different navigation message bit transition time errors

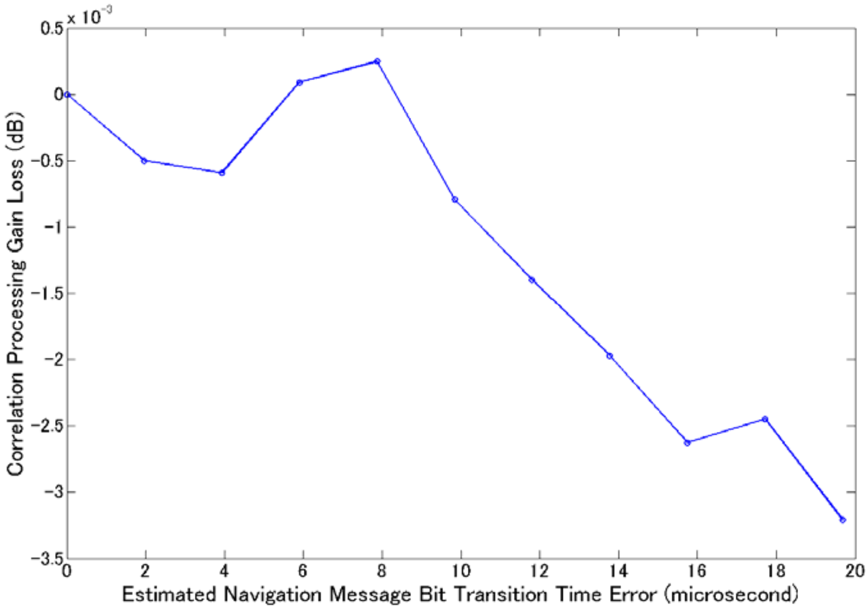

Figure 4. Noise added GPS signal correlation processing gain loss at different navigation message bit transition time errors

The horizontal axis in the figure is the estimated navigation message arrival time error at the user handset. The vertical axis is the corresponding correlation processing gain loss in dB. Figure 3 shows that the baseband signal correlation processing gain decreases linearly concomitant with the time error. Figure 4 is the noise added signal correlation gain loss for different estimated time errors. Although it does not decrease linearly, the similar trend can be found while comparing to that of the baseband signal. If we assume the estimated navigation message data arrival time error is within 20 microseconds, the processing gain loss is no more than 0.0035 dB (Fig. 3 and 4). This value means the correlation peak decrease when using the estimated navigation message data arrival time and data sequence to wipe off the navigation message is trivial in comparison with the decrease when using the timing aligned navigation message data stream.

Thus, our method can strip off the navigation message and enables long coherent integration during the acquisition stage. Concurrently, one navigation message bit includes 20 pieces of C/A code and the C/A code phase is aligned to the beginning of the navigation message data. Therefore, for our simulation time setting of 20 microseconds, the C/A code phase can be obtained by searching within only ± 20 code phases instead of searching all 1023 possible code phases. That is, the searching time is reduced to about 4% and the corresponding power consumption is also restrained.

3.2 Frequency Search Simulation

First, the orbit of a certain satellite in one day was calculated by using 24-hour precise satellite ephemeris data provided by IGS (International GNSS Service) [4]. The Doppler frequency shift of PRN 1 observed from a certain location (Setagaya-ku, Tokyo, Japan) during one day is illustrated in Figure 5. Some times lack corresponding data because PRN 1 was under the horizon of this location.

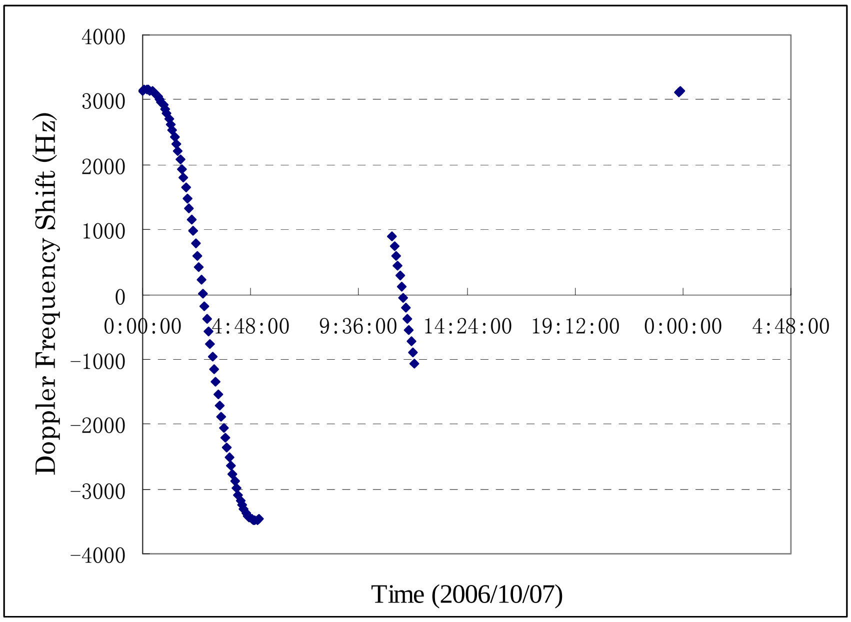

Figure 5. Doppler shift frequency in 24 hours

With this information and a receiver oscillator frequency offset within 1600 Hz, an uncertain frequency search range can be obtained by adding 1600 Hz to the Doppler frequency transferred by the server at a certain time. Equation 5 shows this estimation method.

$$F_{search} = f_{IF} + f_{Doppler} \pm f_{osi} \qquad (5)$$

$(f_{IF} + f_{Doppler})$ is the searching centre frequency, and the search range is $\pm f_{osi}$, that is, ± 1600 Hz.

3. CONCLUSIONS

We presented a fast high-sensitivity acquisition scheme based on a timing-synchronized network in the context of the AGPS architecture. The C/A code search and Doppler frequency search range were calculated, and the effect of errors in the process was evaluated. The simulation results indicate the C/A code initial phase search range can be limited to ± 20 chips, compared with 1023 chips in conventional methods, if the time error in the C/A code search process is set to 20 microseconds. However, the time synchronization accuracy in a timing-synchronized mobile network is in practice less than 20 microseconds. Hence if the time error is less than 1 microsecond, the C/A code search is not necessary and only the frequency search is needed. Furthermore, the frequency search range can be reduced to ± 1600 Hz, that is, about 1/3rd of the ± 5000 Hz that is often used in the conventional acquisition stage. Our method can be simply and quickly executed with few hardware resources at the user handset, thereby conferring low calculational loads and power savings. With efficient usage of information from the assisting server and synchronization information, the receiver can do a hot-start even in a cold start condition at the beginning of acquisition stage. Thus, TTFF (Time To First Fix) is reduced as well.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Seiichiro Hirata, Professor Lawrence R. Weill and Mr. Katsumasa Tsuneyoshi (Magellan Systems Japan, Inc.), for their helpful discussions and valuable comments on this paper.

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