OPTIMAL BALANCED SINR TRACKING FOR MULTI-CHANNEL CDMA BASED RANGING SYSTEM

Xu Jiuling, Zhang Chaojie, Wang Chunhui, Huangjiajun
Micro-Satellite Research Center, Zhejiang University, Hangzhou, China
E-mail: zhangcj@zju.edu.cn.

Abstract: Code Division Multi-Access (CDMA) is suitable technique for one to multi-point ranging, but it suffers from the Near-Far effect (NFE) i.e. the signal of a farther one will be masked by the nearest one. Unlike the territorial CDMA system aiming at achieving the acceptable lowest Signal to Interference plus Noise ratio (SINR) for a large number of users, the space CDMA ranging system requires higher SINR for a better ranging performance. Consequently, the method of dynamically tracking the Optimal Balanced SINR based on fuzzy logic control is proposed for satellite cluster relative position recognizing.

Keywords: CDMA, multi-channel ranging, Optimal Balanced SINR Tracking, fuzzy logic control.

Introduction

Future space missions are envisioned to become more complex and diversed, such as gravity mapping, tracking of forest fires, finding water resources, etc. [1], this demand may be beyond the capability of a traditional monolithic satellite. Consequently, the distributed satellite system is proposed to overcome this drawback [2]. The most successful applications of distributed satellite system are GRACE [3] and TanDem-X [4], which is based on two satellites only. Nowadays, clusters consisting of more than two micro-satellites are becoming attractive due to their fast development and low costs. The knowledge of relative distance among satellites is one of the most important observations for relative position recognizing and collision avoidance [5]. Consequently, the point to point ranging system is no longer suitable for this requirement. Code Division Multi-Access is qualified for one to multi-point ranging, and it can also support data communication. However, CDMA system will suffer from the Near-

Far effect (NFE) when the signal of a farther one is masked by the nearest one. The territorial CDMA system uses Power Control (PC) [6] to mitigate NFE, and the goal of territorial PC is to reach the acceptable lowest SINR for the largest number of user access. However, the space CDMA system is totally different, firstly, the number of access points is limited and fixed, secondly, the accuracy of ranging depends on Signal to Interference plus Noise ratio (SINR), so higher SINR is required for the optimal ranging performance. Additionally, the scale of inter-satellite distance varies from several hundred meters to hundreds kilometers, the SINR is changing from time to time. Therefore, the Optimal Balanced SINR Tracking (OBST) is proposed to solve this problem. We use a cluster of four satellites to verify the OBST method, the simulation result shows that the optimal SINR can be always tracked.

System model

Let us define a basic cluster with four satellites, the one connected directly to other satellites is designated as the master (denoted as A), and the other three serve as the slaves (denoted as B,C,D) as shown in Fig. 1.

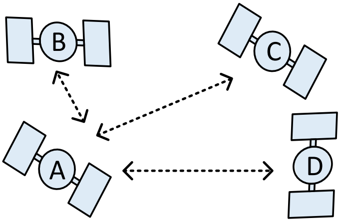


Fig. 1 Basic cluster with four satellites.

The ranging system is based on CDMA, so all the connections can be held simultaneously with little interference by code division. In order to acquire optimal performance, the receiving SINR of each slave should be balanced and be as large as possible. The optimization can be achieved by synchronous maximizing of the receiving power of each slave according to the Power Limiting Condition (PLC) of the smallest receiving power. Therefore, the block diagram of Optimal Balanced SINR Tracking is like that proposed in Fig. 2(a).

In OBST, the target power (PWR^{tar}) can be tunable referring to the relative distance between the satellites. For the inner-loop control, the slave adjusts its transmission power (PWR^{Tx}) referring to the Transmit Power Command (TPC) provided by master,

$$PWR^{Tx}(k) = PWR^{Tx}(k-1) + TPC(k-1) \cdot PWR^{step} \ , \tag{1}$$

where PWR^{step} is the adjusting step, $k \in \mathbb{Z}$, representing the k-th inner-loop update slot. In order to save the transmission data bandwidth, the TPC is a one bit sign generated by comparing the receiving power (PWR^{Rx}) to the PWR^{tar},

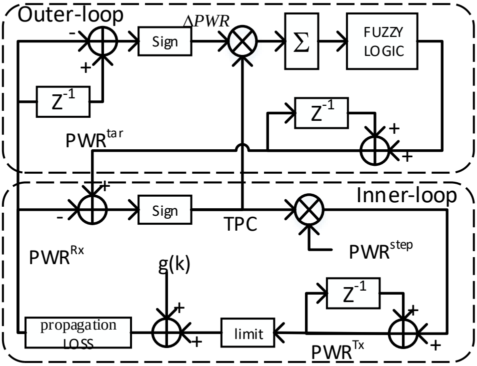
$$TPC(k) = \mathrm{sgn}[PWR^{tar}(j) - PWR^{Rx}(k)] \ , \tag{2}$$

where $j \in \mathbb{Z}$, representing the j-th outer-loop update slot whose period is usually integer multiplies of inner-loop update period, as shown in Fig. 2(b). $g(k)$ is the sum of white noise and receiving power estimate jitter, $L(k)$ is the propagation loss. So the power estimation at receiver can be expressed as

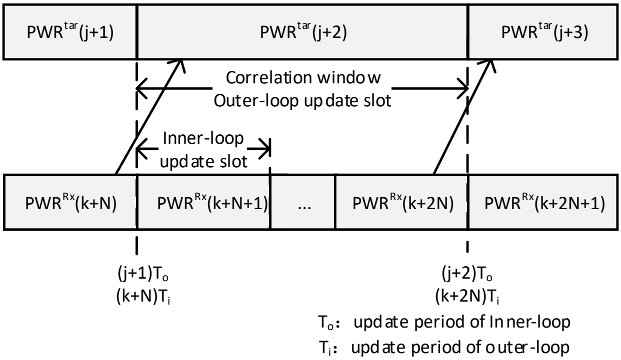
$$PWR^{Rx}(k) = PWR^{Tx}(k) + L(k) + g(k) \tag{3}$$

For the outer-loop control, the master calculates the correlation between TPC and the sign of ΔPWR^{Rx}, where $\Delta PWR^{Rx}(k) = PWR^{Rx}(k) - PWR^{Rx}(k-1)$. The correlation ($R_N$) implies the relationship between PWR^{tar} and the minimum PLC which is usually decided by the farthest slave due to the largest propagation loss. Assuming that the PLC were not reached, $R_N \approx 1$, since $\mathrm{sgn}[\Delta PWR(k)] = TPC(k-1)$, otherwise, $R_N \approx 0$ due to inner-loop control is invalid. Consequently, R_N can be used as a flag to indicate whether the PLC is reached or not. But unfortunately, R_N only tells us the PWR^{tar} can be set higher or lower, there is no strict expression to describe their relationship, so we use a fuzzy logic controller to achieve the maximum power tracking.

$$R_N(j) = \frac{1}{N} \sum\nolimits_{k=jN-N+1}^{jN} \mathrm{sgn}[\Delta PWR(k)] \cdot TPC(k-1) \tag{4}$$



(a) Block diagram for OBST



(b) Inner/outer-loop updating diagram

Fig. 2 Block diagram for OBST & inner/outer-loop updating diagram.

Theoretically, the sign of $\Delta PWR^{Rx}(k)$ will be the same as TPC(k-1) since transmit power is decided by TPC, as shown in Eq.(1). However, the false judgment of ΔPWR^{Rx} may occur when the error of power estimation is too large or PWR^{step} is too short. We assume that power estimation obeys normal distribution $X \sim N(\mu_k, \sigma^2)$, where μ_k represents the real receiving power, and σ^2 is the variance. Therefore, ΔPWR^{Rx} obeys normal distribution $Y \sim N(\mu_k - \mu_{k-1}, 4\sigma^2)$, and the probability of false judgment is:

$$P_{err} = P(Y < 0 \mid \mu_k - \mu_{k-1} > 0) + P(Y > 0 \mid \mu_k - \mu_{k-1} < 0)$$
$$= \Phi\left(\frac{-\Delta\mu}{2\sigma}\right) = 1 - \Phi\left(\frac{\Delta\mu}{2\sigma}\right) \tag{5}$$

where $\Delta\mu = \mu_k - \mu_{k-1} = PWR^{step}$, Φ is the Cumulative Distribution Function of standard normal distribution. If the transmitter power did not reach its up-limit and with the consideration of false judgment probability, R_N can be expressed as:

$$R_N = \frac{(1-P_{err})N - P_{err} \cdot N}{N} = (1 - 2P_{err}) \tag{6}$$

If current PWR^{tar} were larger than the PLC, ΔPWR^{Rx} would obey normal distribution $Y_1 \sim N(0, 4\sigma^2)$ since $\mu_k = \mu_{k-1}$, which leads the probability of false judgment to be $P_{err1} = \Phi(0) = 0.5$. So that, the correlation would be

$$\overline{R}_N = \frac{(1-P_{err1})N - P_{err1} \cdot N}{N} = 0 \tag{7}$$

In fact, $\overline{R}_N$ usually is around zero due to the limited length of correlation window. The gap between $\overline{R}_N$ and R_N is large enough to set a threshold to decide PWR^{tar} to be increased or decreased.

Fuzzy logic controller

In this paper, a Fuzzy Logic Controller (FLC) is employed for tracking the largest receiving power. The structure is shown in Fig. 3. There are three parts, i.e., fuzzification, knowledge base and inference engine.

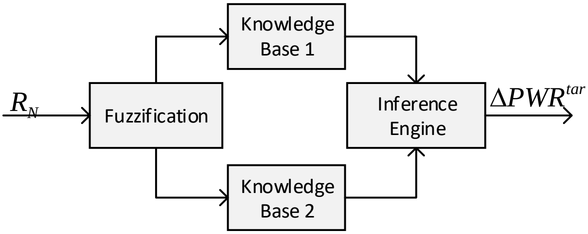
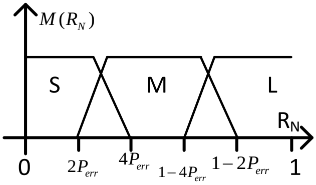


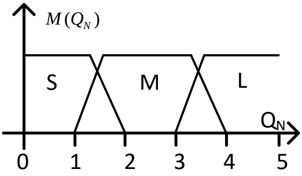
Fig. 3 Structure of fuzzy logic control.

1. *Fuzzification*: This component converts the input value into fuzzy value. In order to speed up the maximum power convergence process, we define the unchanged times of fuzzied R_N (denoted as Q_N) as a second input. The bounds of R_N, Q_N are [0,1], [1,5] respectively. The corresponding fuzzy sets are Large (L), Medium (M), and Small (S).

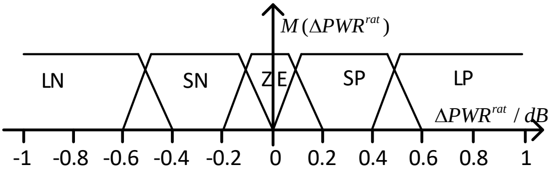
2. *Knowledge Base*: This step defines the linguistic control rules for an FLC by IF-THEN statement. The design of target-power tracking should achieve the goal of fast rise time and small steady-state error in outer-loop. Therefore, the bound of target power step (ΔPWR^{tar}) is [-1 dB,1 dB], and the corresponding fuzzy sets are Large Positive (LP), Small Positive (SP), Zero (ZE), Small Negative (SN), and Large Negative (LN). The membership functions are shown in Fig. 4.



(a) R_N



(b) Q_N



(c) target power step

Fig. 4 Membership function for FCL.

3. *Inference Engine*: This is the decision-making part of FLC, it infers fuzzy control action by employing fuzzy implication and fuzzy control rules. According to Fig. , the target power step is given by FLC and the target power can be updated as

$$PWR^{tar}(j+1) = PWR^{tar}(j) + \Delta PWR^{tar}(j) \tag{8}$$

for

$$\Delta PWR^{tar}(j) = FLC\{R_N(j), Q_N(j)\} \tag{9}$$

where $FLC\{\bullet\}$ is the fuzzy inference function, which can be decided by simulation and the knowledge of experts. According to aforementioned rules, $FLC\{\bullet\}$ has been summarized in Table 1, so that, the controller can be easily realized by look-up table.

Table 1 Fuzzy control rules of the FLC

$R_N \setminus Q_N$	L	M	S
L	LP	LP	SP
M	SN	SN	ZE
S	LN	LN	SM

Simulation results

Although the optimal SINR tracking could be achieved by OBST, the initialization of the system is totally different since all the slaves have to connect to master before enabling OBST. Consequently, the PWR^{tar} is set to be a low value until all the connections have been established. After that, the PWR^{Rx} of all slaves is rising synchronously to a certain level which equals to the minimum PLC of these slaves. Consequently, the receiving power will be tracking up to the minimum PLC, as shown in Fig. 5.

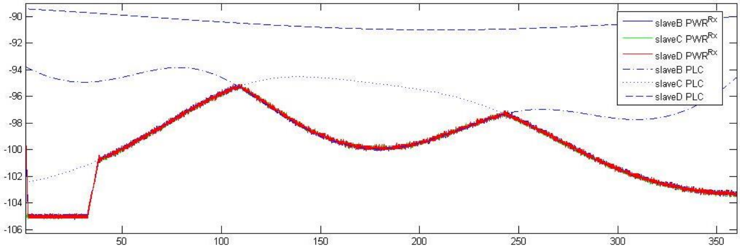


Fig. 5 Simulation result.

The dotted lines represent the PLC of slaves, and all the PWR^{Rx} coincide together since inner-loop control when initialization is made.

Introduction

In this work, a novel OBST system is proposed to optimize the receiving SINR, it is meaningful for CDMA ranging system since the performance can be enhanced. The correlation between TPC and ΔPWR^{Rx} is built to detect whether the current PWR^{tar} has been reached power limiting condition, after which a fuzzy logic controller is employed to complete the minimum PLC tracking. The effectiveness of OBST is validated by a cluster of four satellites.

References

1. Radhika, Radhakrishnan, William W. Edmonson, Fatemeh Afghah, Ramon Martinez Rodriguez-Osorio, et al. Survey of Inter-Satellite Communication for Small Satellite Systems. IEEE COMMUNICATIONS SURVEYS & TUTORIALS, 2016, 18(4): 2442-2473.
2. Marco D’Errico, et al. Distributed Space Missions for Earth System Monitoring. Microcosm Press and Springer, California, 2013.
3. Bertiger W, Bar-Sever Y, Desai S, Dunn C, Haines B, Kruizinga G, Kuang D, Nandi S, Romans L, Watkins M, Wu S, Bettadpur S. GRACE: millimeters and microns in orbit. Proceedings of ION-GPS-2002, Portland, Oregon, USA, 2002: 2022–2029.
4. G. Krieger, “TanDEM-X: A satellite formation for high-resolution SAR interferometer,” IEEE Transactions on Geosciences and Remote Sensing, 2007, 45(11): 3317-3341
5. Casey Lambert and Alfred Ng, Intersatellite Separation Mechanism for the JC2Sat Formation-Flying Mission. Journal of Spacecraft & Rockets, 2011, 48 (4) :654-663.
6. F Lin， X Huang， Y Wu. An uplink power control scheme in CDMA mobile communication system. IEEE Vehicular Technology Conference, 1998, 3(3): 2479-2482.