2005－UBI－8（68）
2005／6／10

Weighting strategy in the state space problem for DS-CDMA code acquisition

Ruo Ando,Yoshiyasu Takefuji
Graduate School of Media and Governance,Keio University,
5322 Endo Fujisawa, Kanagawa, 252 Japan
{ruo,takefuji}@sfc.keio.ac.jp

Abstract: We present a formulation of state-space problem of which solution is directed by redundant reasoning control method for semi-heuristic and lightweight DS-CDMA code acquisition. The reasoning of the state-space problem provides us with the way to find a K bit synchronized sequence among K dephased sequences with less calculation cost compared with serial search and matched filter. In this process, redundancy-restriction method called weighting strategy enhances the searching ability of FOL (First order logic) reasoning for the faster and lightweight code acquisition. The combination of weighting strategy and correlator enables us to achieve the peak-detection within K/3 times of calculating inner products and its measurement. Our system is evaluated by the reduced cost of proving state-space problem using weighting strategy and its robustness of using the proposal code acquisition framework. Experiment shows that the proposal method is robust if K/N sequences are grouped with N ranging 3 from 5.

Keywords: DS-CDMA code acquisition, State space problem, FOL based automated reasoning, redundancy-restriction control, weighting

1 Introduction

Synchronization is an important task for telecommunication, especially for CDMA. In this paper we propose a semi-heuristic and lightweight code acquisition method applying this puzzle.

"the billiard balls and balance scale puzzle"
There are N billiard balls, N-1 of which are identical in weight. The remaining ball – the odd one – has a different weight. We are not informed whether it is heavier or lighter. We have a balance scale for weighting the balls. Can we find which ball is the odd ball in N/4 weightings, and also find out whether it is lighter or heavier than the others?

In proposal system, this puzzle is formulated as state-space problem which is solved by automated reasoning with some resolution strategies.

1.1 DS-CDMA

Since 1990, as the usage of cellular phone has been spread, the market of wireless communication has been increased dramatically. Among many wireless communication systems, Direct Sequence Code Division Multiple Access is applied to representative low bandwidth wireless communication devices such as cellular phone. In CDMA, all users send signals in the same bandwidth simultaneously with the unique code assigned to each terminal. Every user can coexist and transmit at the same time with smaller interface compared with TDMA and FDMA. This multiple access system protects users from interference and jamming.

These advantages is possible since the cross-correlations between the code of target user and one of other users are small while pseudo noise has a maximal value repeating itself every period. The receiver can decode information of each users when the code acquisition is completed, which means that we can detect the point where the correlation between the received signal and unique code in each terminals has maximal value.

The perfect synchronization is an important task in any sort of telecommunication. Particularly in CDMA, the unique sequence must be synchronized precisely to the received signal. Unless a maximal output from the correlator is not acquired, each user in CDMA system cannot get the information.

1.2 PN sequence

As we discussed in the previous section, the pseudo noise play an important role in the simultaneous usage of the same bandwidth. To achieve the immunity of interference, jamming and radio multipath fading, the assigned code must have these properties.

Balance property: relative frequencies of 0 and 1 are each 1/2.
Run property: run lengths of zeros and ones are as expected in a Bernoulli sequence.
Shift property: if the random sequence is shifted by any nonzero number of elements, the resulting sequence will have an equal number of agreements and disagreements with the original sequence.

The m-sequence have the balance, run and shift properties. The m sequences are almost ideal when viewed in terms of their autocorrelation function.

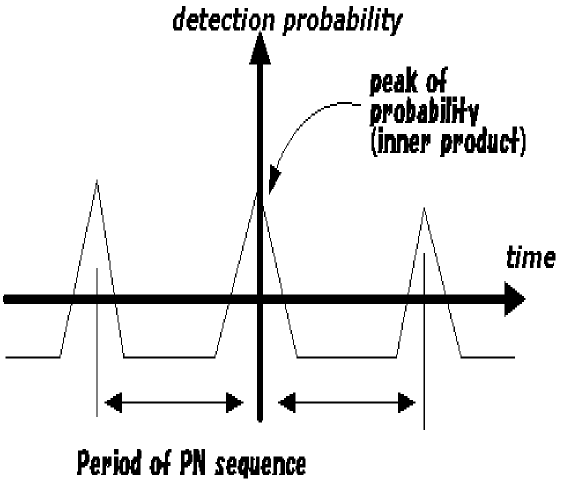

Figure1. PN sequence

2 Proposal method

In this paper we formulate the state-space problem for DS-CDMA code acquisition. Typical state space to decide if a state is reachable from another state or to find the shortest path between two states. We begin with the initial state and apply kind of transition axiom to pass from one solvable state to another. In our model, the solution of the problem provides the way of code acquisition of PN sequences of which properties are the balance, run and shift property.

2.1 Formulation

In this paper, we apply automated reasoning for the formulation of DS-CDMA code acquisition. From the beginning of 1960s, automated reasoning has been improved with puzzles, mainly represented as state-space problem. The famous state-space problems that can be solved by automated reasoning method are "the checkerboard and dominoes puzzle", "the missionaries and cannibals puzzle" and "the billiard balls and balance scale puzzle". Among state-space problem, concerning DS-CDMA code acquisition, the billiard balls and balance scale puzzle is applied.

There are N billiard balls, N-1 of which are identical in weight. The remaining ball – the odd one – has a different weight. We are not informed whether it is heavier or lighter. We have a balance scale for weighting the balls. Can we find which ball is the odd ball in N/4 weightings, and also find out whether it is lighter or heavier than the others?

The solution of this puzzle takes advantages that the finding odd ball, that is, detecting synchronized sequence, can be achieved in N/4 weightings. Compared with serial search and matched filter, the proposal method based on this puzzle is lightweight. The key of formulation of the puzzle is that from the properties of PN sequences discussed in section 1.2, the N-1 sequences excluding the synchronized one could be represented as "the same weight". Owing to the shift property of PN sequences, the result of inner product calculation is not changed if we add some sequences that is not synchronized.

The notion of state is the point of this puzzle. The transition axioms to pass from one achievable state to the other one are used. According to this puzzle, the sequences are classified into "standard", "heavy or standard", "light or standard" or "heavy or light or standard". In the initial state, all N sequences are recognized as heavy or light or standard. And then, put these conditions together, we can formulate the DS-CDMA code acquisition as follows:

There are N sequences, including synchronized sequence of which auto-correlation is –1 or 1. You are not told whether its correlation is 1 or –1. Can you find which sequence is the synchronized one in N/4 weightings, and also find out whether its class is "heavy or standard" or "light or standard"?

On the process of reasoning, many of generated states is solvable, of which any transition of the state is not lead to goals, is deleted. The number of outcomes that can occur when there are n weightings remaining is 3^n. If the number of possibilities for the odd ball is greater than the number of outcomes, then the situation is hopeless. That is, the state is unsolvable. The other fact necessary for applying the transition axiom is there are three cases after balancing (calculating inner product).

Let the sequences in initial state that is heavy or light or standard be XHLS, the sequences picked up for multiplier YHLS, the sequences picked up for multiplicand ZHLS. And let the number of users M.

<u>*Case 1: "scale balanced" with inner product around N/M.*</u>

All the sequences calculated is standard weight

(unsynchronized).
Thus resulting state is:
HLS=XHLS-(YHLS+ZHLS)
HS=XHS-(YHS+ZHS)
LS=XLS-(YLS+ZLS)
The number of standard class sequences in the resulting state
*S=XS+YHLS+ZHLS*YHS+ZHS+YLS+ZLS*

Case 2: "scale tips left" with inner product around –N/M.
Thus resulting state is:
HLS=XHLS=0
HS=XHS-(YHS+ZHS)
LS=XLS-(YLS+ZLS)
The number of standard class sequences in the resulting state
S=XS+ZLS+YHS+(XHLS-YHLS-ZHLS)+(XHS-YHS-ZHS)+(XLS-YLS-ZLS)

Case 3: "scale tips right" with inner product around 0.
Thus resulting state is:
HLS=XHLS=0
HS=XHS-(YHS+ZHS)
LS=XLS-(YLS+ZLS)
The number of standard class sequences in the resulting state
S=XS+ZLS+YHS+(XHLS-YHLS-ZHLS)+(XHS-YHS-ZHS)+(XLS-YLS-ZLS)

We apply the inference rule of hyperresolution as the approach for the reasoning program to know that this problem has been solved. Also we choose the set of support strategy discussed in the following section. The clauses placed in the set of support are the clause that gives the initial state and the one that denies that the initial state is solvable. The state with which the initial state is generated a proof by contradiction is found is three. In one, no weightings remain, N-1 of billiard balls are known to be of standard weight, and one belongs to HS class. A second state is the counterpart to this one but with the Nth ball known to be in LS class. A final state is that all N sequences are known to be of standard weight, which means this puzzle is not solvable. In the process of resolution, the third process turn out be useful although in this state the problem is incorrectly given.

3 ATP strategy

On the usage of OTTER, the automated reasoning program, a strategy is available to prevent the reasoning program from wandering through the examination of various combinations of facts, the vast number of paths of inquiry. There exist some categories of strategies in OTTER, ordering strategy, restriction strategy and pruning strategy. Without these directions, the program would seldom reach the solution generating too many resolutions and clauses, even for the simplest problems.

3.1 Set of support strategy

Set of support was introduced by L.Wos, S.Robinson and Carson in 1965[11]. If the clause T is retrieved from S, SOS is possible with the satisfiability of S-T. Set of support strategy enable the researcher to select one clause characterizing the searching to be placed in the initializing list called SOS. For the searching to be feasible and more effective, the resolution of more than one clauses not in SOS is inhibited in order to prevent the prover go into abundant searching place.

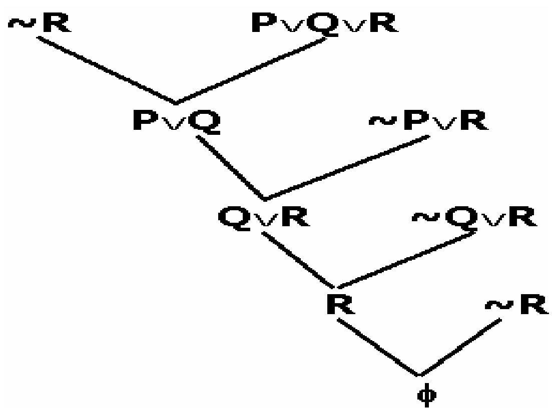

Figure2. Set of Support resolution strategy

Figure2 show the resolution process in set of support strategy, where
S={P and Q and R, ~P and R, ~Q and R, ~R}.
The restriction imposes the reasoning so that the program do not apply an inference rule to a set of clauses that are not the complement of set of support.

3.2 Hyperresolution

In generating encoder, we apply the inference rule called hyper resolution, which is a kind of resolution that can do resolutions at once compared with several steps in another rules. For hyperresolution, these must be the negative or mixed clause with the remaining clauses equal to the number of literals in the negative or mixed clause. Figure3 shows the framework of hyperresolution. The positive clause are described as satellites, the negative clause nucleus. “Hyper” means that in this resolution more process has occur than another resolution such as binary resolution.

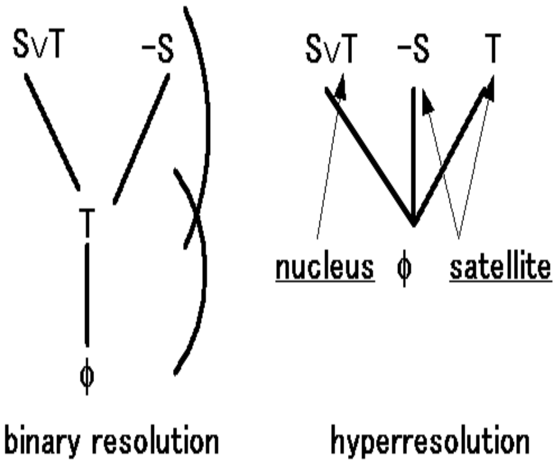

Figure2 Hyperresolution

3.3 Weighting strategy

In contrast to the restriction strategies which block a reasoning path to apply an inference rules to many kinds of subsets of clauses, a direction (ordering) strategy dictates what to set focus on next. Among these strategies, we apply weighting strategy. With this direction strategy, we can assign priorities to terms, clauses and concepts which make it possible to reflect the knowledge and intuition about how a reasoning program should proceed.

Weighting strategy, opposite to the restriction strategy called Set of Support, can be used complementarily. In the situation where the set of support strategy is adopted, the remaining clauses can be processed to complete the application of various inference rules. After the clauses assigned to set of support have been focus of attention, we can choose among the new clauses generated and retained for the following various kind of inference application. With weighting, you can supply various criteria for defining interests and for defining complex information. After the input clauses have been focus of attention, the choice is made from among the new clauses – those clauses that have been generated and retained because they represent new information that is deemed acceptable.

4 Experimental and evaluation

In this paper we utilize the open source software OTTER(Organized Techniques for Theorem proving and Effective Research). OTTER is first order logic prover, of which statements written in prolog-style format with equality featuring the inference rules binary resolution, hyperresolution, UR-resolution and binary paramodulation. This prover has autonomous mode where the user inputs a set of clauses which OTTER does a syntactic analysis. OTTER3.3 is released on August 2003, similar to AURA and LMA/ITP theorem provers, is associated with Argonne National Laboratory. The problem in this paper originated from “the billiard balls and balance scale puzzle” is solved on OTTER with formulation for CDMA code acquisition. In the next section, we discuss the statistics and CPU utilization of the process of proof.

4.1 Evaluation of weighting strategy

The performance measurements were collected on Linux kernel 2.4.8-13 host computer system using Pentium III 700 MHz with 512K RAM.

clauses given	**5605**
caluses generated	**21696**
demod & eval rewrites	**178926**
clauses forward subsumed	**16084**
clauses kept	**5604**
empty clauses	**16**
user CPU time (sec)	**109.23**
system CPU time(sec)	**0.33**

Table1. 16 sequences (length 16 bit)

clauses given	**17773**
clauses generated	**69478**
demod & eval rewrites	**573078**
clauses forward subsumed	**51692**
clauses kept	**17772**
empty clauses	**28**
user CPU time (sec)	**1709.7**
system CPU time(sec)	**1.75**

Table2. 32 sequences (length 32 bit)

clauses given	**153**
clauses generated	**444**
demod & eval rewrites	**3630**
clauses forward subsumed	**288**
clauses kept	**152**
empty clauses	**8**
user CPU time (sec)	**14.7**
system CPU time(sec)	**0.02**

Table3. 12 sequences (length 12 bit)

Table1 and 2 show the result of solving problem with each 16 and 32 sequences. It does not show liner increase, which means some kinds of resolution strategy is necessary according to the kind of PN sequences.

clauses given	**148**
clauses generated	**432**
demod & eval rewrites	**3531**
clauses forward subsumed	**280**
clauses kept	**147**
empty clauses	**8**
user CPU time (sec)	**14.36**
system CPU time(sec)	**0.02**

Table4. 12 sequences (length 12 bit) with weighting strategy

Table 3 and 4 show the result of solving problem with 12 bit sequences. In table 4, weighting strategy is enabled. Experiment show that weighting is effective to reduce redundant clause generation, for faster solving problem.

4.2 Results of inner products calculation

As we discussed before, the proposal system provides the cost reduction of DS-CDMA code acquisition. In our model, we can find the synchronized PN sequence among N sequences in N/K (K=2,3,4) times of inner product calculation. In experiment, we pick up 128 bit PN sequences and 3 users model shown in Figure.

To make this technique more lightweight, we grouped 4 and 8 sequences. According to the properties of PN sequences discussed in previous section, it is expected that detection probability is not changed if several 0/1 sequences are added to one.

	USER1	**USER2**	**USER3**
Including synchronized	**-44**	**-52**	**-36**
Another(average)	**18.7**	**19.87**	**17.73**

Table5. 16 groups of 8 users

	USER1	**USER2**	**USER3**
Including synchronized	**-78**	**-46**	**-70**
Another(average)	**9.29**	**7.8**	**11.8**

Table6. 32 groups of 4 users

Table5 lists the inner product of each user. In this 3 user model, the value ± 40 is set as threshold. Experiment show that the proposal method is effective because the average of inner product is around 40. However, several values are over 40 in table (8 sequences * 16 uses). Table6 lists the result in 4 sequences*32 users. It is expected to better that we group mote than 32 group by adding each 4 sequences.

To put all thing together, the proposal method can acquire the code of N sequences in

$$T = \frac{N}{K * L}(K = 2,3,4)$$

where T is times of calculating inner product. L is the number of groups.

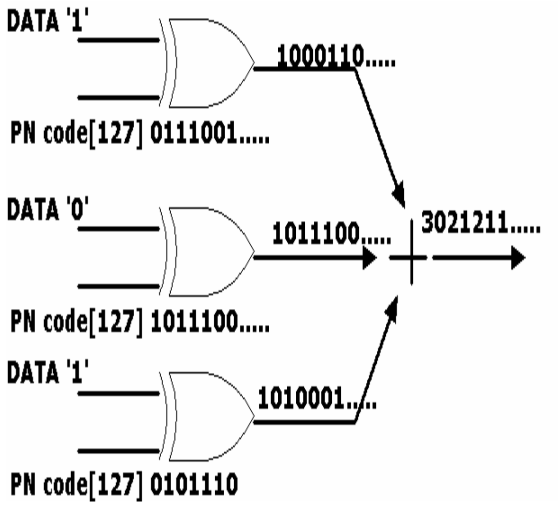

Figure3. 3 user CDMA model

5 Conclusions

We have presented the formulation of state-space problem of which solution is directed by redundant reasoning control method for the heuristic and lightweight DS-CDMA code acquisition. The reasoning of the state-space problem provides us with the way to find a K bit synchronized sequence among K dephased sequences with less calculation cost compared with serial search and matched filter. In this process, redundancy-restriction method called weighting strategy enhances the searching ability of FOL (First order logic) reasoning for the faster and lightweight code acquisition. The combination of weighting strategy and correlator enables us to achieve the peak-detection within K/3 times of calculating inner products and its measurement. Our system is evaluated by the reduced cost of proving state-space problem using weighting strategy and its robustness of using the proposal code acquisition framework. Experiment shows that the proposal method is robust if K/N sequences are grouped with N ranging 3 from 5.

References

[1]M.M.Mustapha and R.F.Ormondroyd,"Performance of a serial-search synchronizer for fiber0based optical CDMA system in the presence of multi-user interference",Proc.SPIE,vol.3899 pp.297-306 Nov.1999

[2]Abtin Keshavarzian and Jawad A. Salehi, "Optical Orthogonal Code Acquisition in Fiber-Optic CDMA Systems via the Simple Serial-Search Method," IEEE Transaction on Communications, vol. 50, no. 3, March 2002.

[3]M.M.Mustapha and R.F. Ormondroyd, "Dual-threshold sequential detection code synchronization for an optical CDMA network in the presence if multi-user interference", IEEE J.Lightwave Technol, Vol18,pp1742-1748, Jun 2000.

[4]Wos, L.; Robinson, G.; Carson, D., "Efficiency and completeness of the set of support strategy in theorem proving" J. ACM 1965 pp. 536-541

[5]Larry Wos: The Problem of Explaining the Disparate Performance of Hyperresolution and Paramodulation. J. Autom. Reasoning 4(2): 215-219