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Automated Test Sequence Optimization Based on the Maze Algorithm and Ant Colony Algorithm

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Abstract: With the rapid development of China train operation and control system, validity and safety of behavioral functions of the system have attracted much attention in the railway domain. In this paper, an automated test sequence optimization method was presented from the system functional requirement specification of the high-speed railway. To overcome the local optimum of traditional ant colony algorithm, the maze algorithm is integrated with the ant colony algorithm to achieve the dynamical learning capacity and improve the adaptation capacity to the complex and changeable environment, and therefore, this algorithm can produce the optimal searching results. Several key railway operation scenarios are selected as the representative functional scenarios and Colored Petri Nets (CPN) is used to model the scenarios. After the CPN model is transformed into the extensible markup language (XML) model, the improved ant colony algorithm is employed to generate the optimal sequences. The shortest searching paths are found and the redundant test sequences are reduced based on the natural law of ants foraging. Finally, the Radio Blocking Center (RBC) test platform is designed and used to validate the optimal sequence. Testing results show that the proposed method is able to optimize the test sequences and improve the test efficiency successfully.
Keywords: Ant colony algorithm, maze algorithm, test sequence, optimization, CPN model

1 Introduction

As the safety-critical system, the Chinese Train Control System Level 3 (CTCS-3) is capable of ensuring the safe and efficient operation for a train with high speed and density. Before the system comes into service, it is essential to execute series of tests, including laboratory testing, field testing, integrated testing, and interoperability test to verify the consistence of the system to the requirement specification [1]. A timely and complete test can significantly contribute to finding the drawbacks in the system design and to assuring the appropriate functional behaviors of the system. Taking the "7.23" accident in China as an example, there existed flaws in the fault-tolerant design of the acquisition drive unit, with the result that the Train Control Center (TCC) misunderstood the train occupancy information. One of the reasons was that the software functionalities of the TCC were not fully tested because there were not efficient test methods and enough test time for the signal system before it was put into operation. As the safety-critical system, the Chinese Train Control System Level 3 (CTCS-3) is capable of ensuring the safe and efficient operation for a train with high speed and density. There are more and more different test methods for the safety-critical train control system [2]- [3]. Behrmann proposed the method of test generation based on UPPAAL timed automata [2]. Hessel described how to generate real-time verification tool for the test case [4]. Lee referred to a method of black box testing based on the input and output finite state machine (I/O FSM) [5]. Zhao proposed the input and output automata of port labeled (LPTIOA), which automatically realizes the test sequences generation for the LPTIOA model validated by UPPAAL of CTCS-3 on-board system [6]. Jaafar put forward a kind of automatic generation method of testing script based extensible markup language (XML) for the characteristics of safety critical system such as large script in scale, complex structure, difficult maintenance and safety testing demand [7]. Although these methods have achieved some success, it still exist many defects .For instance, the concurrent behavior of the system cannot be described by test generation method based on timed automata. Because the generation of test cases in the railway domain has high levels abstraction, automation can not to be realized. In addition, most current test methods are semiautomatic, and the test cases and test sequences manually generated have the drawbacks of a heavy workload, low efficiency, and high demand for professional expertise.

Ant colony optimization (ACO) is employed to find optimal path in the graph theory. It is proposed by Marco Dorigo in his doctoral thesis in 1992 and the idea comes from the behavior that ants search food to find the path [8]. Experiments show that the algorithm has strong robustness and the ability of finding optimal solution. However, there are still some defects in it such as slow convergence speed and stagnation behavior. Ant colony algorithm has attracted wide attention of scholars and the new ant colony algorithm has been widely applied to various fields, such as fault identification, TSP problem and the construction of roads. At present the study of ant colony algorithm is mainly focused on the improvement and application of algorithm. Wu [9] made full use of the concision and efficiency of "2 - exchange method" by leading in mutation mechanism to the basic ant colony algorithm and proposed an ant colony algorithm with mutation features. Wang [10] put forward the meeting algorithm based on ant colony algorithm, improved ant touring quality, combined meeting algorithm with the parallel segmentation strategy, and proposed a segmentation algorithm for TSP problem based on ant colony algorithm.

Taking all these aspects into consideration, a type of improved ant colony algorithm is proposed in this paper to deal with the problems of inefficiency and repetition of the test sequences in railway domain. The ant colony algorithm and maze algorithm are integrated to generate the executive optimal sequences automatically. They are applied to generate Extensible Markup Language (XML) test cases and XML test sequences respectively. These test sequences are totally feasible for practical test executions. In addition, the repeatability rate of the generated test sequences is reduced. Finally, four scenarios from the CTCS-3 system specification are taken as the example and modeled with Petri nets. The algorithm is validated on the radio block center (RBC) test platform.

The rest of this paper is organized as follows. In Section 2, the basic definitions of Petri nets are introduced and the improved ant colony algorithm is specified. In Section 3, the Colored Petri nets are used to model the typical operation scenarios. After the reachable graph of the Petri nets model is analyzed, the test generation software tool is presented. Finally, the generated test sequences are validated by the RBC test platform. Some concluding remarks are presented in Section 4.

2 Automated test generation

The automated test method by CPN model can be depicted as Fig.1 and it is mainly divided into three stages including modeling, test case generation and test sequence generation. From the system requirement specification and the modeling rules, the CPN model is built for the operation scenarios, and then the XML file and the reachable graph of the model are obtained. On the basis of CPN model with XML format, the proposed improved ant colony algorithm is applied into generate the set of original test cases. Test subsequence can be generated by concatenating the test cases using ant colony algorithm and the information in test cases. Finally, the set of original test cases and the test sequences can be transformed into files with XML format, and then the XML-format test sequences can be used directly in practical test process.

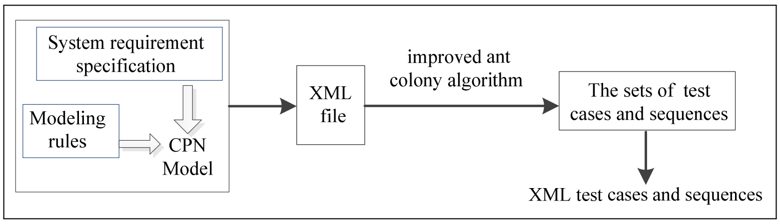

Figure 1: Frame diagram of the test generation method

2.1 Introduction of Colored Petri nets

Colored Petri nets (CPN) is an advanced network system in 1981 introduced by the Jensen Kurt based on basic Petri nets [11]. It is mainly composed of the place, transition, token and arcs to establish a system model. The basic Petri nets has the theoretical basis as well as the wide application in different domains, but it has no data and level concepts so that it is hard to model the complex systems because the model will be very large and difficult to analyzed. CPN extends the basic features of basic Petri nets and introduces the colored markers, arc description, level page and so on, to compensate the drawbacks of the base Petri nets. CPN has the description capacity for the concurrent, synchronous, asynchronous features, resources competition and the coordination of the discrete event dynamic system behavior. If it is combined with the high-level programming language, it can model the large-scale system with the definition of complex data types and data processing.

2.2 Ant colony algorithm

As the ant colony search for the food, they can usually find an optimal path from the nest to food because the ants in the searching path will release a special kind of pheromone. When they encounter a road they never meet before, they randomly select another path. At the same time, the ants release a kind of pheromone associated with the path length. The longer the path, the lower the concentration of hormone released. If the following ants meet this intersection again, the probability that they choose the path with higher hormone concentration will be relatively large. This forms a positive feedback mechanics. The hormone concentration of the optimal path is stronger and stronger, while the other path will diminish as time goes by. Eventually the whole colony will find the optimal path. In addition, the ants can adapt to the environment change. If the obstacle suddenly appears on the moving route of the ants, they can quickly find the optimal path. During the process of searching for the route, although the selecting ability of single ant is limited, the path information is exchanged with the effect of the hormone between different ants, and therefore the ant colony could finally find the optimal path.

There exists other path searching algorithm such as traditional depth-first searching (DFS) algorithm and Bee colony algorithm. Although DFS algorithm is able to search in different levels [12], it doesn?t take recurring nodes into account so that it easily leads to an endless loop, leading to the instability of the searching process. Bee colony algorithm is a type of optimization method by imitating the behavior of bees and the main characteristics of the algorithm is it need not know specific information and only compare the merits of the issue. However, the bee colony optimization algorithm method is too restrictive and it can achieve some success in local optimization, but from a global point of view, it is not stable enough and has the relatively large blindness. The principle of genetic algorithm, similar to neural network algorithm, uses eugenics survival of the fittest way and achieves the optimization from generation to generation. The neural network mainly finds the optimal way by training, resulting in the relatively low convergence speed.

2.3 The improved ant colony algorithm

The traditional ant colony algorithm is prone to reach the local optimum. In this paper, the maze algorithm and ant colony algorithm are integrated to overcome this shortcoming. For maze algorithm, facing a fork in the maze, the mice can choose one of the roads. If the road is blocked, the mice will return to the fork and walk the other road. In fact, this idea is a process of learning and optimization, which can adapt to the complex and changeable environment. Therefore, together with the idea and the traditional ant colony algorithm, the solutions for the test sequence optimization are designed.

Assuming that the artificial intelligence ant can secrete a special kind of pheromone, if it finds no food when meeting a node, it can inform the foraging ants that there is no food. The ant returns to the nest (initial point) and informs the ant in the nest that this road is blocked and other roads can be selected. If one of the ants can go straight from the initial point to the end point, this road should be recorded as one of the test sequences. In order to prevent the local optimization, the next foraging ants take different roads from those recorded. If other roads can be found, the recorded optimal road is desired. The reverse thinking can be used to accomplish the aforementioned idea quickly. For one complex scenario, the number of roads is limited, so the test sequence sets can be set up. Those test sequences with nodes containing no food should be deleted from the test sequence set. Among those remaining test sequences, the optimal sequence is the one with the minimum nodes. The reverse thinking can greatly reduce the program running time. In this paper, it is assumed that each node has two different states, in which "0" means there is no food here whereas "1" means this node has food.

From the aforementioned principle, the flow diagram of improved ant colony algorithm is shown as Fig.2 [13].

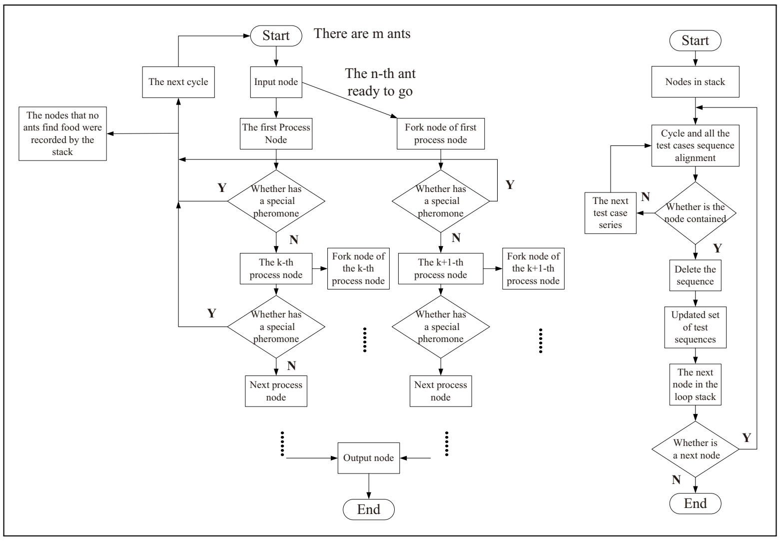

Figure 2: The flow chart of improved ant colony algorithm

3 Application of the test generation algorithm

Radio Blocking Center (RBC), as key trackside equipment in CTCS-3, can generate the movement authority (MA) and other control commands according to the information coming from other subsystems [1]; hence, it should satisfy the functional requirements in the CTCS-3 specifications. Four operation scenarios associated with RBC will be modeled using the CPN and the corresponding test cases and sequences will be generated using the proposed path optimization algorithm. Compared with the RW-TSG [14] and traditional DFS algorithms, the numbers of the test cases and sequences will be seen as the indicators showing the superiority of the proposed algorithms.

3.1 Functionality of RBC

The main functionalities of the RBC include: (1) receiving the position and train data from the onboard equipment through the global system for mobile communications for railways (GSM-R) wireless communication system; (2) generating the MA according to the information from the Balise, the track circuit, the temporary speed restriction server, and the interlocking system; (3) transmitting the MA to the onboard equipment, which will calculate the location-speed curve to protect the train safety operation [15]. In CTCS-3, the RBC is connected with the centralized traffic control (CTC) system, the computer-based interlocking (CBI) system, the temporary speed restriction server (TSRS), and the neighbor RBC (NRBC) by different specific safety data communication "Ethernet," and it is connected with the onboard equipment by GSM-R.

3.2 The main operation scenarios

The main operation scenarios of CTCS-3 includes registration and start, log out, level conversion, movement authority, RBC handover, temporary speed restriction and so on. In this paper, only the registered and start, RBC handover, automatic neutral, and log out are studied.
1. Registration and start: describe the process of the train from the initial location to prepare operation. It mainly includes 6 stages, such as train awaking, train registration, inputting train data and so on.
2. RBC handover: guarantee the train running from one RBC region to another RBC region. The neighboring RBCs should have direct communication to exchange RBC handover information. Schematic diagram is shown as Fig.3.
In the process of RBC handover, RBC1 (handover RBC) is responsible to send the handover warning information (ID, the border of RBC Balise group ID, train data) , route request information, switching notice information, switching confirmation information and so on. RBC2 is responsible to send route information to take over train information to RBC1.

3. Automatic passing over of neutral section: the operation scenario of phase area has no electric interval of the electrified railway. For CTCS-3, RBC sends the phase zone information and movement authorization (MA) to train, and the zone information includes the distance to phase point, the length of phase zone and so on. The schematic process is shown in Fig.4.
On-board equipments receive the activated phase information transmitted by RBC, supervises speed and position of the train in real time, process as followed: 1) When there are 10 seconds running distance from the neutral section to the front of the train, the on-board equipment warns the driver;2) When there are 3 seconds running distance from the neutral section to the front of the train, the on-board equipment sends neutral-section passing order to Electric-Multi-Unit(EMU); 3) After the front of the train crossing the phase region, the related commands are canceled by train equipment.

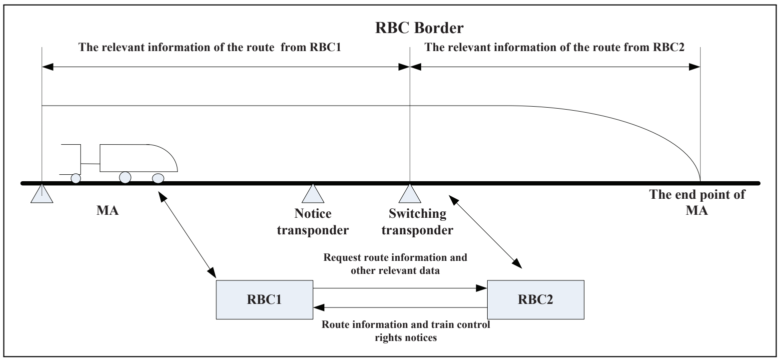

Figure 3: Schematic diagram of RBC switching

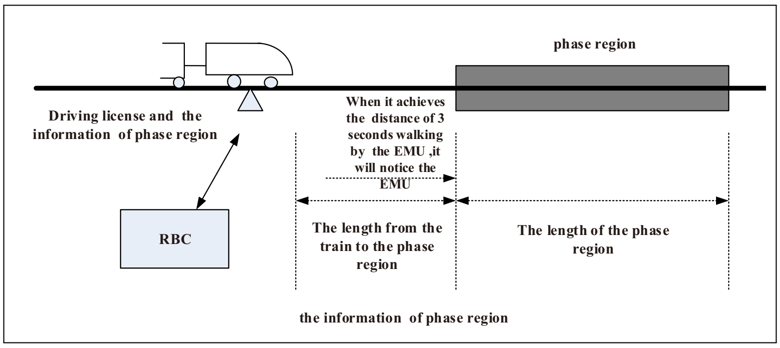

Figure 4: automatic passing over of neutral section

4. Logout: describes the process from logout information to shut off the power for the train. It mainly includes 2 stages: RBC logout and the power of the train is cut off.

3.3 RBC scenarios modeling and test optimization

From the functional characteristics of RBC and the overall technology scheme of CTCS-3, the RBC test cases of XML format and state space reachable graph are established. By the improved ant colony algorithm, several cases are optimized and generated to test sequences with XML format. Finally, the set of the generation test sequence with XML format was validated by RBC simulation testing platform.

1. Operation scenarios modeling

Taking the four scenarios as the example including "Registration and start", "RBC handover", "Automatic passing over of neutral section" ,"Logout", the four operation processes are modeling with CPNs and the high level model are presented by Fig.5 and the other low level mode are described as Fig.6 to Fig.8.

2. Reachable state analysis of the Petri nets model

According to the four functional scenarios selected and the relevant requirement specifications of CTCS-3, the state space reachable graph can be generated with the XML from the CPN models. Some of those redundant states are deleted. After simplification, the simplest 36 states can be

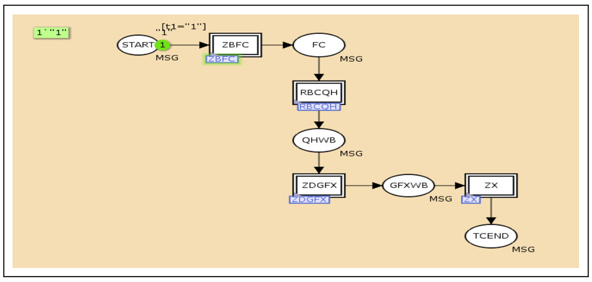

Figure 5: High-level model for the four operation scenarios

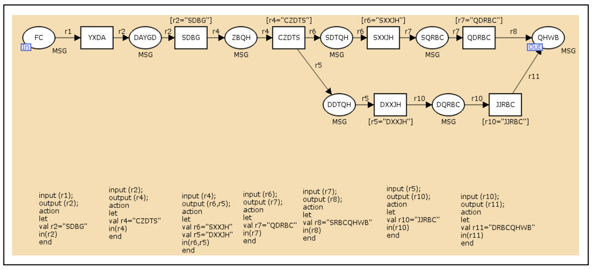

Figure 6: RBC handover scenarios

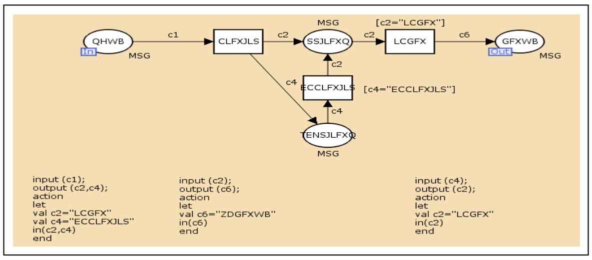

Figure 7: Automatic passing over of neutral section scenario

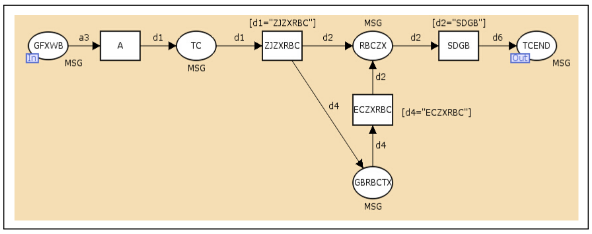

Figure 8: Registration and start scenario

attained through the equivalent markers, as shown in Fig.9.

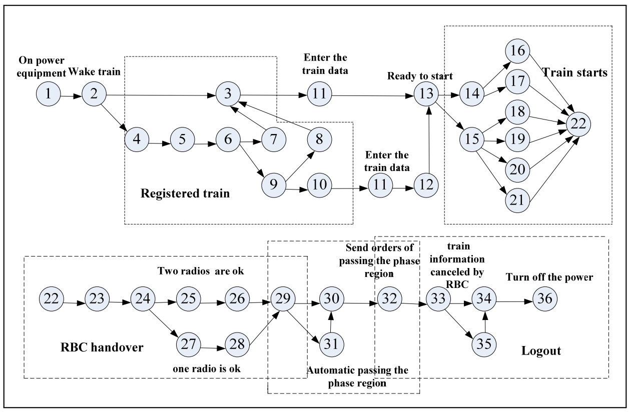

Figure 9: The state diagram of four scenarios

The input, the output nodes of four scenarios are shown in Tab.1.

Table 1: Description of the scenario

Number	Scenario	Input node	Output node
1	Registration and start	1	22
2	RBC switch	22	29
3	Automatic passing the phase region	29	32
4	Logout	32	36

As is shown in Table 1, the input node and output node of scene 1 is 1 and 22 respectively and so on. In order to ensure that all nodes are covered, between two adjacent, input nodes and output nodes have overlapped.

3. The theoretical analysis of the state diagram

From a simplified state diagram of Fig.9, one of the test sequences is "1 2 3 11 13 14 16 22 23 24 25 26 29 30 32 33 34 36". Assuming that the ant A finds "no food" in node 3 during foraging process, which means the next ant need not go into the node. Then ant A goes back to the initial point to exchange the information to ant B. Node 3 is no food and then ant B will go to node 6 and finds that fork in the road. Ant B comes to node 7, finding that the next node is node 3, and then return to the initial point and record that node 7 should not go, until the ant reaches the end. Assuming that in a certain state, node 3, node 15, node 17 and node 25 are dead, according to the above process, we know that the remaining 4 test sequences, such as "2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 30 32 33 34 36", "1 2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 31 30 32 33 34 36", "1 2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 31 30 32 33 35 34 36", "1 2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 30 32 33 35 34 36". From these four test sequences, in order to find the shortest test sequence, after comparing one by one, sequence "1 2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 30 32 33 34 36" will be identified and this test sequence contains the least test cases.

From the simplified state space reachable graph, the program may used to generate the test cases, as shown in Table 2.

From the results, the scenario 1 generates test subsequence ①(1 2 4 5 6 9 10 11 12 13 14 16 22); test subsequence ②(22 23 24 27 28 29) is generated by scenario 2; test subsequence ③(29 31 30 32) and test subsequence ④ (29 30 32) are for the scenario 3; test subsequence ⑤(32 33 34 36) and test subsequence ⑥(32 33 35 34 36) are for the scenario 4. Based on the improved ant colony

Table 2: Test subsequences of the scenarios

Scenarios	Generated test subsequences
1	1 2 4 5 6 9 10 11 12 13 14 16 22
2	22 23 24 27 28 29
3	29 31 30 32/29 30 32
4	32 33 34 36/32 33 35 34 36

algorithm proposed in this paper, the test subsequences combinations by the scenarios are shown in Tab.3:

Table 3: The test subsequences combinations

The number of subsequence	The test subsequences combinations
1	① ② ③ ⑤
2	① ② ③ ⑥
3	① ② ④ ⑤
4	① ② ④ ⑥

After those test sequences is optimized, the final optimization test sequences are generated and shown as Table 4.

Table 4: Optimization of the test sequences

The number of sequence	The test subsequences combination	The test sequences
1	① ② ③ ⑤	1 2 4 5 6 9 10 11 12 13 14 16 22 23 24 27 28 29 30 32 33 34 36

From the aforementioned data, the experimental results conform to the theoretical analysis. By the improved ant colony algorithm, four test sequences are generated and optimized to one eligible case sequence with the minimum redundancy. The test results are real and effective, which not only saves time but also improve the test efficiency greatly.

3.4 Test generation software tool for the ant colony algorithm

This test generation software tool is achieved by C++ language. It executes the ant colony algorithm and generates the test sequences. Fig.10 shows the main interface of the software and it reads the XML model from the CPN model and shows the test sequence generation from several functional scenarios.

If the top right button "reads the XML file" of the main interface is pressed, Fig.11 will appear and show the contents of the XML files to be read.

If natural number greater than 36 is input to the top left four boxes of the screen, Fig.12 presents the optimized test sequences generation.

3.5 Test generation method validation

From the rules of all modules functional requirements of CTCS-3 RBC test that are made by the Ministry of Railways, the RBC test platform is designed and the platform structure is shown in Fig.13.

In order to verify the practicality and feasibility of the test automated generation method, an RBC functionality test platform is developed and the generated test cases and sequences are

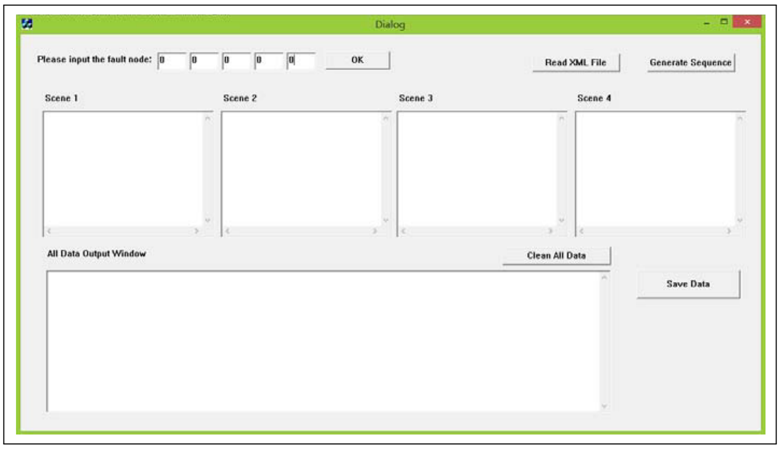

Figure 10: The main interface of the test generation software tool

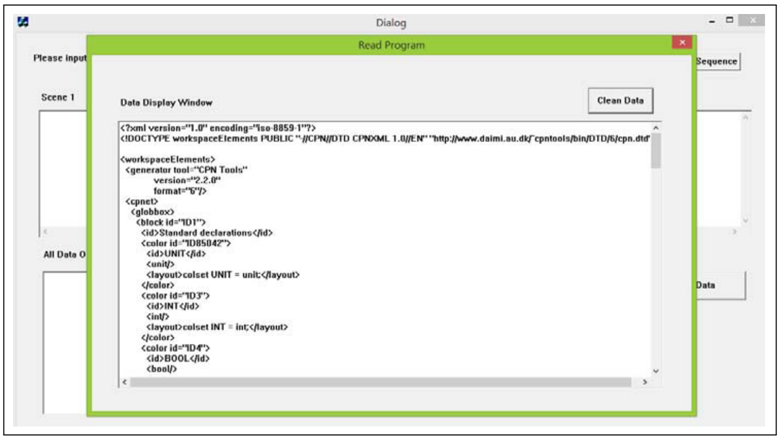

Figure 11: Contents of the XML files

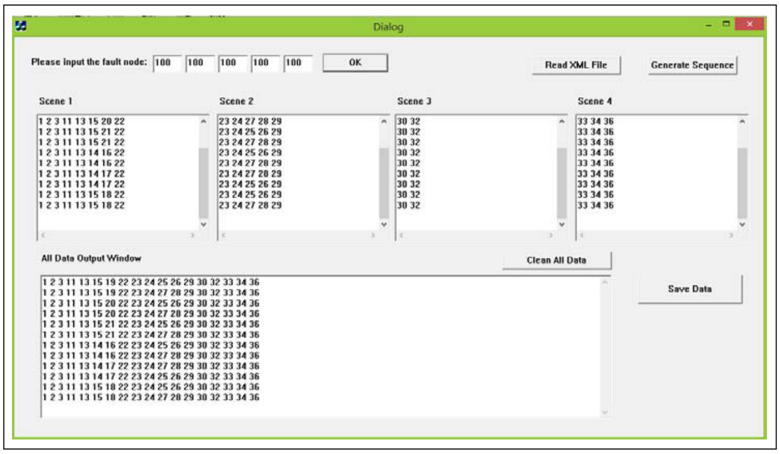

Figure 12: Test sequence optimization generation interface

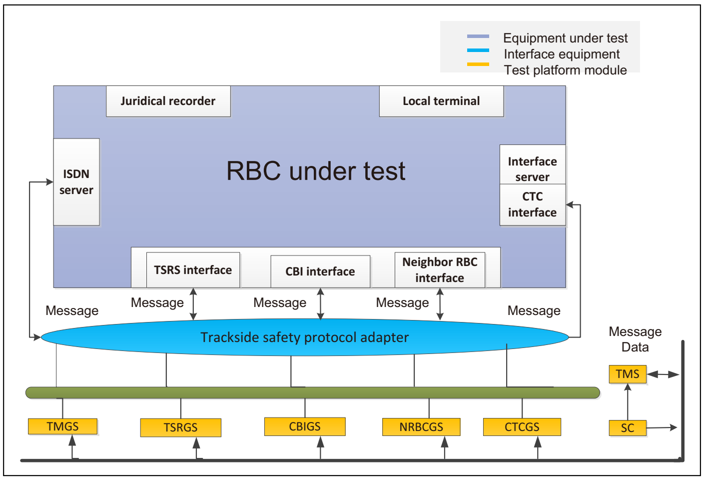

Figure 13: Framework of the RBC test platform

injected to test.

This RBC test platform consists of scenario controller (SC), the centralized traffic control generation simulator (CTCGS), the train message generation simulator (TMGS), the computer-based interlocking generation simulator (CBIGS), the Neighboring RBC (NRBC) generation simulator (NRBCGS), the temporary speed restriction generation simulator (TSRGS), and the train movement simulator (TMS). Five subsystems (except the SC and the TMS) only have message interaction with the RBC under test, and six subsystems (except the SC) have no communication with each other. The SC can control the whole test process and the data for these six subsystems during the test process come from the SC and the SC can directly read the XML test cases and sequences files to get the test data.

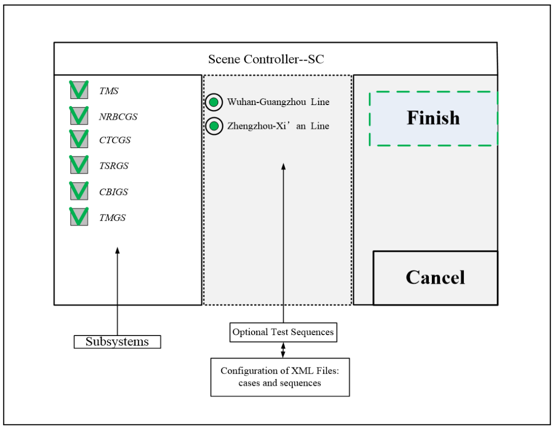

Figure 14: The control interface screen of the SC

The control interface screen of the SC is shown in Fig.14. During the test process, the XML files has the distinguished characteristics, such as understandability, platform independence, the formatted structure, and the ability of hierarchical data description [16] . /citeli and it contains all the test data and can be directly read by the SC, which makes the test process automatically. If a test begins, the involved subsystems and the optional test sequence should be selected first. When the button "Finish" is pressed, the SC will load the XML configuration document and distribute the data to the corresponding subsystems. Then, each subsystem begins to communicate with the RBC under test until the test process is an error or until the test is normally over. The optimal test sequence with XML format generated by the proposed algorithm is applied in the RBC test platform. Part of the key interaction interface data are shown in Tab.5, including the interaction message from the operation scenario "registration and start", "RBC handover" and "Logout"

Table 5: Test data of the RBC platform validation process

Operation scenario: Registration and start							
Data_id	TestSeq_ID	Time	Event	Direction	Msg_ID	Meaning of Msg_ID	MsgData_bit
1	1	2014/11/23/11:48:01	Running	Train→RBC	155	Communication begins	9B0280000019020C01BF
2	1	2014/11/23/11:48:02	Running	Train←RBC	32	System version	2002C00000191FFFFFE4
3	1	2014/11/23/11:48:03	Running	Train→RBC	146	Confirmation	920380000EB4020C0180
4	1	2014/11/23/11:48:04	Running	Train→RBC	159	Communication sets up	9F0280000E90020C01BF
5	1	2014/11/23/11:48:06	Running	Train←RBC	24	General information	1805C0000E903FFFFFE7
6	1	2014/11/23/11:48:07	Running	Train→RBC	129	Train data	8109C0000EB4020C0180
7	1	2014/11/23/11:48:07	Running	Train←RBC	8	Train data confirmation	080380000EB41FFFFFE0
Operation scenario: RBC handover							
Data_id	TestSeq_ID	Time	Event	Direction	Msg_ID	Meaning of Msg_ID	MsgData_bit
1	1	2014/11/23/11:51:50	Running	Train←RBC	3	Movement authority	0327000021F631E0E381F
2	1	2014/11/23/11:51:51	Running	Train→RBC	136	Train location	880600002374820C048001
3	1	2014/11/23/11:54:52	Running	NRBC→RBC	201	Handover announcement	C90020023C00010830060
4	1	2014/11/23/11:54:53	Running	NRBC←RBC	205	Reply	CD0523C000820C01A3C0
5	1	2014/11/23/11:54:54	Running	NRBC→RBC	202	Movement authority request	CA0018023C00010830060
6	1	2014/11/23/11:54:54	Running	NRBC→RBC	205	Reply	CD0523C000820C01A3C0
7	1	2014/11/23/11:54:55	Running	NRBC→RBC	221	Information request	DD2B23C000820C01A3C
Operation scenario: Logout							
Data_id	TestSeq_ID	Time	Event	Direction	Msg_ID	Meaning of Msg_ID	MsgData_bit
1	1	2011/11/23/12:11:45	Running	Train→RBC	156	Communication terminates	9C06000065ED820C02BF
2	1	2011/11/23/12:11:46	Running	Train←RBC	39	Confirmation	2702800065ED91E0621F2
3	1	2011/11/23/12:11:47	Running	Train←RBC	39	Confirmation	2702800065ED91E0621F3

In Table 5, "Msg_ID" records the message ID, and "MsgData_bit" records the content of messages. Taking operation scenario "registration and start" as the example, firstly, the train send Message 155 to RBC, presenting "the communication begins"; Then the RBC send Message 32 to the train, informing the "system version" . After the train confirms the same system version with Message 146, it sends Message 159 to RBC, meaning "the communication sets up". Then the RBC sends general Message 24 to train, presenting the successful communication. Finally, the train set train data Message 129 to RBC and after the RBC uses Message 8 to confirm the train data, the train may start. Thus, the practicality and feasibility of the test automated generation method are verified.

4 Conclusion

This paper has put forward a more efficient improved ant colony algorithm integrated with the maze algorithm, which not only completes the automatic generation of test sequence but also greatly improves the test efficiency. The RBC test platform is designed to validate the effectiveness of the optimal test sequences. Although only four train operation scenarios are employed as the example, the proposed algorithm can be applied on all the other operation scenarios described in the high-speed railway system requirement specification. This approach is able to effectively improve the test efficiency, lower the test difficulty, and achieve the goal of test automation.

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