Analysis and Design of Railway Communication Control System Based AADL

Yunxiao Li, Lichen Zhang* and Minglv Chen

Faculty of Computer Science, Guangdong University of Technology, Guangzhou 510006, China
{jxliyunxiao@yahoo.com.cn, zhanglichen1962@163.com, gofansy@gmail.com}

Abstract

Aiming at the hugeness and complexity of Communication Based Train Control system, analyzing the characteristics of the system's functions, the system can be split into four subsystems. Using the Architecture Analysis and Design Language gives the design and modeling of each subsystem with OSATE tools, and defines the interfaces between the subsystems. According to the specific needs of the railroad system, the modeling of each subsystem uses the reasonable AADL components.

Keywords: *AADL Railroad system Train control system component OSATE*

1. Introduction

In September 1999, IEEE defined that a CBTC system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and train-borne and wayside processors capable of implementing automatic train protection functions, as well as optional automatic train operation and automatic train supervision functions [1]. CBTC system is a system whose center is vehicles, and it gets rid of the constraint that using the traditional urban rail transit information and check the rail occupied by train, and makes full use of the wireless communication means of transmission to communicate between train and wayside in time or periodically. According to the characteristics of the CBTC system's functions, generally, the system can be effectively split into four subsystems: automatic train supervision (ATS) subsystem, zone control subsystem, vehicle on-board subsystem and data communication subsystem.

2. Related Work

In recent years, the research of the train control system, has always been very popular. Many experienced people on the train control system have carried on the thorough analysis and research in all aspects. For example, in the field of design and modeling, in order for a train to be operated safely in driverless mode, automatic train protection (ATP) and automatic train operation [15] (ATO) functions have to be safely designed based on the high credibility, especially for the train which is run in driverless mode, Chan-Ho Cho focused on the development of CBTC carborne ATO functions using SCADE [2]. And Sehchan Oh designed automatic train protection simulator for radio-based train control system, and present an algorithm of automatic train protection, system configuration of the simulator and experimental results [3]. In the field of train positioning, Mohammed Abdul Qadeer gave a design and implementation of location awareness and sharing system using GPS and 3G/GPRS [4]. In the field of train communication, Sattarova Feruza Y. studied a method of encryption to protect data security in communication process [5]. And in the parking field, Li-Der Chou designed a novel automatic vehicle parking system for secure parking [6].

3. The Introduction of AADL

AADL (Architecture Analysis and Design Language) [7, 14], which is a modeling language that supports text and graphics, was approved as the industrial standard AS5506 in November 2004. Component is the most important concept in AADL. The main components in AADL are divided into three parts: software components, hardware components and composite components. Software components include data, thread, thread group, process and subprogram. Hardware components include processor, memory, bus and device. Composite components include system [8, 10, 11].This paper closes by highlighting the use of the AADL and its tools in the modeling of CBTC system. The tools of AADL include modeling tools, analysis tools and code generation tool. In this paper, we mainly use OSATE tools .It is based the Eclipse platform, and contains the complete AADL tools. When users finish the AADL codes, OSATE can generate automatically the AAXL codes that store the system information by the XML files. The diagram of AADL component comes from the AADL code, but we must new a file whose name ends with aaxldi [9, 11].

4. Design and Modeling of Train Control System

4.1. Design and Modeling of CBTC

It is known that CBTC system can be effectively split into four subsystems: automatic train supervision subsystem (ATS), zone control subsystem, vehicle on-board subsystem and data communication subsystem.

The ATS subsystem, also named center control subsystem, includes a series of servers for different purposes, printers, displays, many workstations and so on. Via the data communication subsystem, the ATS subsystem gets respectively the information of databases, train position, wayside devices and movement authority from the database storage unit in data communication subsystem, vehicle on-board subsystem and zone control subsystem. After handling them, they are transferred to the correlated devices and subsystems.

The vehicle on-board subsystem includes the VOBC (vehicle on-board controller), DMI (Driver Machine Interface) and so on. The subsystems accepts many different types of data in zone control subsystem and ATS subsystem，then calculates the train movement curve, measures the train speed and movement distance associating with the guide way databases to protect the safety of train movement.

The zone control subsystem [12, 13] contains zone controller, computer interlocking (CI) devices, axle counter, signals, platform doors ,switches and other wayside devices. The subsystem gets and handles the useful data and statue information from other subsystems to generate the movement authority for the trains in control zones and update persistently as required. Then the subsystem transfers the movement authority to the vehicle on-board subsystem through the data communication subsystem in order to control the train movement. It also controls the switches, signals, and platform doors, and acknowledges the request of adjacent zone controller.

The data communication subsystem mainly contains database storage unit, backbone fie-optical network, wayside access points, on-board wireless units and network switches. Data communication subsystem is the other subsystems communication bridge making normal communication between the subsystems and ensuring the safety of train operation. As shown in Figure 1, the communications between the subsystems are via the data communication subsystem.

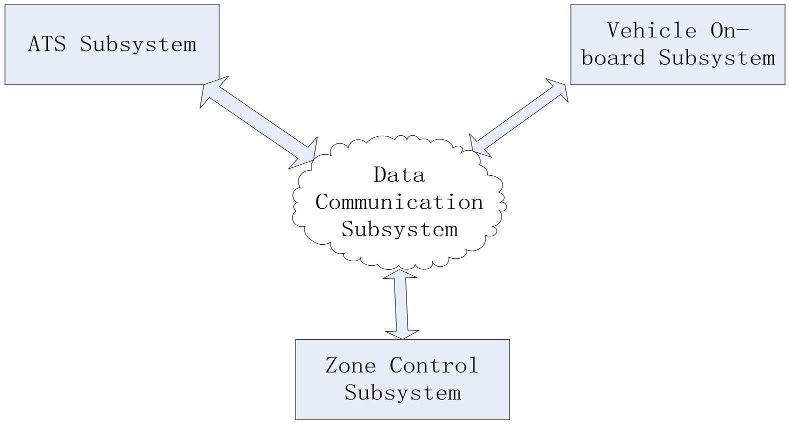


Figure 1. The Communication between the Subsystems

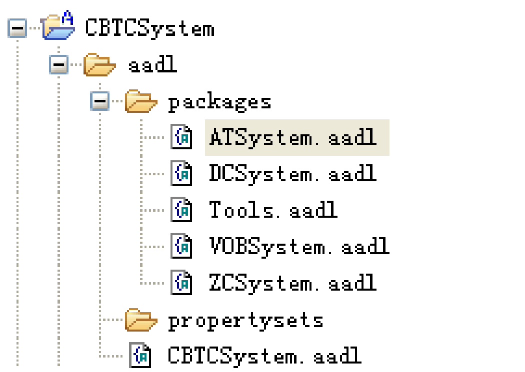


Figure 2. CBTC System's File Structure

In OSATE environment, we will use the AADL to give the design and modeling of the CBTC system. The CBTC system's file structure is shown in Figure 2.

Each subsystem corresponds to a file whose name ends with aadl. In view of the repeated use of some tools, the system provides a common tool file(Tools.aadl).Four subsystems are combined to form a complete CBTC system through a file(CBTCSystem.aadl) . The four subsystems are achieved by using the system components in AADL, and the connections between the subsystems use the bus components. In AADL, components contain component type and component implementation. Component type specifies the external interfaces of component implementation, and component implementation describes the internal structure of the component. Each component implementation corresponds to a component type, a component type can have zero or more component implementations. The AADL code of CBTC system overall framework is as follows:

```
system CBTCSystem
end CBTCSystem;
system implementation CBTCSystem.Impl
```

```
  subcomponents
    ATSys: system ATSystem::ATSys.Impl;
    ZCSys: system ZCSystem::ZCSys.Impl;
    VOBSys: system VOBSystem::VOBSys.Impl;
    DCSys: system DCSystem::DCSys.Impl;
  connections
    conn1: bus access ATSys.toDCS -> DCSys.fromATS;
    conn2: bus access ZCSys.toDCS -> DCSys.fromZC;
    conn3: bus access VOBSys.ToDCS -> DCSys.fromVOBS;
    conn4: bus access DCSys.toATS -> ATSys.fromDCS;
    conn5: bus access DCSys.toZC -> ZCSys.fromDCS;
conn6: bus access DCSys.toVOBS -> VOBSys.FromDCS;
…
end CBTCSystem.Impl;
```

As can be seen from the above code, the CBTC system contains four subsystems, data communication subsystem is a bridge of communication between the other three subsystems. OSATE will automatically generate an aaxl file for each aadl file, we can take advantage of aaxl file to new a corresponding graphics file (aaxldi file). The file lists the graphical representation of all components. And each implementation of the system components will generate a system instance diagram. The system instance diagram of the CBTC system implementation (CBTCSystem.Impl) is shown in Figure 3.

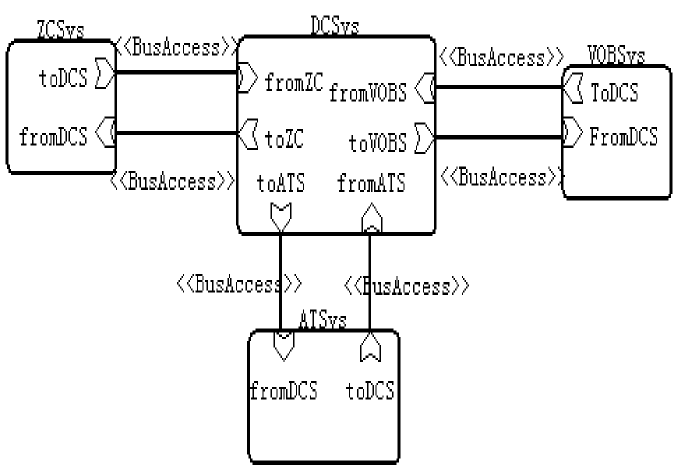


Figure 3. System Instance Diagram of the of CBTC System Implementation

4.2. Design and Modeling of ATS Subsystem

The main parts of ATS subsystem are as follows: application server, external interface servers, large screen interface workstation, maintenance workstation, dispatcher workstations (director workstations, dispatcher workstations and station workstations), printers, large-screen display and other equipments.

The application server is a core part in the ATS subsystem, it receives the database information and the stations, equipments, train position and status information coming from the ground device, and processes the information, and then sends it to the relevant clients. Meanwhile, it compares the information according to the received train with the schedules and the running diagram, then executes offset calculation and program adjustments, and send the adjustment commands to the vehicle on-board subsystem for execution. In addition, the ATS system is also responsible for the full range of the processing functions, and their specific functions are mainly train tracking, automatic scheduling, automatic route and control requests confirmation. The external interface server provides the interfaces and protocol conversion between the CBTC system and external system. Maintenance workstation monitors the ATS signal system equipments working and connection state, and displays devices normal and failure state information. The main functions of dispatcher workstations are to monitor the platform equipments along the railroad, the ground signal equipments, as well as the location and status of the train, and to allow dispatchers to operate some functions, such as the change of control mode. The large screen interface workstation connecting to a large screen display, and displays the field map of the entire station, including station platforms, signals, switches, tracks, route status and train running status. The system generally sets up three types of printer. A color laser printer, as the running diagram printer, A event printer is for all events in the system at any time, including the status of the train, the route sets / cancels, the turnout position changes. The last printer is a report printer for printing a variety of statistical reports and fault reports in system.

All above devices can use the device component in AADL to represent. Since the ATS subsystem needs to calculate and process a large number of data, therefore, the system uses a dedicated processor component to do it. These components exchange the data and commands through the bus component. A processor component includes one memory component or request one bus access at least. Therefore, the system puts the required memory component into Tools.aadl file for common use. It needs a process component to handle the data displayed between the large screen interface workstations and the large-screen display, and It uses a data port to transfer data between them. In addition, each component needing to be powered is connected to the power supply, the power supply is also used by bus component, and also put into Tools.aadl file for common use. The bus and data port needed for the transmission of information are declared in component features. Features is a part of the component type definition, it assigns how to connect among the components in the system, it includes four categories: port, subprogram, parameters and subcomponents access. In this paper, we use the port and subcomponents access to connect among the hardware components.

All of the components in the ATS subsystem are shown in Figure 4.

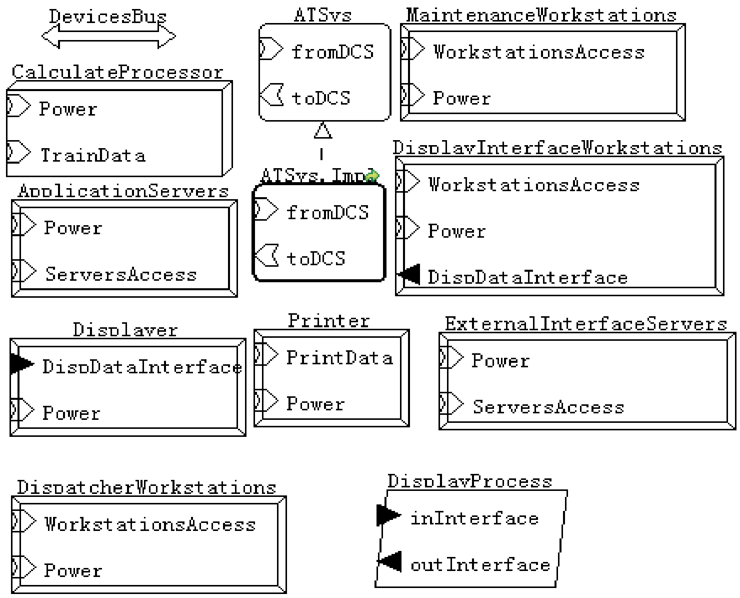


Figure 4. The Components in the ATS Subsystem

The system instance diagram of ATS subsystem implementation (ATSys.Impl) is shown in Figure 5. The fromDCS is the interface from data communication subsystem to the ATS subsystem, and the toDCS is from ATS subsystem to data communication subsystem. Data and commands are exchanged through the DataBus, and MainPower is a power bus.

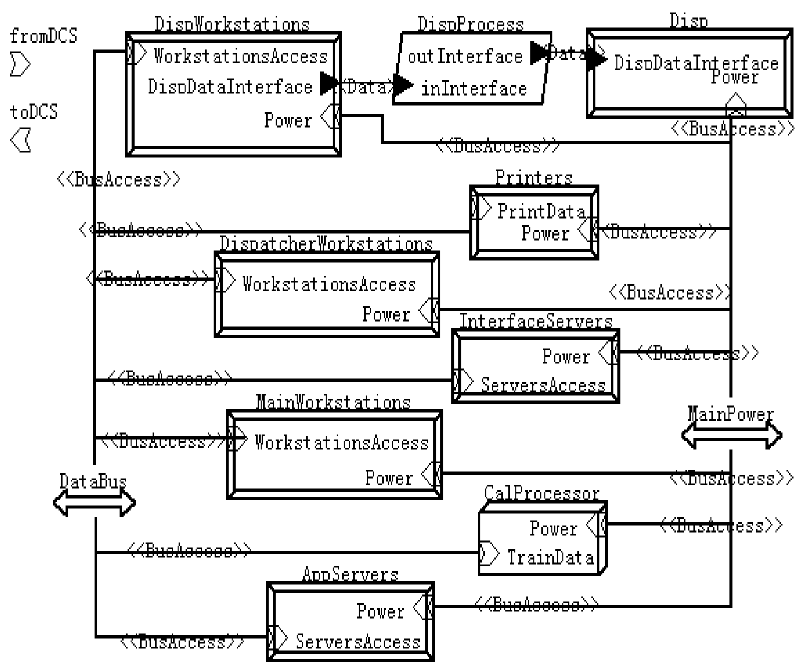


Figure 5. System Instance Diagram of the of ATS Subsystem Implementation

4.3. Design and Modeling of Zone Control Subsystem

Zone control subsystem includes zone controller (ZC), the computer interlocking (CI) devices, axle counting equipments, signals, platform doors, switches, platform emergency stopping button, position plate, balises, train departure indicator and a series of wayside equipments [16].

ZC uses the data coming from the computer interlocking devices and other subsystems to generate movement authority for the trains in the area and sent it to the vehicle on-board subsystem and ATS subsystem in order to ensure the train safe driving, the system uses a processor component to calculate the movement authority. The main functions of the computer interlocking are to process the idle track and to control switches, signals and schedule. By the correct interlocking relationships between the various devices, the system ensures the safe operation of train, and has effective protection capabilities for the errors from the equipments. The main function of the axle counting equipment is to determine whether the track is occupied. The balise is used to determine the position of the train, and position plate is used to determine the parking position of the train. The train departure indicator provides the plan departure time to the drivers.

In addition to the ZC needing to calculate the train movement authority and represented by processor component, all above equipments can use the device component to represent, and use the bus component to exchange data and provide power. The components used in the subsystem are shown in Figure 6.

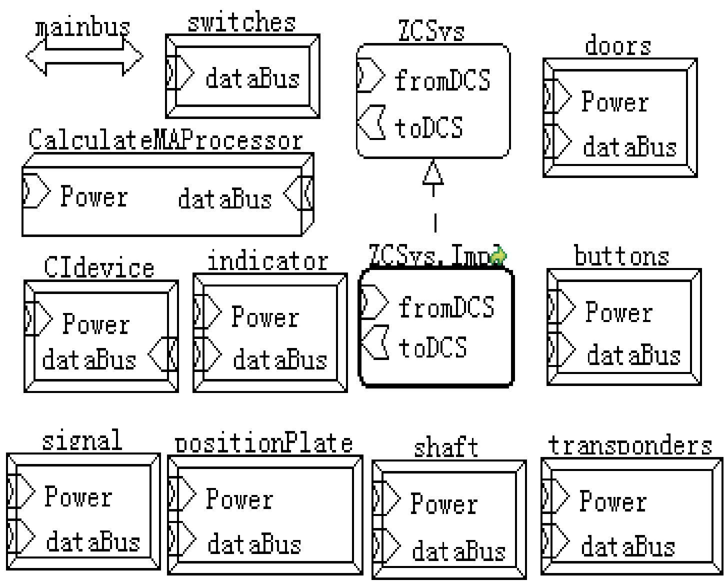


Figure 6. Components used in the Zone Control Subsystem

The system instance diagram of zone control subsystem implementation (ZCSys.Impl) is shown in Figure 7. The fromDCS is the interface from data communication subsystem to the zone control subsystem, and the toDCS is the interface from the zone control subsystem to the data communication subsystem, data and commands are exchanged with other components through ZCBus, and MainPower is the power bus.

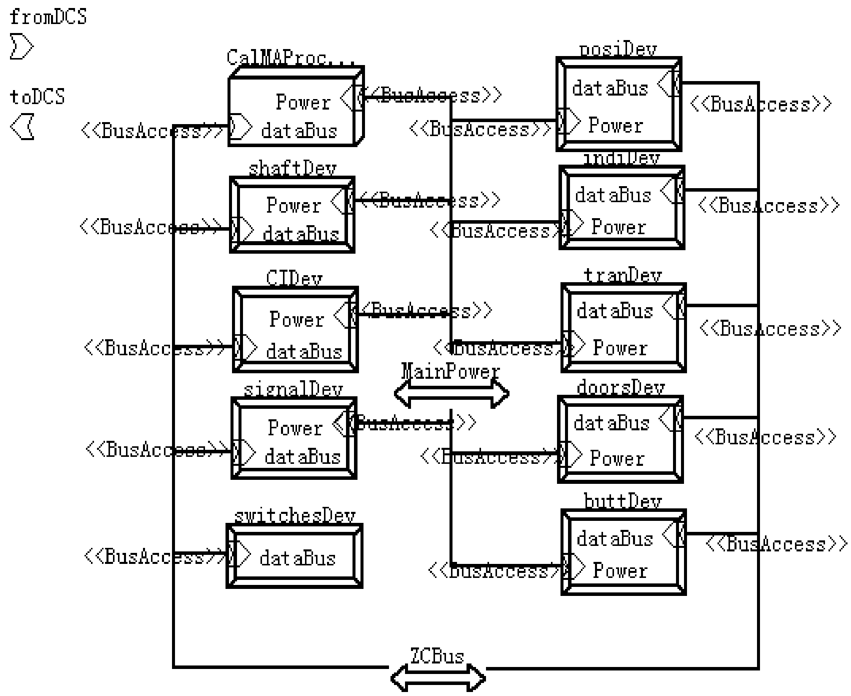


Figure 7. System Instance Diagram of the Zone Control Subsystem Implementation

4.4. Design and Modeling of Vehicle On-board Subsystem

The vehicle on-board subsystem includes the vehicle on-board controller (VOBC) and its peripheral devices. The VOBC contains the electronic unit (EU), the interface relay unit (IRU), power supply unit and other components. The EU includes a high-frequency receiver / transmitter, data receiver / transmitter, receiving / transmitting cards, CPU, GPS computers and other equipments. The IRU contains relay panel, interconnect cables between EU and IRU. The peripheral devices of the VOBC include speed sensor, accelerometer, the driver console, the driver display and position plate sensor.

The VOBC communicating with the ZC is via the data communication system. Its main function are train protection, automatic driving and train positioning. The VOBC uses two out of three votes, and can effectively reduce the system failure time, and greatly improve the reliability of the system. Speed sensor and accelerometer are used to calculate the speed of the train. The driver display and console is for the communication between the driver and the VOBC. The position plate sensor, union the position plate in zone control subsystem, determines the parking position of the train.

In the design of the vehicle on-board subsystem, we also used a system component to represent the VOBC, and considered it to be a smaller subsystem of the vehicle on-board subsystem. The VOBC connects with peripheral devices by bus component. CPU uses a processor component to represent, and it carries out the calculation and processing of data. In addition, the system does not carefully distinguish the various signals and data receiver / transmitter, just summarized as two device components being receiver and transmitter. The driver display can display data and receive driver operation commands, we used a process component to process the display data and the receiving commands, and the port is bidirectional. Therefore, we used a in out port in data port. A in out port is both in port and out port. Its in-association and out-association can be connected to the same component or a different component.

The components used in the subsystem are shown in Figure 8.

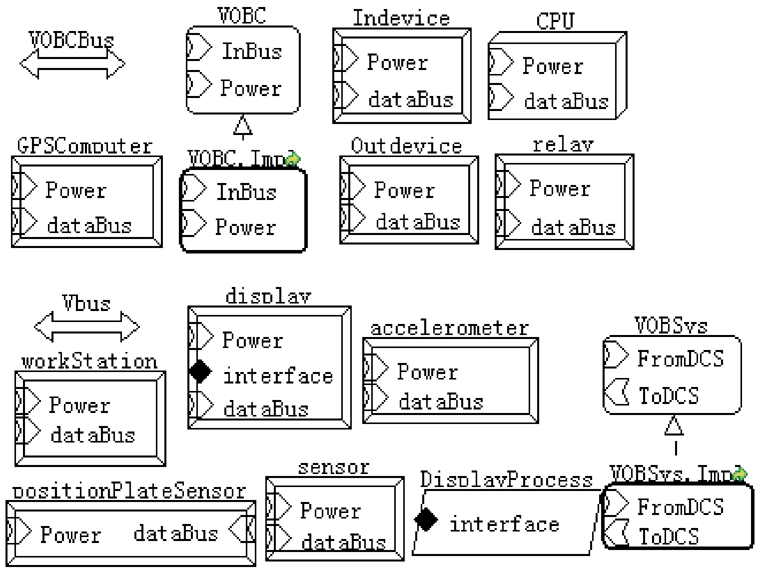


Figure 8. Components used in the Vehicle on-Board Subsystem

The vehicle on-board subsystem has two system implementations: the VOBC system implementation (VOBC.Impl) and vehicle on-board subsystem implementation (VOBSys.Impl). Their system instance diagrams are shown in Figure 9 and Figure 10.

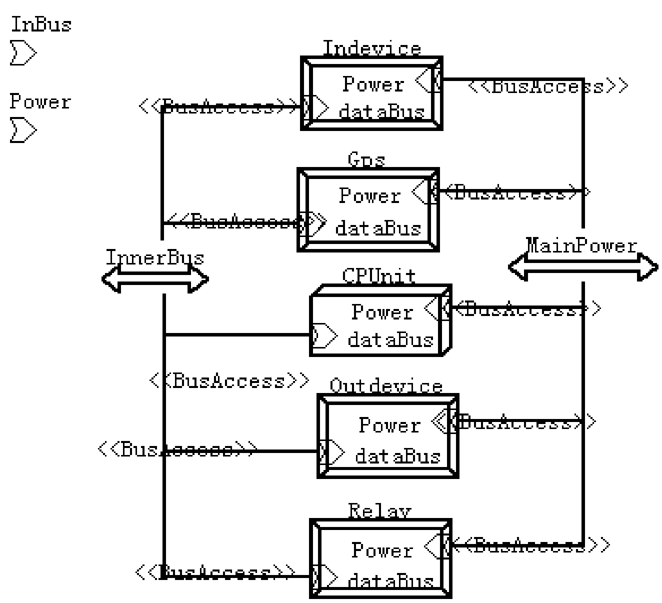


Figure 9. System Instance Diagram of the VOBC Subsystem Implementation

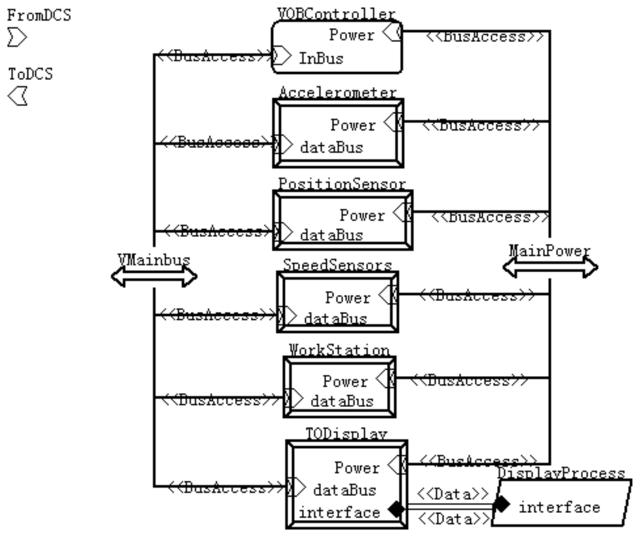


Figure 10. System Instance Diagram of the Vehicle on-board Subsystem Implementation

4.5. Design and Modeling of Data Communication Subsystem

The data communication subsystem can provide the communication between the other subsystems. Any two indirect electronic devices connecting with data communication subsystem, can communicate with each other. The subsystem includes wireless access point (AP), the vehicle on-board wireless units, network switches, database storage unit and the backbone network.

Wayside wireless access point is used to communicate with zone control subsystem, vehicle on-board wireless unit is used to communicate with the vehicle on-board subsystem, and the network switch is used to communicate with the ATS subsystem. The database storage unit includes a variety of databases and configuration files, it is the as data center of CBTC system.

The components used in the subsystem are shown in Figure 11.

The system instance diagram of data communication subsystem implementation (DCSys.Impl) is shown in Figure 12. We used processor component and process components to process data in the database.

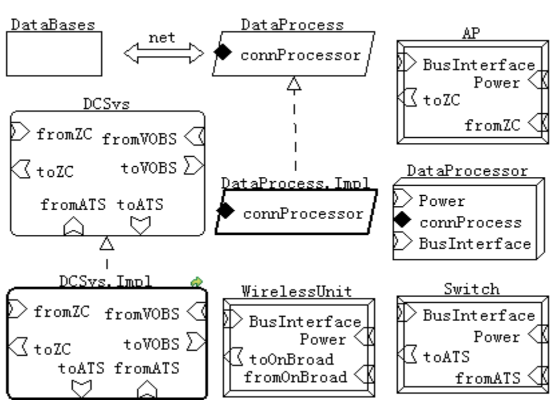


Figure 11. Components used in the Data Communication Subsystem

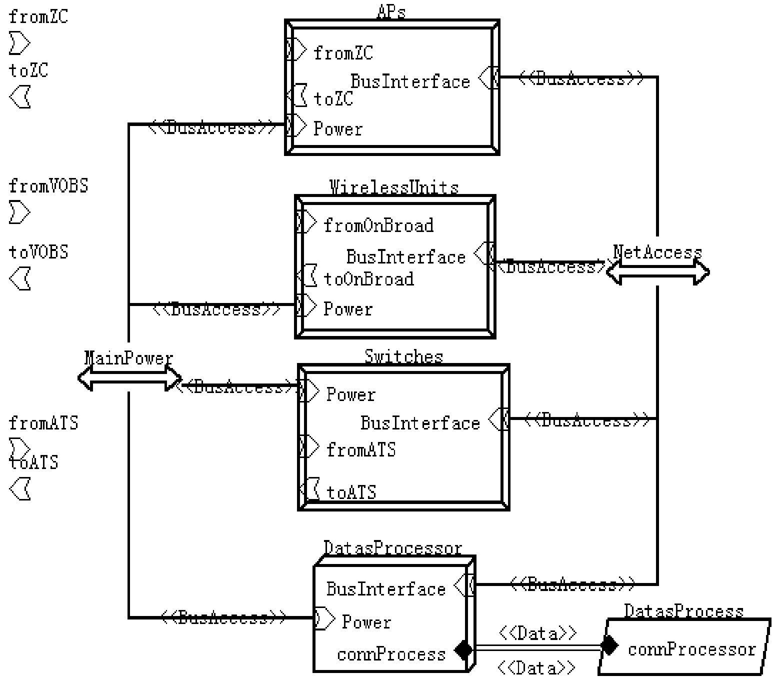


Figure 12. System Instance Diagram of the Data Communication Subsystem Implementation

5. Conclusion

In this paper, it is given a detailed analysis and design of the CBTC system, and the CBTC system is split into four subsystems, it makes friendly communication between the other three subsystems connecting to the data communication subsystem. At the same time, we use the AADL in each subsystem detailed analysis and modeling, and make an effective integration of all subsystems together to form a complete CBTC system. The entire system uses reasonable components to build model, but because of the time, this paper does not give the verification and analysis of system reliability and security, which will be the next focus of the study.

Acknowledgements

This work is partly supported by National Natural Science Foundation of China under Grant No. 61173046 and Natural Science Foundation of Guangdong province under Grant No.S2011010004905.

References

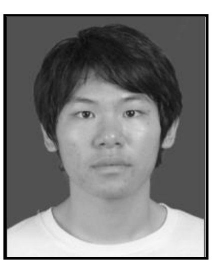
[1] H. Zhou, "Design and Implementation of ATS Based on CBTC", Chengdu China:Southwest Jiaotong University, **(2010)**.
[2] C. -H. Cho, D. -H. Choi, Z. -H. Quan, S. -A. Choi, G. -S. Park and M. -S. Ryou, "Modeling of CBTC Carborne ATO Functions using SCADE", 11th International Conference on Control, Automation and Systems, Korea, **(2011)**, pp. 1089-1094.
[3] S. Oh, Y. Yoon and Y. Kim, "Automatic Train Protection Simulation for Radio based Train Control System", Information Science and Applications (ICISA), Korea, **(2012)**, pp. 1-4.
[4] M. A. Qadeer, A. Chandra and S. Jain, "Design and Implementation of Location Awareness and Sharing

System using GPS and 3G/GPRS", International Journal of Multimedia and Ubiquitous Engineering, vol. 7, no. 4, **(2012)**, pp.125-140.
[5] Y. S. Feruza, A. T. Furkhat and S. -H. Jeon, "Cryptographic Protection of the Information and Algorithms of Enciphering", International Journal of Hybrid Information Technology, vol. 2, no. 4, **(2009)**, pp. 25-38.
[6] L. -D. Chou, C. -C. Sheu and H. -W. Chen, "Design and Prototype Implementation of A Novel Automatic Vehicle Parking System", International Journal of Hybrid Information Technology, vol. 2, **(2006)**, pp. 292-295.
[7] Z. Li, Z. Jiang and B. Gu, "Research on design method of AADL mode transition", Computer Engineering and Design, vol. 32, no. 12, **(2011)**, pp.4269-4272.
[8] Z. Yang, L. Pi and K. Hu, "Complex Embedded Real-time Systems Architecture Analysis and Design Language: AADL", Journal of Software, vol. 21, no. 5, **(2010)**, pp. 899-915.
[9] SAE Aerospace. SAE AS5506A[S]: Architecture Analysis and Design Language V2.0, **(2009)**.
[10] Y. Hou, X. Wu and F. Zhang, "Design of AADL Modeling Tool", Computer Engineering, vol. 38, no. 20, **(2012)**, pp. 236-242.
[11] F. Guo, "Research of AADL in Model-Driven", Chengdu: Southwest Jiaotong University, **(2010)**.
[12] L. Liao, "Simulation of High-Speed Train Operation Control System", Beijing:Beijing Jiaotong University, **(2009)**.
[13] J. Lv, T. Tang and F. Yan, "UPPAAL-based Simulation and Verification of CBTC Zone Control Subsystem in Rail Transportation ", Journal of the China Railway Society, vol. 31, no. 3, **(2009)**, pp. 59-64.
[14] P. H. Feller and A. Rugina, "Dependability modeling with the architecture analysis & design language", Technical Note.CMU / SEI-2007. TN-043, **(2007)**.
[15] Z. -H. Quan, S. -A. Choi, D. -H. Choi, C. -H. Cho, G. -S. Park, M. -S. Ryou, "Modeling for CBTC Car-borne ATP/ATO Functions and Its Applications", SICE Annual Conference 2011.Korea, **(2011)**, pp. 1929-1932.
[16] K. -Y. Park and G. -M. Park, "Analysis of Urban Transit Environment for Video Analytics Application and Processing Scenarios", International Journal of Security and Its Applications.Korea, vol. 6, no. 2, **(2012)**, pp. 437-442.

Authors

Yunxiao Li, Male, PHD student, main research areas: distributed systems and real-time systems.

Lichen Zhang, Ph.D., Professor, research areas: Cyber-Physical systems, distributed processing and real-time systems.



Minglv Chen, PHD student, main research areas: distributed processing and real-time systems.