Improved Test Platform and Evaluation Scheme for Train Vehicle Ethernet Systems

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Abstract. Ethernet networks have been widely studied for vehicle transportation applications. However, most vehicle Ethernet test schemes only use single PC software or distributed hardwares, without comprehensive evaluation for the system framework. This paper presents a novel test and evaluation scheme for vehicle Ethernet systems. Industrial cards are adopted to formulate the hardware platform, while multiple softwares are included to evaluate the system performance with network flow prediction. Thus, the novel scheme has superior potentialities for system design and engineering applications.

1. Introduction

Recent years have seen growing interests and applications in vehicle communication networks. There have been various train communication networks (TCNs) like LonWorks, ArcNet, WorldFIP, and MVB[1],[2]. But the increasingly complex and high demand of system performance require higher network bandwidth, whereas the aforementioned networks have relatively lower bandwidth, with poorer flexibility, limited output capacity, and weaker propagation topology[3],[4]. Comparatively, vehicle Ethernet has been a new issue for modern train communication network system design, providing low system cost, stable transmission.

The most dominating Ethernet standards are provided by the IEC (International Electrotechnical Commission), with specifications as IEC 61375-3-4[5], IEC 61375-2-3[6]. Based on these standards, there have been developments on Ethernet cards, among which the Duagon cards are the most popular products and have been widely studied in TCNs because of the high stability, strong robustness and diverse capabilities on industrial applications.

However, there have been rare methods on testing and evaluating the Duagon cards. Actually, this series of cards have very unique characteristics and structures for Ethernet network. Traditional test methods and softwares can hardly be directly applied to the cards. Therefore, it is vital but difficult to evaluate the performance of systems using the Duagon cards. It is necessary to formulate the test system and evaluate scheme for the novel network system[7].

Besides, there are exactly less studies on the performance degradation and flow prediction for Duagon based systems. Due to the special power supply module, it is unique to distinguish the performance degradation from voltage drop and network congestion. From this point, the flow prediction enables early warning for the performance degradation.

Motivated by the above observations, we present a novel system and corresponding scheme for the Duagon network module. The key innovations of this work can be summarized as follows.
1) A novel platform is formulated to demonstrate the vehicle Ethernet with Duagon cards. The corresponding test scheme is proposed to measure the performance and degradations like packet loss and time delay. This lays solid foundation for more complex engineering development of Duagon Ethernet projects.

2) An improved network flow prediction method is proposed by using the ARIMA model. It is found that the ARIMA method can well fit the autocorrelation characters of the flow, and the prediction helps network monitoring, optimization, and safety.

The rest of the paper is organized as follows. First, the Duagon cards are used to formulate the vehicle Ethernet platform with aid of PC. Then, the network performance is tested especially regarding to the packet loss due to voltage drop and network congestion. Further, the ARIMA method is applied to predict the network flow. Finally, the conclusions are drawn for the novel platform and evaluation scheme.

2. Platform formulation and evaluation based on Duagon Ethernet cards

Based on the modern TCN protocols of IEC 61375 series, the vehicle Ethernet network system is formulated in this section. The test and evaluation methods are provided as well.

2.1. Platform formulation using Duagon Ethernet cards

To ensure the highly reliable and rapid flow transmission between Ethernet modules, we develop a platform for vehicle Ethernet experiments. The platform is composed of two Duagon I303 Ethernet cards, an Ethernet switch, two power supply modules, and personal computers (PCs). The vehicle Ethernet communication is realized and monitored by using this platform, as well as the performance degradation like packet loss, as shown in Fig.1.

Figure 1. Vehicle Ethernet platform based on Duagon modules.

(1) PCs: The personal computers in this platform is used to control and measure the information transmission among the platform modules, and the Multiprog software is installed to configure and monitor the packet flow between Ethernet nodes. Note that the random data are generated by the PCs for tests so that various scenarios can be simulated.

(2) Ethernet switch: The switch is used as the bridge between the Duagon nodes and PCs. It is used to transmit the network information between different Ethernet nodes, to share the information of control modules, and so as to ensure effective utilization of information flow.

(3) Power supply: The two power supply modules are used to provide steady and high precision AC power for the two Duagon modules, respectively. Note that the level of AC will greatly affect the network performance, and insufficient voltage will lead to network performance degradation, as to be explained in the coming section.
(4) Duagon modules: The two Duagon modules are used in the platform. Each Duagon module is composed of a series of cards, including the I201 card for power supply, the I101 card for CPU, I206 card for MVB, I303 card for Ethernet, and input output cards like I202, I213, and I211. Especially, the I303 card is the key module in the Ethernet test platform.

Note that the two Duagon modules used in this platform are actually the same in hardware, but different in parameter configuration. That is, one is used for packet transmission, and other one is used for reception. The two Duagon modules are connected to PCs via RJ45 interfaces, with program setting, loading, and monitoring. Besides, the M12 interfaces are used to connect the two Duagon modules, and meanwhile enable the PC monitoring.

2.2. Performance evaluation for the Ethernet platform degradation

To evaluate the performance of the Ethernet platform based on Duagon cards, we perform simulation tests especially for the cases that performance degradation occur due to voltage drop and network congestion.

2.2.1. Degradation caused by voltage drop

In the real operation environments of train vehicle operation, there may be electromagnetic interference, equipment faults, complicated surroundings which may bring negative effects on the power supply model. It has been stated before that voltage drop may deteriorate the Ethernet module and even lead to breakdown. Therefore, to evaluate the effects of voltage drop on the packet loss, we perform experiments as follows:

Step 1: We make tests on the limited voltage that the Duagon cards can stand, so that the thresholds of normal operation are determined.

Step 2: In the scope where the Duagon modules can operate, we measure the packet loss rates versus varying voltage levels. Clearly, this scope begins from the lowest value where the packet can still be transmitted to the maximum value (i.e., the rated power of the Duagon module, 110 V in this work). By sending the same packets, the packet loss rates can be recorded by using the Wireshark software installed in the PCs.

Step 3: The analysis for the captured packets by the Wireshark is made, with computation of the corresponding packet loss rates with the Matlab. To avoid the randomness of packet loss, we make three times of tests and computations for each DC voltage point, and take the average voltage as the final packet loss rate.

By performing Step 1 repeatedly, we can find that the lowest voltage limit of operation for the Duagon module is 43.8 V. Then, we sample from 43.8 V to 110 V, as 110 V, 100 V, 90 V, 80 V, 70 V, 60 V, 50 V, 45 V, 43.8 V. The average voltage of three times of test for the final packet loss rates are plotted in Fig. 2.

![Figure 2. Packets loss rates versus varying operating service voltage](image_url)

Figure 2 indicates that in the available service voltage scope where the Duagon module can operate normally, the packet loss rate can be kept below 0.04%. The packet loss rate is higher near the
minimum limit voltage (43.8), and drops to zero when the operating voltage is higher than 80V. This may bring technical support for applying the Duagon cards into the real engineering fields.

2.2.2. Degradation caused by network congestion. Due to the various flow density and environments in different periods, there may occur network congestion which may also lead to packet loss, just as the voltage drop. However, rare studies distinguish these two types of degradation. In this subsection, to analyze the effects of different packet density or volume on the packet loss, we perform the tests as follows:

Step 1: In the condition that the voltage falls in the scope that the Duagon module can operate normally, we inject extra packets into the switch, so that the Ethernet commutation volume is increased, and the interference circumstance is formulated.

Step 2: By analyzing the captured packets, the lost packets are found and corresponding loss rates are computed. Similar to the tests on voltage drop, we make three times of tests and computations for each DC voltage point, and take the average voltage as the final packet loss rate.

The packet loss versus the injected data volume is plotted in Fig. 3.

![Figure 3. Packet loss rate versus the injected data volume](image)

It can be seen from Fig.3 that by increasing the volume of injected interference data or packets, the loss rates may increase slightly, but will be kept in a relatively steady and small region, i.e., 0.0025%. This meets the requirements of modern train vehicle communication.

3. Ethernet network flow forecast

The network flow/traffic forecast helps enhance the understanding of the network mechanism, and enables better monitoring of system performance. However, there have been no studies regarding to flow forecast for Duagon module based Ethernet system. In this section, the ARIMA algorithm is used for the flow forecast, and the simulation tests using the simulated Duagon packets are provided to validate the scheme.

3.1. ARIMA model

ARIMA (Auto Regressive Integrated Moving Average) is a preferable method used to predict time series. It is specially fit to address the problems with random characters versus time while the non-stationary causes are also random rather than deterministic[8].

The ARIMA\((p, d, q)\) model can be described as:

\[
\Phi(B)(1 - B)^dX_t = \theta(B)\varepsilon_t
\]

\[
\Phi(B) = 1 - \phi_1B - \phi_2B^2 - \ldots \phi_pB^p
\]

\[
\theta(B) = 1 - \theta_1B - \theta_2B^2 - \ldots \theta_qB^q
\]

where \(p\) is the autoregressive order, \(q\) is the Moving average order, \(d\) is the difference number when the series is steady or smooth, \(B\) is the lag operator, and \(\varepsilon_t\) is the error.
The modeling process of ARIMA can be briefly described as:

Step 1: Get the time series packets of the target system.

Step 2: Plot the observed packets and judge whether it is smooth. If not, the non-smooth series should be made order difference, so that a smooth series can be achieved.

Step 3: For the time series achieved in Step 2, we compute the autocorrelation coefficient function (ACF) and partial autocorrelation coefficient function (PACF), which are used to get the optimal class $p$ and order $q$.

Step 4: Based on the $d$, $q$, $p$ computed above, the ARIMA model is achieved. Then the model check is performed.

Step 5: Make forecast by using the ARIMA model.

3.2. Packet flow forecast using ARIMA model

Using the simulated packets generated from the Ethernet platform, we perform flow forecast using the ARIMA model. The key steps are provided as follows.

As stated before, the vital step is to determine the $d$, $q$, $p$ for the ARIMA model. To this end, we first determine the $p$ and $q$, and then make smoothness test for the Ethernet packets. To those non-smooth time series packets, repetitive difference process is done to adjust them into smooth series. Actually, packets in real engineering can be make smooth after one time of difference, with the parameter $d=1$. Then, the parameters $p$ and $q$ are set to be 0.5 by observing the ACF and PACF. Thus, the ARIMA forecast model parameters are set as ARIMA(0,1,5). Herein, a data set with 280 samples is used to validate the method, and the forecast results are shown in Fig.4.

The real data and forecast data are plotted with blue and red curves, respectively. For the forecast results, the corresponding mean squared error (MSE) is computed to be 0.042451. This indicates that the ARIMA model used in this work fit the non-smooth Ethernet packets, with small prediction error. Thus the proposed scheme may be of useful reference for real Ethernet flow predictions.

4. Conclusion

In this work, the modern vehicle communication network using Ethernet structure is studied. A novel comprehensive platform is developed using the Duagon cards, together with multiple softwares like Multiprog, Matlab, and Wireshark. Then, communication tests and performance evaluation are done based on the platform. The degradation causes are studied by using an improved evaluation scheme, which indicates that the voltage drop and network congestion can be kept below 0.05%, and fit for real engineering applications. Moreover, based on the results, the ARIMA method is adopted for packet flow forecast, which enables effective and highly precise monitoring for Ethernet packet communication. This work may provide useful reference and technical support for future vehicle communication system development.
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