Comparative Analysis of PRP and DRN

Xiangying Kong [1], Xuebing Chen [1,2], Zhenhua Zhang [1,2]

[1] *Jiangsu Automation Research Institute, Shenghu Road 18, Lianyungang, China*
[2] *Southeast University, Sipailou, Nanjing, China*

Abstract

This paper introduces the mechanism of two high-availability network communication schemes, IEC 62439-3 parallel redundant communication protocol and marine dual-redundant Ethernet. An in-depth comparison of the two is carried out in six aspects, such as the number of frames lost when the fault occurs, the application communication delay, and the applicability of the scheme, and the applicable occasions and usage suggestions of the two schemes are given.

Keywords

Dual redundant network, Parallel redundant protocol, Reliability, Communication delay

1. Introduction

Compared with other communication methods, Ethernet is more and more widely used in safety-critical fields such as industrial control, power system, rail transit, command and control because of its good openness, compatibility and low maintenance cost. However, the use environment in these fields is relatively harsh, resulting in high equipment failure rate, so the failure between com- munication network nodes is often unavoidable. In order to improve the availability of communication, applications in these fields usually use redundancy technology to ensure that in the event of a certain failure, the redundantly configured components intervene and undertake the work of the faulty components, thereby reducing the failure time of the system, and the system is still available or extremely short. return to normal work within time to avoid catastrophic consequences. At present, there are many solutions that use redundancy to improve communication reliability. The more representative ones are HSR (High-availability Seamless Redundancy), PRP (Parallel Redundancy Protocol, High-availability Seamless Redundancy) stipulated by IEC 62439. Parallel Redundancy Protocol) [1], Linux Bonding link aggregation, and Dual Redundant Network (DRN) with Dual Redundant Network Cards (DRNC) as the core commonly used in the shipboard field [2] et al.

PRP is a zero-packet-loss, high-availability, red- undant communication protocol specified by IEC 62439-3, which is widely used in electric power [3], rail transit [4], nuclear industry [5] and other industries. This paper introduces the principles of PRP and DRN, from six aspects, including the reliability of communication, the available effective bandwidth of the application, the compatibility with ordinary communication nodes, the number of lost packets in the event of failure, the delay of application communication, and the applicability of the scheme. The authors made an in-depth comparison, and gave the applicable occasions of the two schemes for reference.

2. Introduction to PRP and DRN

2.1. PRP

The international standard to which PRP belongs is IEC 62439. The implementation of the PRP redundancy mechanism mainly relies on two logically or physically separated network cards, which are

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EMAIL: iamkxy@aliyun.com(Xiangying Kong); 99091cxb@163.com (Xuebing Chen); zzhkarl@126.com (Zhenhua Zhang)
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respectively connected to two different subnets (LAN A, LAN B, usually referred to as A network and B network), as shown in Figure 1.

When sending information, the PRP sender (Source DANP, Doubly Attached Node implementing PRP) copies the original information frame (called C Frame), and adds an RCT (Redundancy Control Trailer, redundant control body) to both copies.) specific fields to form PRP information frames (referred to as A Frame and B Frame), which are sent out from their own two network card ports (corresponding to A network and B network respectively), and each reaches the same one through two independent subnets. PRP receiver (Destination DANP): After the PRP receiver receives the two PRP information frames from the two network card ports, it uses the repeated frame judgment algorithm to discard the received frame and use the RCT field of the first received frame. Submit the upper layer protocol stack after culling. The PRP function is usually implemented by an LRE (Link Redundancy Entity). The hierarchical relationship between LRE and protocol stack and network card in DANP node is shown in Figure 1.

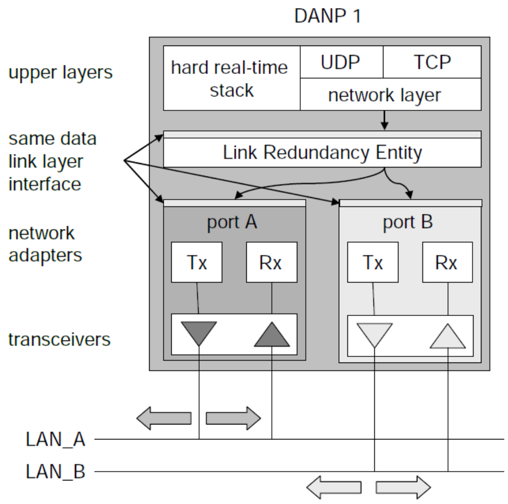


Figure 1 PRP network mechanism

The PRP frame format based on 802.3 standard Ethernet is shown in Figure 2.

6Byte	6Byte	2Byte	46-1494Byte	2Byte	12bits	4bits	2Byte
Destination Addr	Source Addr	L/T	Payload	Sequence Number	LSDU size	Lan ID	PRP Suffix

Figure 2 PRP frame format based on 802.3 standard Ethernet

When a network node that does not implement the PRP function (called SAN: Singly Attached Node, single-port node) is connected to the PRP network, a specific conversion device is required: RedBox (Redundancy Box), the redundant box realizes PRP Protocol conversion.

2.2. DRN

The physical composition of DRN is similar to that of PRP network, the difference is that a cascade mode is added between the two switches. Figure 3.

The DRN software is managed by the Driver of Dual redundant network cards (DoDRNC), which is functionally equivalent to the LRE in the PRP.

Different from the PRP network, at any time, only one port (network card) of the DRN is in the active (Active) state, and the other is in the standby (Backup) state, and the sending and receiving of packets is completed by the active port. The network cards corresponding to the two ports use the same MAC address and the same IP address. In fact, the port corresponding to the standby network card does not have an IP address. DoDRNC monitors the status of the two ports. When the port in the active state is faulty, if the port in the backup state is normal, it will become the active state, and subsequent network transmission and reception are completed by the port in the new active state. When it needs to be explained, DoDRNC does not do any processing on the message frame sent or received, but directly submits the message frame to be sent to the network card currently in the Active state; when the network card receives the message frame, it will receive the message frame. The received data is directly submitted to the upper-layer protocol stack.

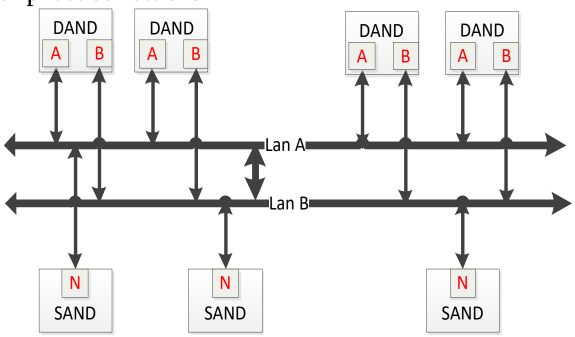


Figure 3 DRN connection topology

A node using DoDRNC is called DAND (Doubly Attached Node with DoDRNC, DAND). For ordinary normal nodes that do not use DoDRNC, they can directly access DRN and communicate with DAND normally, as shown in Figure 3.

3. Comparison of PRP and DRN

3.1. Application Available Bandwidth

PRP changes the frame length and increases the frame processing time due to the addition of the RCT field, frame duplication, repeated frame detection and other operations. For applications, the effective transmission bandwidth of the system may be reduced. Assuming that the length of each frame of the application is $\mathrm{len_i}$, the network transmission bandwidth is reduced to the original:

$$B_{prp-n} = \frac{\sum_{i=1}^{n} len_i}{\sum_{i=1}^{n} len_i + 6} \tag{1}$$

The actual impact on application transmission performance will also be affected by the following factors: 1) The ability of the software to process the protocol between the sender and the receiver: recorded as the software processing capability bandwidth B_{prp-s}; 2) The performance of the bus to carry data: recorded as the bus Carrying capacity bandwidth B_{prp-b}. The ability of software to process the protocol is affected not only by the complexity of the PRP software algorithm (mainly duplicate frame detection), but also by the performance of the processor. Therefore, for the application, the real communication bandwidth should be:

$$B_{prp} = min(B_{prp-s}, B_{prp-b}, B_{prp-n}) \tag{2}$$

B_{prp-s} mainly considers adding RCT when sending, repeating frame judgment when receiving (involving table lookup), stripping RCT and submitting it to the upper protocol stack. If $\mathrm{B_{prp-s}} \geq \mathrm{B_{prp-n}}$, $\mathrm{B_{prp-b}} \geq 2 * \mathrm{B_{prp-n}}$, the available bandwidth of the application using the PRP scheme can still approach the original network bandwidth. If the hardware performance is low (processor, bus), when $\mathrm{B_{prp-b}} < 2 * \mathrm{B_{prp-n}}$, or $\mathrm{B_{prp-s}} < \mathrm{B_{prp-n}}$, PRP is used, and the application is valid Bandwidth may be significantly reduced.

For DRN, since the content of the message is not changed during transmission and reception, only one frame of ARP message needs to be sent during switching to notify the switch and other nodes that the mapping between IP/MAC and switch ports has changed. Therefore, the application communication bandwidth for:

$$B_j = min(B_{j-s}, B_b, B_n) \tag{3}$$

Usually $\mathrm{B_{j-s}}$, $\mathrm{B_b}$ is greater than $\mathrm{B_n}$. Obviously, the DRN solution has higher bandwidth available to the application than the PRP.

3.2. Reliability

As shown in Figures 2 and 3, in the two schemes, the devices that may fail are: the network card (Port-A, Port-B) and the network cable between it and the switch (we regard it as a whole), the switch

(Switch- A, Switch-B), its reliability is: Rn, Rs.

Then in the PRP network, there are two parallel communication links for communication between two DANP nodes: the reliability of the two parallel links is:

$$R_{prp} = 1 - (1 - R_n^2 R_s)^2 \quad (4)$$

For DRN, since two switches are cascaded, there are four links for communication between two DAND nodes. For simplicity, we consider the reliability of the cascaded line of two switches in the DRN solution to be 1. Then the reliability of the scheme is:

$$R_{drn} = 1 - \left(1 - R_n^2 R_s - R_n^2 R_s^2 (1 - R_n)\right)^2 \quad (5)$$

Since $R_{prp} = 1 - (1 - R_n^2 R_s)^2$, and the last item in the brackets in formula (5) $R_n^2 R_s^2 (1 - R_n) > 0$, so $R_{drn} >= R_{prp}$, that is to say, DRN reliability is higher than PRP network, see Figure 4.

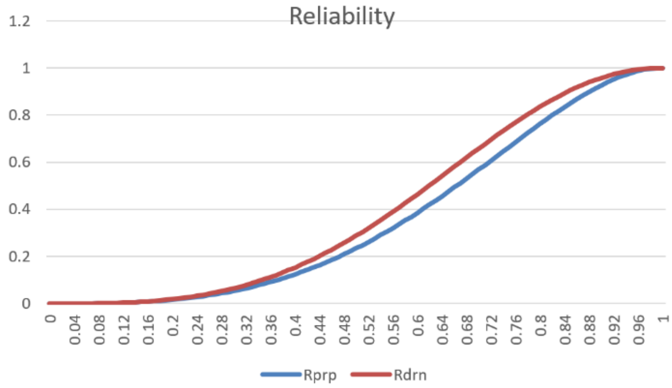


Figure 4 Reliability curve of the two schemes

3.3. Number of frames dropped

PRP adopts the method of copying and sending, and detecting and discarding duplicate frames. Therefore, when a single-channel fault occurs, theoretically, frame loss will not occur.

Since the DRN adopts the Active-Backup mode, on the one hand, there is a certain delay in detecting the status of the Active NIC, and on the other hand, it takes time for the Backup NIC to convert to the Active. Therefore, the DRN failure recovery time is greater than 0, which is usually 20ms in most current implementations.

A single Ethernet frame consists of a 7Byte preamble and a 1Byte frame start delimiter (Start Frame Delimiter, SFD), followed by a 14Byte Ethernet header, followed by 46~1500Byte payload data, followed by a 4Byte frame check sequence (Frame Check Sequence, FCS), and then at least 12Byte interval between every two frames.

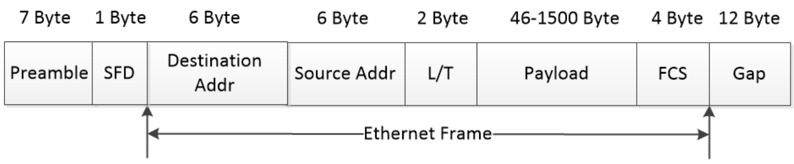


Figure 5 Ethernet frame format

For a 1Gbps network, the maximum number of frames that can be transmitted within 1ms is (when all the shortest packets are):

1000Mbps/1000/8(7+1+14+46+4+12)=1488

For a 100Mbps network, the maximum number of frames that can be transmitted within 1ms is 149 frames

Multiplying these two numbers by 20 is the theoretical maximum number of message frames that may be lost within the DRN fault recovery time, which are 29760 and 2980 frames, respectively. However, in practical applications, the number of frames sent or received within the switching time (20 ms) of each node is relatively small, usually only a few or a dozen frames. But for the control system, even if only one frame is lost, if the key information is lost, it may still have serious consequences, so the advantage of PRP zero frame loss is extremely important.

3.4. Impact on application communica- tion delay

The PRP sending and receiving process is shown in Figure 6. Compared with the standard Ethernet sending and receiving process, because PRP firstly needs to copy the message (the network protocol stack usually emphasizes zero copy), and secondly, it needs to perform repeated frame judgment processing (red font) when receiving, and both the receiving and sending processes need to be processed. The RCT field requires a certain amount of time, thus increasing the communication delay

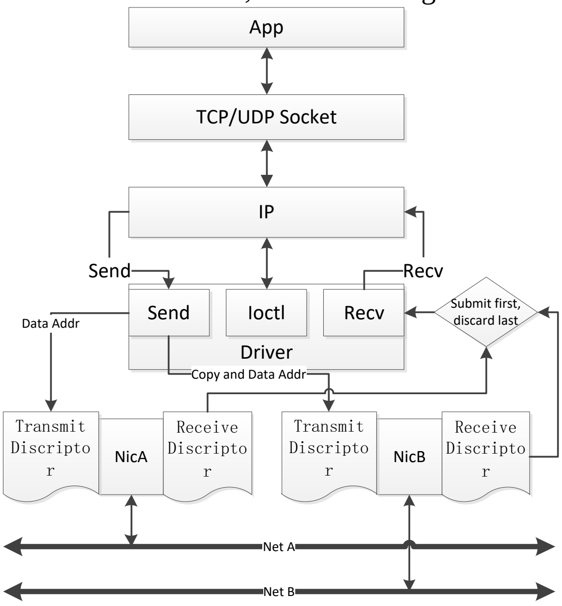
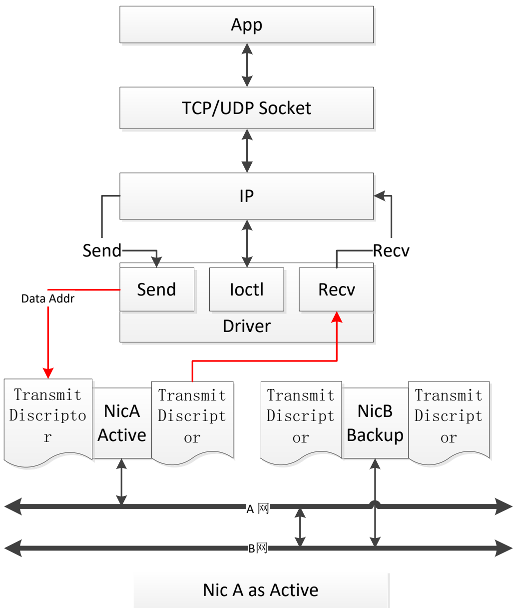


Figure 6 Schematic diagram of PRP network transceiver process



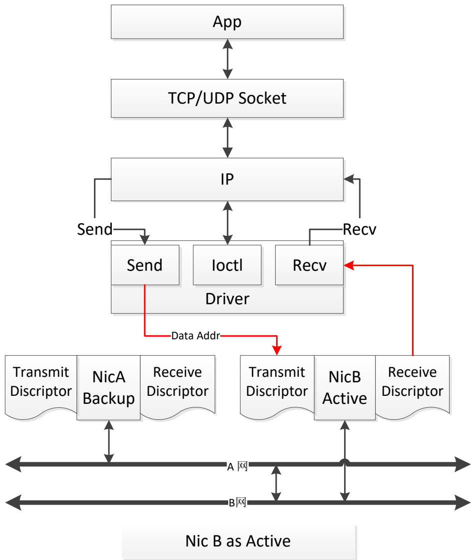


Figure 7 Schematic diagram of shipboard dual-redundancy network transceiver process

It should be emphasized that memory copying and judging repeated frames are very time-consuming, especially for short frames, the performance of memory copying is very low. When it is low, the time to copy (memory) 100 bytes is about 2us, that is, every time a frame of message is sent, a delay of about 2us is added only because of the memory copy. On the receiver side, MAC comparison needs to be performed in order to discard duplicate frames. Section 4.1 has already given that, even under a Core CPU with a main frequency of 2.7GHz, a 6-byte MAC comparison needs 37ns. In the PRP network of each node, it takes 2.37us in the worst case to find the MAC address once.

The DRN sending and receiving process is shown in Figure 7. Compared with the standard Ethernet sending and receiving process, it can be seen that no packet processing is performed, so the communication delay will not be changed.

3.5. Compatibility with common communication nodes

The common communication node of non-PRP node (SAN) needs to rely on RedBox[2] to access the PRP network. A common communication node that is not a dual-redundant network node can normally access any switch in the dual-redundant network, and when the switch is fault-free, it can communicate normally with a node using a dual-redundant network card.

In addition, PRP frames without additional MAC address information cannot be exchanged through Layer 3; DRN does not change the frame data, so it can be exchanged through Layer 3. It can be seen that DRN compatibility is better.

3.6. Applicability of scheme

In summary, the comparison of the two redundant network solutions is shown in the table below.

Table 1
Comparison of PRP and DRN

terms	PRP	DRN
reliability	high	higher
Effective bandwidth	significantly lower than using standard Ethernet.	Same as standard Ethernet
Compatibility	requires RedBox	Good
Switching time	0	20ms
Number of dropped frames	0	Max: 1Gbps：29780
delay time	0~2us	0

4. Conclusion

The highlight of PRP lies in zero packet loss and zero failover time, but it requires a high cost to send replicated frames. When the actual communication network bandwidth and processor load are low, and the processor does not have heavy load calculations, choosing PRP will neither It affects the processing and computing performance, and can ensure zero switching time and zero packet loss. The advantage of the DRN solution is that it does not increase the load on the processor and network communication, and does not affect the application computing performance. The disadvantage is that a certain number of frames will be lost when a failure occurs. In the future, we will carry out research on DRN network technology with zero frame loss without increasing the computational load.

5. References

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