

INTERNATIONAL STANDARD

Information technology –
Responsive link (RL)

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INFORMATION TECHNOLOGY – RESPONSIVE LINK (RL)

FOREWORD

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International Standard ISO/IEC 24740 was prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

This International Standard has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

INTRODUCTION

The Responsive Link standard defines a real-time communication protocol between computers networked in a machine or in a site with point-to-point interfaces. Complex machines, such as robots, automobiles and network routers, have a growing demand for distributed processing. In addition, modernization of facilities such as factories, offices, schools and homes is creating a ubiquitous computing environment. Unlike conventional PC applications for documentation and internet applications that exchange texts without hard time constraints, these types of cooperative computing require real-time and reliable responses to physical events occurring in the real world. Although most conventional real-time systems employ a single processor that invokes tasks corresponding to outside events, the need for distributed processing architecture is inevitable for the larger-scale systems mentioned above, because operational targets are physically separated and scalable processing power becomes necessary as the number of components increases. For distributed nodes to cooperate in real-time, an interconnecting network shall realize real-time communication. The Responsive Link provides such real-time communication between computers by providing dual full-duplex communication channels, fixed-size prioritized packets, packet overtaking based on priority, and automatic error correction.

Real-time

An operation of a dynamic system is called a real-time operation if the combined reaction- and operation-time of the task is shorter than the allowed maximum delay, with respect to circumstances outside the operation. A system is said to be a hard real-time system if the correctness of an operation depends not only on logical correctness, but also on the time at which it is performed. An operation performed after the deadline is, by definition, incorrect, and has no value. In a soft real-time system the value of an operation declines steadily after the deadline expires. Whether a system is hard real-time or soft real-time and how much time is allowed before a deadline are application dependent.

Although it is known that static estimation of the time required for generating a response is important for a computer to output a response before a deadline, such static estimation is often very difficult or impossible. Instead, most real-time systems rely on priority-based scheduling.

Real-time scheduling

As real-time scheduling algorithms, the earliest deadline first (EDF) scheduler, the rate monotonic (RM) scheduler and their variations have been established, as explained in Annex B. These algorithms commonly schedule tasks based on priorities determined by margins to deadlines. Thus, an important function is preemption, i.e. the scheduler deprives the execution privilege of the lower-priority task and allows the higher-priority task to run.

In order to realize real-time communication, a function similar to task preemption shall also be employed in communication. There are several methods for this communication preemption: provision of two separate channels for high- and low-priority packets, setting different communication paths according to priority and assigning a shorter path for high-priority communication, and allowing higher-priority packets to overtake lower-priority packets. Responsive Link has all of these capabilities.

Important features

Responsive Link has the following distinctive features that allow realization of real-time communication.

- Separation of data transmission and event transmission (see Annex A).
- Prioritized routing: When multiple packets with different priority levels are sent to the same destination, different routes can be set in order to realize exclusive communication lines or detours (see Annex E).
- Priority-based packet overtaking: The packet with the highest priority overtakes the other packets at each node (see Annex B and Annex D).

- Packet acceleration/deceleration using priority replacement: Packet priority can be replaced with a new priority at each node in order to accelerate/decelerate packets under distributed control and realize real-time communication.
- Fixed packet size: 64-byte data and 16-byte event.
- Point-to-point serial link (see Annex A).
- Independent routing of the data link and the event link (see Annex E).
- Hardware forward error correction to prevent retransmission.
- Other useful features are as follows:
 - variable link speeds (533, 267, 133, 66,7, 33,3, 16,7 and 8,3 Mbit/s),
 - automatic reconfiguration (plug & play),
 - topology free,
 - low latency (240 ns required to pass through one routing node at 66,7 Mbit/s).

Typical applications and operations

As a typical application of the Responsive Link, Figure 1 shows a distributed control configuration of a humanoid robot. The electronic control part of the humanoid robot consists of several control nodes with local sensing and actuating devices. The distributed controllers are connected to each other by Responsive Link. In this figure, rectangles represent node controllers, and dotted lines show the Responsive Link cable, which is a point-to-point serial link.

For a humanoid robot to walk stably, a servo loop of 1 ms or shorter is needed. In this configuration, the farthest two nodes can exchange a 16-byte packet within 5 μ s. Since the time is guaranteed not to fluctuate, the distributed control of a humanoid is considered to be sufficiently possible.

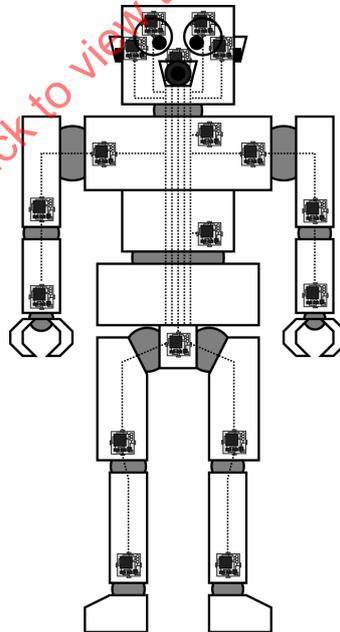


Figure 1 – A humanoid robot

INFORMATION TECHNOLOGY – RESPONSIVE LINK (RL)

1 Scope

This International Standard specifies the communications protocol and interface of Responsive Link, the real-time communication for parallel/distributed control. This standard corresponds approximately to the functions specified in layer 1 to layer 4 of the OSI reference model.

The purpose of this standard is to facilitate the development and use of Responsive Link in real-time systems by providing a common data protocol. This standard provides a real-time communication protocol for interconnections among distributed real-time systems, including embedded systems, control systems, amusement systems, robot systems and intelligent buildings.

2 Normative reference

The following referenced document is indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 7498-1, *Open systems interconnection – Basic reference model: The basic model*

3 Definitions, terms and abbreviations

3.1 Terms and definitions

For the purpose of this standard, the following definitions apply.

3.1.1

byte

group of eight bits

3.1.2

data

data set transmitted through a data link

3.1.3

data link

medium on which data packets are transmitted

3.1.4

data packet

data packet consists of a 4-byte header including the network address with a priority, a 56-byte payload and a 4-byte trailer

3.1.5

destination

node at the end of the interface that receives data

3.1.6

event link

medium on which event packets are transmitted

3.1.7

event

data set transmitted through an event link

3.1.8

event packet

event packet consisting of a 4-byte header including the network address with a priority, an 8-byte payload and a 4-byte trailer

3.1.9**packet**

data set sent from a source to a destination; there are two kinds of packets: the data packet and the event packet

3.1.10**priority**

priority is an 8-bit value from 0 (0x00) to 255 (0xff) attached to a packet; the larger the number, the higher is the priority

3.1.11**source**

node at the end of the interface that transmits data

3.1.12**word**

unit of information, consisting of 32 bits

NOTE A word contains an ordered set of four bytes.

3.2 Abbreviations

BUFX	overtaking BUFFer Xth.
DPLL	Digital Phase Lock Loop.
DRAM	Dynamic Random Access Memory
FATAL	FATAL bit to indicate uncorrectable error
INFO	INFORmation digits to be transmitted
LSB	Least Significant Bit
MSB	Most Significant Bit
NRZI	Non-Return-to-Zero-Inverted
RED	REDundant digits for error correction
SDRAM	Synchronous DRAM

4 Conformance

For an entity to conform to this international standard, the following applies.

- a) The structure and configuration shall conform to the requirements of 5.1.
- b) The layer 1 structure and configuration shall conform to the requirements of 6.1.
- c) The layer 2 protocol shall conform to the requirements of Clause 7.
- d) The layer 3 protocol shall conform to the requirements of Clause 8.
- e) The layer 4 protocol shall conform to the requirements of Clause 9.

5 Responsive Link structure**5.1 Outline of Responsive Link**

For better real-time performance a Responsive Link consists of two communication links, namely a data link and an event link. A node has at least one Responsive Link port. Normally, each node has a Responsive Link switch with multiple ports. The Responsive Link switch of each node has a unique node address. The priority of a packet is set by software, such as a real-time scheduler, based on any time constraints. A source node address, a destination address and a priority are attached to the header of a packet by software for routing. In order to route a packet from a source node to a destination node according to the address with priority, every Responsive Link switch has a routing table and routing capability. An input packet to an input port of the Responsive Link switch is routed to (an) output port(s) according to the routing table. The data link and the event link are routed independently. When multiple

packets with different priorities are sent to the same destination, different routes can be set in order to realize exclusive communication lines or detours.

In order to realize fine-grained real-time communication, packets with higher priorities overtake other packets at each node. Packet priority can be replaced with a new priority at each node in order to accelerate/decelerate packets under distributed control. The link speed of Responsive Link can be changed dynamically between 533, 267, 133, 66,7, 33,3, 16,7 and 8,3 Mbit/s in order to balance real-time capability, power consumption, and noise tolerance. Responsive Link also supports automatic reconfiguration (plug & play) in order to reconstruct systems easily.

5.2 OSI reference model

This standard covers the functionality of layer 1 to layer 4 of the OSI reference model, although the packet format does not have a layered structure for better real-time performance, especially for the routing hardware to handle packets efficiently. (See ISO/IEC 7498-1.)

6 Layer 1 (physical layer)

6.1 Separate transmission of data and event

The event transmission shall be separated from the data transmission as shown in Figure 2. (See Annex A.) Each link shall be composed of a full-duplex serial link that connects point-to-point. The data link and the event link can be used for both soft and hard real-time communication. Although each of event and data links can ensure real-time communication, better real-time service is accomplished when they are used cooperatively. (See 8.2.3 and 8.2.4.)

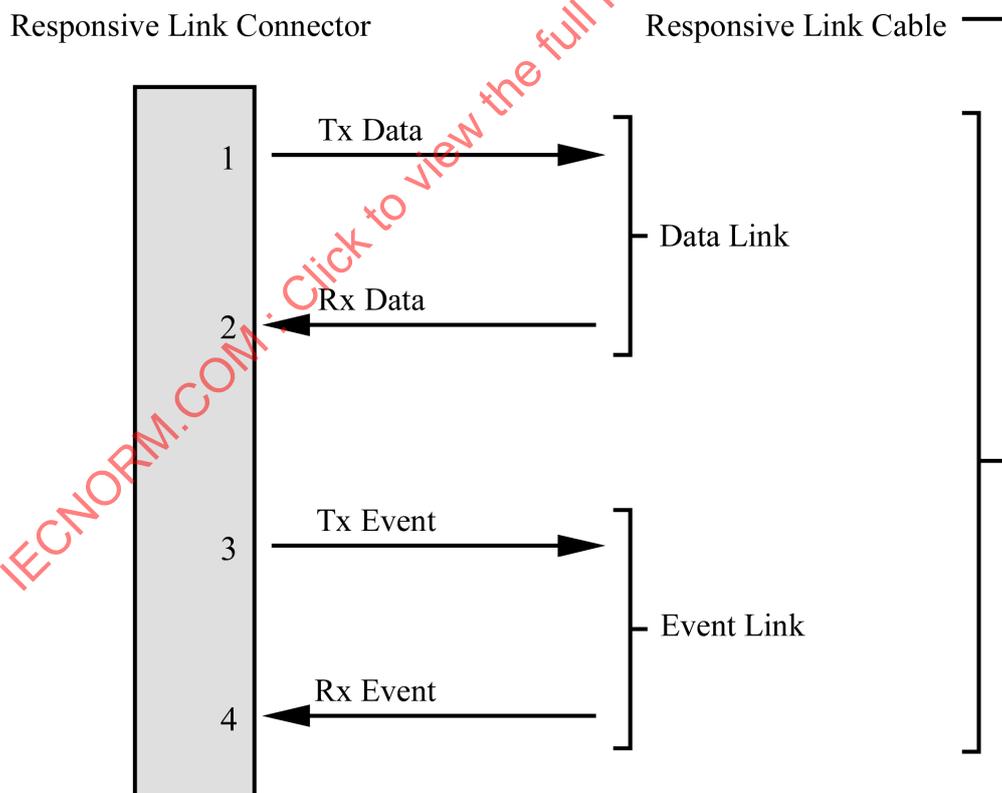


Figure 2 – Logical interface of Responsive Link

6.2 Physical interface

The recommended physical interface of Responsive Link is described at Annex C.

7 Layer 2 (data link layer)

7.1 Error correction

7.1.1 General

Responsive Link shall provide error-free transmission for reliable real-time control. Error correction shall be performed by hardware at every hop. Responsive Link shall perform error correction on a byte-by-byte basis. Four extra bits shall be attached to each byte for this purpose. This 12-bit frame enables one-bit error correction and two-bit error detection for a one-byte data (8 bits of information digits).

Since Responsive Link attaches 4 bits for error correction to a byte (8 bits), the communication speed at 100 MHz is approximately equal to 66,7 Mbit/s.

7.1.2 CODEC

The CODEC shall handle a 12-bit frame consisting of 8 bits of information digits and 4 bits of redundant digits. First, the original 8 bits of information digits shall be encoded into a 12-bit frame by the hamming cyclic coding method. Additional 'zero' bits shall then be inserted into a bit sequence in which more than five successive 'one' bits exist in order to ensure bit synchronization. Finally, the encoded digits shall be transmitted in a non-return-to-zero-inverted (NRZI) waveform. Each coding method is described in the following subclause.

7.1.3 Error correction encoding

The hamming cyclic code with the generator polynomial of x^4+x+1 shall be used to detect and correct errors in a transmitted frame. With this coding, in which 4 bits of redundant digits shall be appended to the LSB side of an 8-bit information data, any 1-bit error in a frame can be corrected at a receiver without re-sending.

The redundant digits can be generated as the remainder of the operation in which an 8-bit message is shifted to the left by 5 bits and then divided by the generator polynomial '10011' in modulo 2 arithmetic, i.e., 'XOR'ing. At the receiver, the received 12-bit frame is divided by '10011' in modulo 2 arithmetic, and a 4-bit syndrome is obtained as the remainder. Since the syndrome is peculiar to the position of a single-bit error, as shown in the Table 1, the receiver can detect and correct the error by inverting the corresponding digit. Each frame shall be transmitted on the link in a bit-by-bit manner from the MSB.

Table 1 – Syndrome and error digits

Syndrome	Position of the error digit
0000	00000000 0000 (no error)
0001	00000000 0001
0010	00000000 0010
0100	00000000 0100
1000	00000000 1000
0011	00000001 0000
0110	00000010 0000
1100	00000100 0000
1011	00001000 0000
0101	00010000 0000
1010	00100000 0000
0111	01000000 0000
1110	10000000 0000

7.1.4 Bit stuffing

When five successive 'one' digits appear in a transmitted bit stream, an additional 'zero' digit shall be inserted after them. This bit stuff procedure decreases the DC component caused by

the long succession of 'one' digits and ensures bit synchronization by the DPLL in the receiving circuits.

7.1.5 NRZI encoding

Each digit in a frame shall be eventually encoded as a non-return-to-zero-inverted (NRZI) waveform and transmitted. With the NRZI encoding, the signal level on the link shall change from low to high or from high to low when a 'zero' digit is transmitted and keep the previous level when a 'one' digit is sent.

7.2 Frame format

7.2.1 Packet

A packet, which consists of multiple 12-bit frames, shall have different structures for the data link and the event link.

- Data packet: 64 frames
- Event packet: 16 frames

7.2.2 Frame

A frame shall consist of 12 bits, including 8 bits of information digits and 4 bits of redundant digits, as shown in Table 2.

Table 2 – Frame format

INFO	RED
Dddddddd	rrrr
INFO: Information digits to be transmitted. RED: Redundant digits for error correction	

7.2.3 Setup pattern

After the power is first applied, or after an unexpected burst link error occurs, the synchronization between the sender and the receiver can be lost. In such a situation, the link shall be initialized explicitly. The encoder in the initial mode shall send the setup pattern shown below. Since six successive 'one' digits violate the bit stuffing rule, the decoder can distinguish the pattern from normal frames and thus switches to the initial mode. The initialized decoder interprets the first receiving frame after the initialization as the start frame of a new frame.

Setup pattern
000001111110

7.2.4 Idle pattern

When an encoder has no actual communication data, the encoder shall send the idle pattern shown below in order to maintain the synchronization of the link.

Idle pattern
000000001111

7.2.5 Bit synchronization and clock rate

A digital phase lock loop (DPLL) mechanism should be used for decoding. The received signal is sampled at a rising edge of the base clock for the DPLL. The number of samplings for a 1-bit transmission can be dynamically changed by setting the sampling mode. The base clock for the DPLL is 400, 800, 1 600 or 3 200 MHz, and the number of samplings is 4, 8, 16 or 32. Therefore, the maximum clock rate of Responsive Link is 100, 200, 400 or 800 MHz.

The DPLL detects edges of the receiving signal and generates a receiving clock according to the period of the current sampling mode. The receiving clock is adjusted so that the raising edge appears in the center of two edges of the receiving signal.

7.2.6 Error handling

The encoding scheme of Responsive Link can automatically detect and correct any 1-bit error in a frame. However, when errors of greater than 2 bits are present in a frame, the error correction mechanism does not work. In such a situation, the calculation of the syndrome results in one of the following two cases:

Case 1 Value not listed in Table 1

In this case, the decoder can detect an unrecoverable fatal error. If a fatal error is detected in the header (the first four frames) of a receiving packet, then the decoder shall abort the reception of the packet and should interrupt the controller (processor). When a fatal error is present in another part of the packet, the decoder shall not try to correct digits in the received data and set the FATAL bit in the status frame of the packet.

Case 2 Value is listed in Table 1

Although the probability of this case is very low, the decoder cannot detect the occurrence of the fatal error in this case. Since this error is indistinguishable from other correctable 1-bit errors, the received frame is inadequately modified by the decoder. This situation allows transmission of an incorrect packet and is highly undesirable. Therefore, when simple 1-bit errors are corrected in two successive packets, the decoder shall consider this to be a fatal error that cannot be corrected and so handle the packet in the manner described above.

The above information shall be stored in the trailer of the packet. (See 8.2.3 and 8.2.4.)

7.3 Automatic reconfiguration (plug and play)

Responsive Link shall support automatic reconfiguration, also known as the plug and play function, at the layer 2 protocol level, as specified in this subclause.

When the decoder of the Responsive Link receiver receives seven successive 'one' digits, the link controller shall interpret this signal as an indication that the Responsive Link cable is disconnected. Then, the Responsive Link controller shall interrupt its host controller (processor) to inform it of the link-down status.

When the decoder of the Responsive Link receiver receives the initial packet (setup pattern) in the disconnected state, the link controller shall regard the Responsive Link cable to be engaged. Then, the Responsive Link controller shall interrupt its host controller (processor) to inform it of the link-up status.

When in the disconnected state, the encoder of the Responsive Link transmitter shall always try to send the initial packet. In this manner, when an active Responsive Link cable is plugged into the Responsive Link connector, the encoder can force initialization of the connected decoder at the opposite side.

8 Layer 3 (network layer)

8.1 Packet overtaking function

Each packet shall have a priority. A packet shall consist of a header (a source address and a destination address with a priority), a payload and a trailer (control and status information). If no collision occurs at a node, then the data is transmitted through the node. If a collision occurs at a node, then the packet with the higher priority shall overtake the other packets. (See Annex B and Annex D.)

If packets having the same priority continuously collide at the node, then the round-robin rule shall be applied and the packet that arrived first shall be sent out first.

8.2 Responsive Link packet format

8.2.1 Header format

A packet shall have a 4-byte header that represents a source address, a destination address, and a priority, as shown in Figure 3. The source and destination addresses shall be assigned with 12-bit fields, and the priority shall be assigned with 8-bit fields. Priority[7 to 4] corresponds to the 7 to 4 bits of the 8-bit priority, and Priority[3 to 0] corresponds to the 3 to 0 bits of the 8-bit priority. Each node shall have a unique node address.

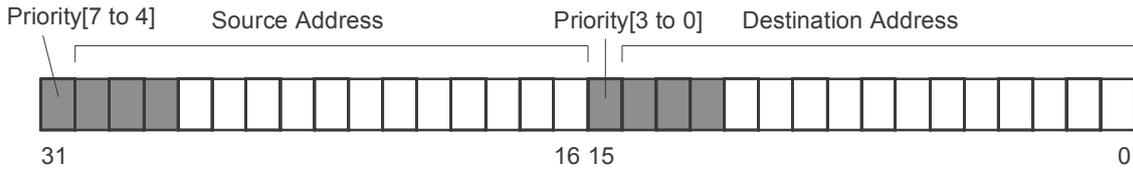


Figure 3 – Header format

8.2.2 Priority

Each packet shall have an 8-bit priority included in a packet header. The greater priority number, the higher priority. The highest priority is 255 (0xff) and the lowest priority is 0 (0x00).

8.2.3 Data packet

Figure 4 shows the format of a Responsive Link data packet.

A data packet shall consist of a 4-byte header composed of a network address with a priority, a 56-byte payload and a 4-byte trailer composed of control and status information.

Data Packet Format (64B)

31			0
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
	Control	& Status	

Figure 4 – Data packet format

Figure 5 shows the format of the 4-byte trailer.

Control & Status Format (32bits)

0	UD	Full			Data Length		
1	Dirty0	Dirty1	Dirty2	Dirty3	Dirty4	Dirty5	Dirty7
2	Dirty8	Dirty9	Dirty10	Dirty11	Dirty12	Dirty13	Dirty15
3	Start	End	Int.	Fatal	Correct	Serial Number (Cnt.)	

Figure 5 – Trailer format of data packet

Key

- UD: Reserved.
- Full: This bit shall be set to 1 if all of the payload data (56 bytes) are valid data. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Data Length: Length of valid payload data (0 to 56). This flag shall be set by the Layer 4 hardware or software at the source node.
- Dirty0 to Dirty15: Indicates which word (4 bytes) in the packet has an error. For example, if the 2nd word of the packet has an error, then Dirty1 bit shall be set to 1. This flag shall be set by the Layer 2 hardware as a result of the error correction procedure.
- Start: This bit shall be set to 1 if this packet is the start packet. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- End: This bit shall be set to 1 if this packet is the end packet. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Int: The Responsive Link shall generate an interrupt to the destination node controller (processor) when this packet reaches the destination node if this bit is set to 1. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Fatal: This bit shall be set to 1 by the Layer 2 hardware if any byte in the packet has an unrecoverable fatal error. Otherwise, this bit shall be set to 0.
- Correct: This bit shall be set to 1 by the Layer 2 hardware if this packet had errors that have been corrected. Otherwise, this bit shall be set to 0.
- Serial Number: Serial number of the packet. The start packet shall have the serial number 0, and this number shall be incremented in the following packets. The serial number shall return to 0 after it reaches 7, and the sequence shall be repeated. This flag shall be set by the Layer 4 hardware or software at the source node.

In order to transmit a large chunk of data that cannot be accommodated in one packet, the start and end bits are used to identify the first packet and the last packet in a series of packets. If the logical size of a packet is smaller than or equal to 56 bytes then both the start bit and the end bit shall be set.

8.2.4 Event packet

Figure 6 shows the format of an event packet of Responsive Link. The event packet shall consist of a 4-byte header, an 8-byte payload and a 4-byte trailer.

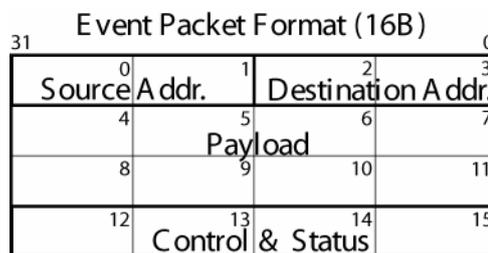


Figure 6 – Event packet format

Figure 7 shows the format of the 4-byte trailer.

Control & Status Format (32bits)

0	UD	Full			Data Length		
1	Dirty0	Dirty1	Dirty2	Dirty3	Dirty4	Dirty5	Dirty6
2	Dirty8	Dirty9	Dirty10	Dirty11	Dirty12	Dirty13	Dirty14
3	Start	End	Int.	Fatal	Correct	Serial Number (Cnt.)	

Figure 7 – Trailer format of event packet

Key

- UD: Reserved.
- Full: This bit shall be set to 1 if all of the payload data (8 bytes) are valid data. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Data Length: Length of valid payload data (0–8). This flag shall be set by the Layer 4 hardware or software at the source node.
- Dirty0 to Dirty15: Indicates which byte in the packet has an error. For example, if the 2nd byte of the packet has an error, then Dirty1 bit shall be set to 1. This flag shall be set by the Layer 2 hardware as a result of the error correction procedure.
- Start: This bit shall be set to 1 if this packet is the start packet. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- End: This bit shall be set to 1 if this packet is the end packet. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Int: The Responsive Link shall generate an interrupt to the destination node controller (processor) when this packet reaches the destination node if this bit is set to 1. Otherwise, this bit shall be set to 0. This flag shall be set by the Layer 4 hardware or software at the source node.
- Fatal: This bit shall be set to 1 by the Layer 2 hardware if any byte in the packet has an unrecoverable fatal error. Otherwise, this bit shall be set to 0.
- Correct: This bit shall be set to 1 by the Layer 2 hardware if this packet had errors that have been corrected. Otherwise, this bit shall be set to 0.
- Serial Number: Serial number of the packet. The start packet shall have the serial number 0, and this number shall be incremented in following packets. The serial number shall return to 0 after it reaches 7, and the sequence shall be repeated. This flag shall be set by the Layer 4 hardware or software at the source node.

In order to transmit a large chunk of data that can not be accommodated in one packet, the start and end bits are used to identify the first packet and the last packet in a series of packets. If the logical size of a packet is smaller than or equal to 8 bytes, then both the start bit and the end bit shall be set.

8.3 Routing**8.3.1 General**

Responsive Link realizes an end-to-end connection by setting the routing tables of all nodes along the transmission path from a source node to a destination node.

8.3.2 Routing table

Each node shall have a routing table to control the packet routing and the priority replacement function. Figure 8 shows the routing table of a network switch with five-ins and five-outs.e

The reference part shall be the same as the header of a packet.

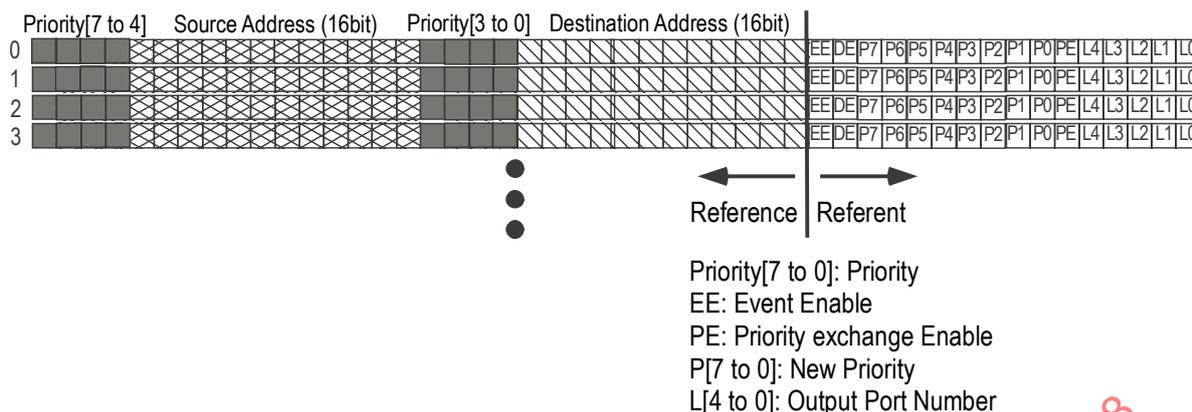


Figure 8 – Routing table

The referent part shall be composed of five parts as follows.

- EE (Event Enable): This bit shall be set to 1 if the event link is valid; otherwise, this bit shall be set to 0.
- DE (Data Enable): This bit shall be set to 1 if the data link is valid; otherwise, this bit shall be set to 0.
- PE (Priority Exchange): This bit shall be set to 1 if the priority replacement function is enabled; otherwise, this bit shall be set to 0.
- P[7 to 0]: New priority level (8 bits). Valid if PE is set to 1.
- L[4 to 0]: Output link numbers. For example, if the L3 bit is set, input packets shall be routed to the link3 port. If several bits are set, then multi-cast is indicated. If all of the bits are set, then broadcast is indicated.

8.3.3 Independent routing of data and event

The event link and the data link may have different routes to the same destination, because the EE bit and the DE bit can be set independently. (See Annex D.)

8.3.4 Priority-based routing

Priority bits are used for matching the routing table. So different routes can be set according to priority, even if the network address is the same. The route of priority “0”, which is the lowest priority, shall be used as the default route of the network address. If the combination of the network address and the priority is matched completely in the routing table, then the matched line shall be used. If, in the routing table, the network address matches, but the priority does not match, then the line with priority 0 shall be used. (See Annex E.)

9 Layer 4 (transport layer)

9.1 Priority replacement for packet acceleration/deceleration

The priority of packets can be replaced at each node. If the PE bit is set, Priority[7 to 0] in Figure 8, which is the original priority of the input packet, shall be replaced with P7 to P0 in Figure 8, which becomes the new priority. The original priority is used for routing and overtaking packets at the current node, and the new priority is used at the next node. (See Annex B.) If the priority of a packet is replaced, then the route of the packet may be changed thereafter.

A packet in which the priority is replaced with a higher priority is accelerated from the next node. A packet in which the priority is replaced with a lower priority is decelerated from the next node.

The packet control can be realized by setting the routing table at each node in a distributed control manner.

9.2 Multi-link

Responsive Link supports multi-links. Any two nodes in a system can communicate with each other on multiple different links by assigning different priorities to each packet, as described in 8.3. In this manner, the priority is used for route selection. Thus, the multi-link can increase the bandwidth between communication-intensive nodes. (See Annex E.)

9.3 Stream data transmission

In order to transmit a large amount of data that cannot fit into one packet, the following fields in the packet trailer shall be set at the source node. (See 8.2.3 and 8.2.4.)

- Full: This bit shall be set to 1 if all of the payload data are valid data. Otherwise, this bit shall be set to 0.
- Data Length: Length of valid payload data.
- Start: This bit shall be set to 1 if this packet is the start packet. Otherwise, this bit shall be set to 0.
- End: This bit shall be set to 1 if this packet is the end packet. Otherwise, this bit shall be set to 0.
- Int: The Responsive Link shall generate an interrupt to the destination node controller (processor) when this packet reaches the destination node if this bit is set to 1. Otherwise, this bit shall be set to 0.
- Serial Number: Serial number of the packet. The start packet shall have the serial number 0, and this number shall be incremented in following packets. The serial number shall return to 0 after it reaches 7, and the sequence shall be repeated. This flag shall be set by the Layer 4 hardware or software at the source node.

Annex A (informative)

Characteristics of real-time communications

Generally, communication data are divided into minimum units, herein called packets, for transmission. Because multi-task systems are required to simultaneously communicate with other systems, they process concurrently and transmit packets to other systems.

The size of normal data, including image data, sound data and sensor data, is large, whereas the size of event data, including inter-module interrupts, inter-module synchronization and control commands, is very small. Thus, there are a large number of normal data packets and a small number of event packets that are very important for real-time simultaneous control on a single shared communication line. The event communication is required to be hard real-time, and the data communication, including multi-media data transmission (moving picture, voice, etc.), may be required to be soft real-time. It is very important to keep the communication latency of events as short as possible and to guarantee their arrival time in a real-time system that controls I/O devices.

It is difficult to realize a hard real-time system using conventional communication that shares a single communication line for data and events, because the communication latency of events cannot be estimated accurately. It is also difficult for conventional communication to bound a time constraint, because the communication bandwidth depends on the number of communication nodes on a serial bus and changes dynamically.

Moreover, the following trade-off in real-time communication exists.

Soft real-time: Guaranteed communication bandwidth => high throughput for bulky data

Hard real-time: Guaranteed communication latency => short latency for events

The packet size becomes larger as the throughput becomes higher. At the same time, the packet latency becomes longer in this case, as shown in Table A.1. The higher the communication throughput is, the longer is the latency. On the other hand, if the packet size becomes smaller, the packet latency becomes shorter, whereas the throughput becomes lower as a result of the increased overhead.

Table A.1 – Syndrome and error digits

Points \ Packet size	Larger	Smaller
Throughput	Higher	Lower
Latency	Longer	Shorter

Therefore, a Responsive Link consists of two point-to-point full-duplex communication links.

Annex B (informative)

Real-time scheduling

There are several real-time scheduling algorithms, including earliest deadline first (EDF), which is an optimal dynamic scheduling algorithm, and rate monotonic (RM), which is an optimal static scheduling algorithm.

The EDF algorithm translates the deadline to a priority. The priority of the task with the earliest deadline becomes the highest.

The RM algorithm translates the cycle time to a priority. The task with the shortest cycle is assigned to have the highest priority.

Many other real-time scheduling algorithms also translate the time constraint to a priority.

Figure B.1 shows an example of EDF scheduling. Priority-based scheduling is performed at every clock tick and at timings when tasks are released (invoked), as well as at execution finish.

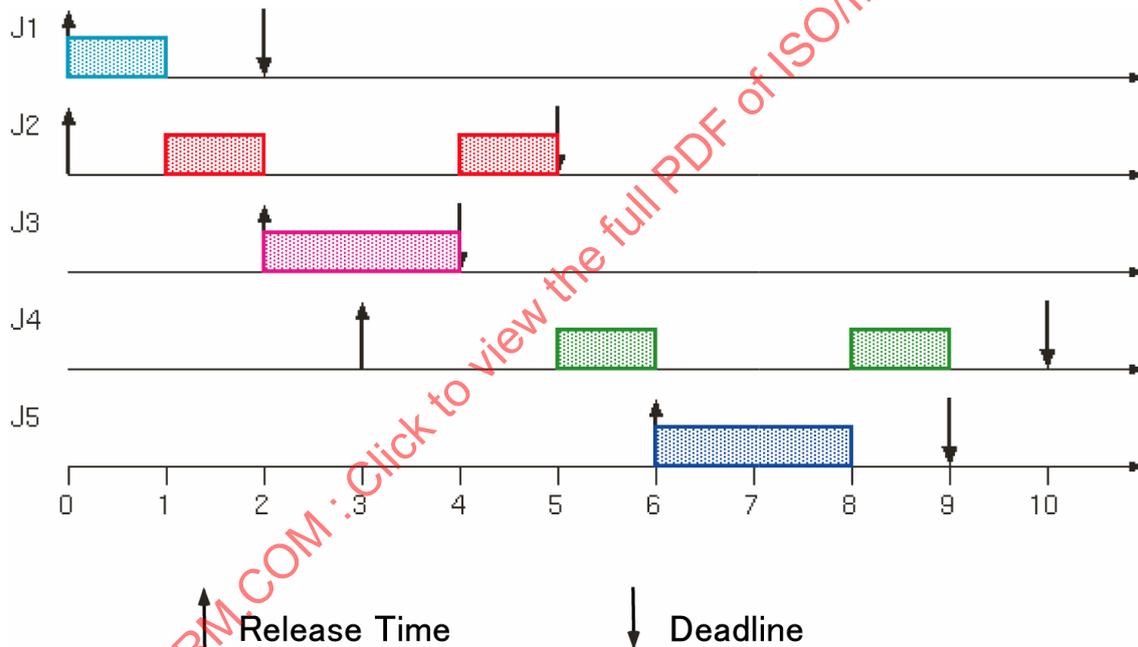


Figure B.1 – EDF scheduling

This real-time task scheduling process can be regarded as an overtaking process, i.e. tasks with higher priorities are executed earlier than tasks with lower priorities. In order to implement this idea in a distributed real-time system, communication of higher priority tasks should be able to overtake other communication. The Responsive Link does this at every node.

Annex C (informative)

An implementation of the Responsive Link interface

The electronic interface of the Responsive Link should be a type of LVDS (low-voltage differential signal).

Cables that meet the requirements of the enhanced category 5, category 6 or category 7 of IEC 61156-5 should be used as the Responsive Link medium as shown in Figure C.1. And IEC 60603-7 connectors should be used as the Responsive Link connectors.

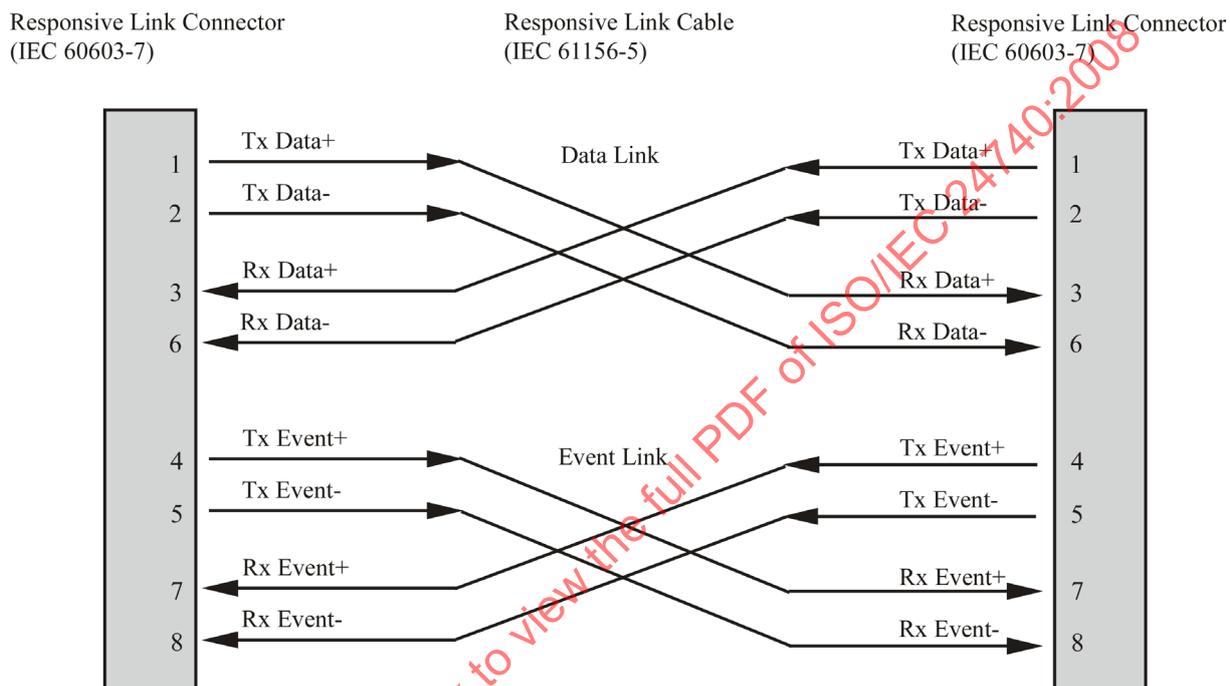


Figure C.1 – Responsive Link connector and cable

The maximum cable length of the Responsive Link changes according to the link speed as shown in Figure C.1.

Table C.1 – Maximum cable length

Clock rate (MHz)	100	200	400	800
Speed (Mbit/s)	66,7	133	267	533
Length (m)	20	15	10	5
Cable performance	Category 5e of IEC 61156-5	Category 6 of IEC 61156-5	Category 6 _A of IEC 61156-5	Category 7 _A of IEC 61156-6
Connector performance	IEC 60603-7-2 IEC 60603-7-3	IEC 60603-7-4 IEC 60603-7-5	IEC 60603-7-7	IEC 60603-7-7