THE EVOLUTION OF SPACEWIRE: A COMPARISON TO ESTABLISHED AND EMERGING TECHNOLOGIES

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Short Paper

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ABSTRACT

Designed for use in space applications, SpaceWire offers many advantages over other comparable communications technologies. It requires relatively simple circuitry to implement, offers low power consumption, and supports high link speeds. It has rapidly gained acceptance and has been successfully employed in support of a wide variety of missions.

Since SpaceWire was standardized in 2003, it has been supplemented by several higher-level protocols. Standards were recently published which specify two such protocols: the Remote Memory Access Protocol (RMAP) and the Consultative Committee for Space Data Systems (CCSDS) Packet Transfer Protocol (PTP). With anticipated introduction of a standard for SpaceWire-RT (SpaceWire Reliable Timely), mechanisms are introduced for SpaceWire to provide for timely delivery of information with Quality of Service (QoS) guarantees. A new standard, known as SpaceFibre, which is derived from SpaceWire and supports even higher transfer speeds is currently in development.

This paper explores the evolution of SpaceWire over time. It compares and contrasts SpaceWire with other high-speed technologies such as Asynchronous Transfer Mode (ATM), Switched Ethernet, Peripheral Component Interconnect (PCI) and Rapid I/O and discusses the trade-off between design complexity and performance.

1 INTRODUCTION

SpaceWire is a simple, low-power, high-speed networking technology derived originally from the IEEE 1355 standard [1]. It has rapidly gained widespread acceptance for use in onboard spacecraft communication systems because it provides many advantages and is easy to implement in radiation-tolerant programmable logic devices. The SpaceWire standard replaced the IEEE 1355 physical layer with low-voltage differential signaling (LVDS) which is more suitable for the harsh space environment [2]. It uses point-to-point links to connect nodes rather than a shared bus and provides much flexibility for incorporating redundancy. SpaceWire has relatively low memory requirements because it uses a wormhole routing technique in which a packet received on an input of a switch begins retransmission on an output before it is completely received.

Since SpaceWire was first published as a standard by the European Cooperation for Space Standardization (ECSS) in January 2003 [3], it has evolved and several new standards based on SpaceWire have emerged. In July 2008, the SpaceWire standard was republished but no changes were made to the technical content [4]. In February 2010, ECSS published a set of supplementary standards including “Space engineering: SpaceWire protocol identification” [5], “Space engineering: SpaceWire – Remote memory access protocol” [6], and “Space engineering: SpaceWire – CCSDS packet transfer protocol” [7]. In addition to these published standards, a number of proposed draft standards are under development. These draft standards include SpaceWire-RT, which extends SpaceWire to include Quality of Service (QoS) guarantees [9], and SpaceWire-PnP (Plug-and-Play), which provides support for device discovery, network management, and device configuration services. As SpaceWire has evolved, it has developed capabilities similar to many new and established network protocols.

2 COMPARISONS TO OTHER PROTOCOLS

2.1 ASYNCHRONOUS TRANSFER MODE

Asynchronous Transfer Mode (ATM) is a networking technology originally designed for efficient transfer of voice, video, and data that was standardized by the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) [8]. ATM uses a connection-oriented model in which a virtual circuit is established between endpoints. In order to support QoS guarantees, ATM switches fixed-size transfer units, called cells, which provide constant transmission delays and guaranteed capacity.

In contrast to the fixed-size cell used by ATM, SpaceWire uses variable-size transfer units, called packets. The SpaceWire standard does not restrict the maximum size of a transfer unit (an approach inherited from IEEE 1355 [1]). Consequently, long packets can cause delay problems in a SpaceWire network as they can block links in their path. Although this can be a serious issue, the size of transfer units is often limited in practice by higher-level protocols.

SpaceWire-RT (SpaceWire Reliable Timely) has been proposed as a higher-layer protocol for SpaceWire to provide a suitable solution where QoS guarantees are needed [9]. SpaceWire-RT supports a scheduled system by segmenting SpaceWire packets into maximum size transfer units, called DPs. DPs are scheduled using fixed-time slots, similar to the multiplexing of cells in ATM. SpaceWire-RT, also like ATM, requires resource reservation in order to establish a timely path through the network.

2.2 ETHERNET

Ethernet is the ubiquitous, asynchronous, packet-switched network technology which dominates the Internet today. Ethernet uses variable-size packets called frames. Similar to SpaceWire-RT, Ethernet restricts transfer units to a maximum size. Early Ethernet implementations used a scheme known as carrier sense multiple access with collision detection (CSMA/CD) to share a common communications channel. Under this scheme, if two senders transmit simultaneously causing a collision, both senders would terminate transmission, delay for a brief random time and then attempt to transmit again. Although this limits throughput, it is simple to implement. Most modern Ethernet implementations are switched. With this approach, Ethernet switches temporarily buffer frames and delay transmission in order to avoid collisions.

Perhaps one reason for Ethernet's immense popularity is that it integrates well with the Internet Protocol (IP). Ethernet conveniently provides support for a link-layer broadcast mechanism and includes network unique source/destination addresses in each frame. This greatly simplifies configuration by providing a mapping to directly support an Address Resolution Protocol (ARP).

SpaceWire too can be characterized as an asynchronous, packet-switched network. However, in contrast to Ethernet, SpaceWire does not provide provisions for a link-layer broadcast mechanism and does not inherently provide network unique addresses within a packet. Fortunately, these features can be added using higher-level protocols [10]. In this way, SpaceWire can effectively be integrated with the Internet Protocol.

2.3 Peripheral Component Interconnect

Peripheral Component Interconnect (PCI) refers to a series of related standards. PCI was originally introduced by the Intel Corporation for use in attaching hardware devices in a computer system. An industry organization, known as the PCI Special Interest Group (PCI-SIG), was formed in 1992 and released the PCI v2.0 standard in April 1993 [11]. The standard defined a 5-Volt, 33-MHz, 32-bit parallel architecture with throughput of 133 MB/s (>1Gbps).

The latest standard in the PCI family is PCI Express. Unlike previous PCI standards which were based on a shared parallel bus, PCI Express shifted to a serial point-to-point architecture in order to avoid issues with clock skew at high clock rates. PCI Express has started to displace conventional PCI in modern day Personal Computers (PCs).

In the PCI family, PCI Express is the most similar in architecture to SpaceWire. PCI Express is typically implemented on a backplane. Backplane implementations of SpaceWire have been proposed and research has been conducted to evaluate connectors suitable for the harsh environments of space [12].

2.4 RapidIO

RapidIO is a high-speed, packet-switched interconnect technology that was designed for use in integrating components on a circuit board. The technology was originally developed as a collaborative partnership between Motorola and Mercury Computer Systems, Inc. with a 1.0 specification released in late 1999 [13]. In 2000, the RapidIO Trade Association was formed to direct development and encourage adoption of the technology. RapidIO exists in Serial and Parallel versions. Although Serial RapidIO achieves higher speeds than SpaceWire, it has not been qualified for use in space applications.

A new standard, known as SpaceFibre, which is derived from SpaceWire and supports even higher transfer speeds is currently in development [14]. SpaceFibre shares some common characteristics with Serial RapidIO such as the use of 8B/10B encoding to transmit the clock along with the data signal. SpaceFibre requirements include the target or reaching link speeds of up to 2.5 Mbps which is comparable to RapidIO.

3 SUMMARY AND CONCLUSIONS

Table 1. Summary of Network Protocols

	SpaceWire	ATM	Ethernet	PCI	RapidIO
Standardized	2003	1988	1982	1993 (v2.0)	2001 (1.1)
Standards Body	ECSS	ITU-T	IEEE	PCI-SIG	RapidIO TA
Created By	ESA/ESTEC	ITU, ATM Forum, et. al.	Xerox	Intel	Motorola and Mercury Computer
Related Standards	RMAP, PTP, SpaceWire-RT, SpaceWire-PnP, SpaceFibre	SONET/SDH	10/100/1000BASET, 1Gb and 10Gb varieties	PCI v2.1, v2.2, v2.3, PMC, PCI-X, PCIe	RapidIO 1.1, 1.2, 1.3, 2.0, 2.1
Capacity	2 – 400 Mbps	155Mbps (OC-3), 10Gbps (OC-192)	10Mbps, 100Mbps 1Gbps, 10Gbps	1Gbps, 2Gbps, 4Gbps	1Gbps (x1) – 10Gbps (x4)
Type	serial point-to-point	serial point-to-point	shared-bus, serial point-to-point	parallel, 32 or 64 bits	serial point-to-point
Transfer Unit	packet	cell	frame	bus transactions	packet

SpaceWire has proven to be a simple, yet versatile networking technology. The creation of integrated higher-level protocols for SpaceWire has made it viable for a variety of practical applications.

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