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(54) **INTERFACE AND RELATED METHODS FOR RATE PACING IN AN ETHERNET ARCHITECTURE**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,596,575 A 1/1997 Yang et al.
5,991,303 A 11/1999 Mills
6,055,268 A * 4/2000 Timm et al. 375/229
6,094,439 A 7/2000 Krishna et al.

6,169,729 B1 1/2001 Feuerstraeter
6,215,816 B1 * 4/2001 Gillespie et al. 375/219
6,275,497 B1 8/2001 Varma et al.
6,559,692 B2 * 5/2003 Kimball et al. 327/109
6,636,531 B1 * 10/2003 Nakashima et al. 370/505
6,697,368 B2 * 2/2004 Chang et al. 370/395.1
6,973,031 B1 12/2005 Kalkunte et al.
2003/0039211 A1 2/2003 Hvostov et al.
2003/0058894 A1 3/2003 Feuerstraeter et al.
2004/0003296 A1 * 1/2004 Robert et al. 713/300
2005/0220180 A1 * 10/2005 Barlev et al. 375/222

FOREIGN PATENT DOCUMENTS

WO WO 0070827 11/2000
WO WO 0176160 10/2001

OTHER PUBLICATIONS

IEEE, "Media Access Control (MAC) Parameters, Physical Layer, and Management Parameters for 10 Gb/s Operation," IEEE Draft P802.3ae/D3.3, pp. i-ii, 14-42, Oct. 23, 2001.

Frazier, H. "Comparison of Rate Control Methods", May 24, 2000, IEEE P802.3ae 10 Gigabit Ethernet Task Force, Ottawa ON, pp. 3 and 9.

Alderrou et al., "XAUI/XGXS Proposal", May 23, 2005, IEEE 802.3ae 10 Gb/s Task Force May 2000 Interim Meeting, Ottawa, ON, pp. 7 and 15.

"802.3ae Criteria", IEEE P802.3ae 10Gb/s Ethernet Task Force. Thatcher, J. "802.3ae Plenary Meeting", Jul. 11-12, 2000, IEEE 802.3ae 10 Gb/s Task Force, La Jolla, CA p. 4.

* cited by examiner

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(57) **ABSTRACT**

An interface and related methods for rate pacing in an Ethernet architecture is described herein.

27 Claims, 5 Drawing Sheets

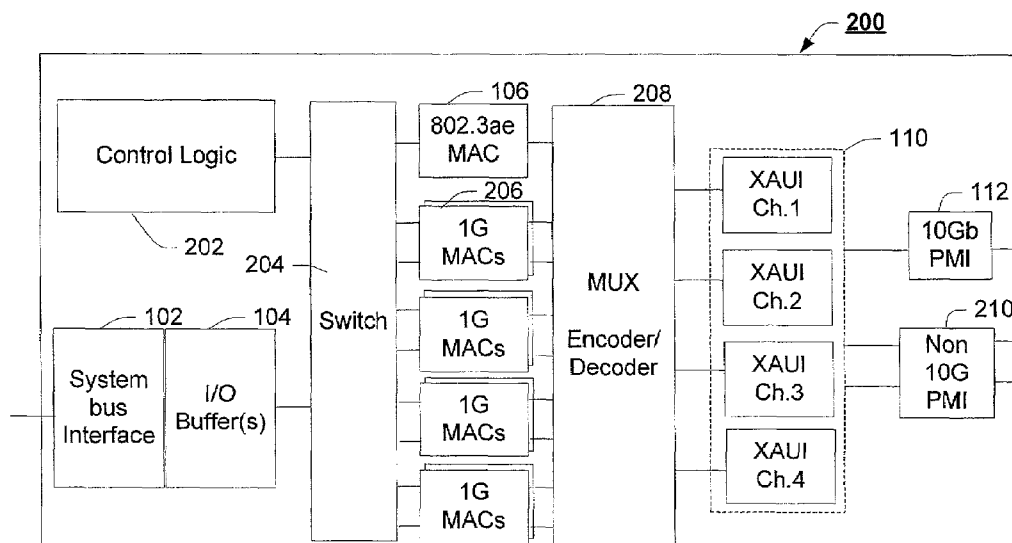


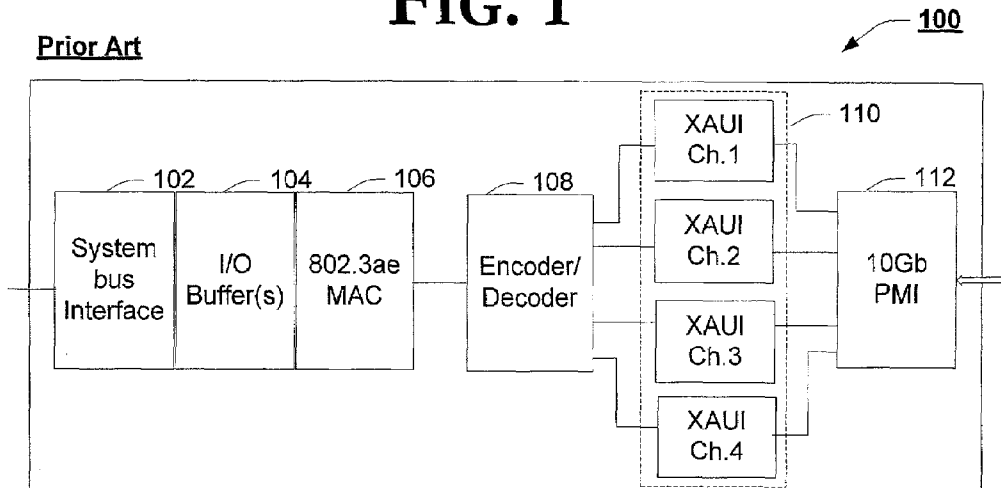
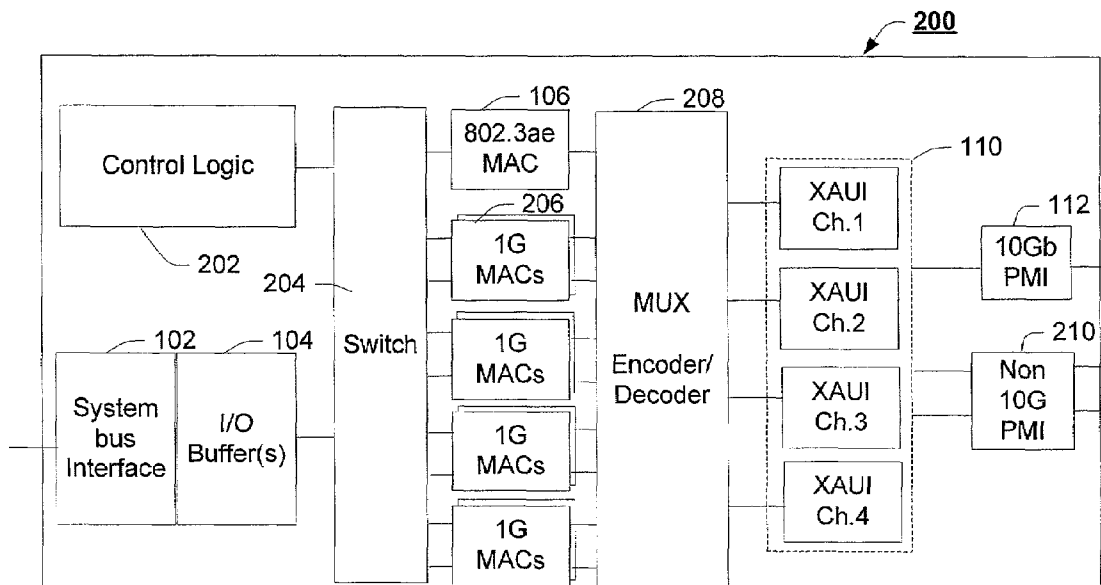
FIG. 1Prior Art**FIG. 2**

FIG. 3

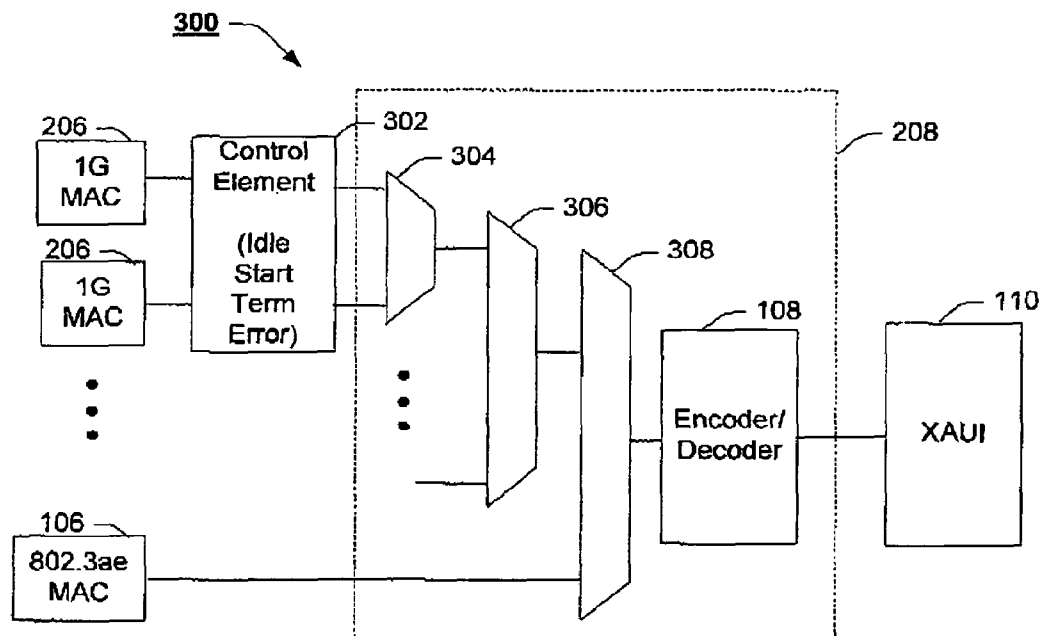


FIG. 7

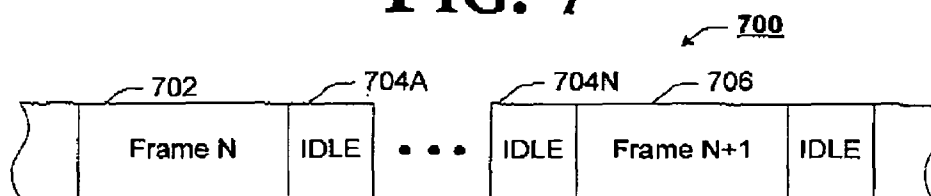


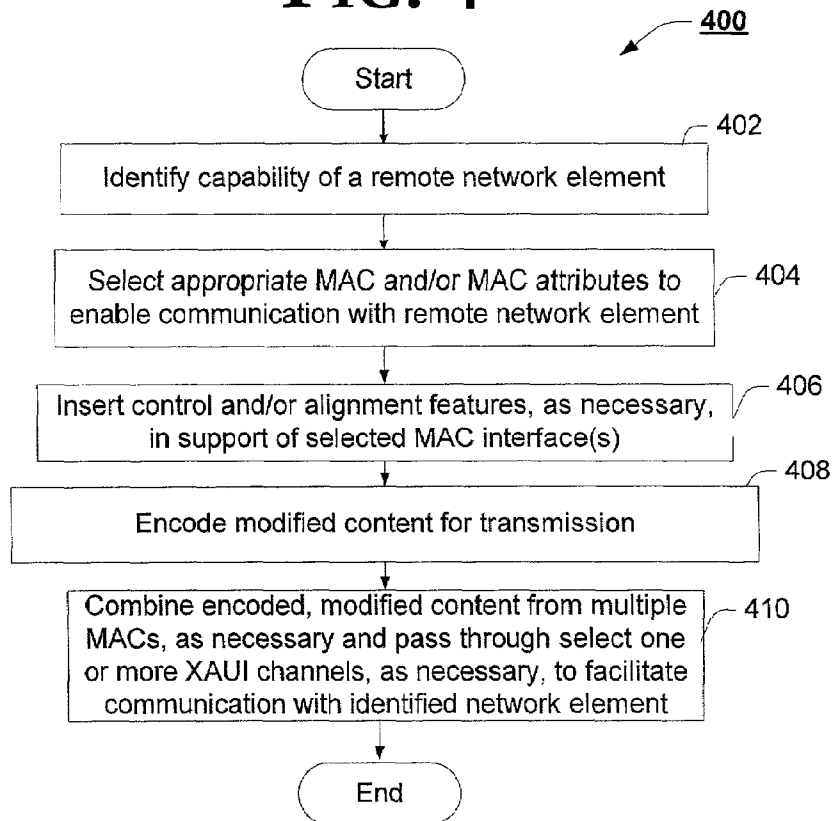
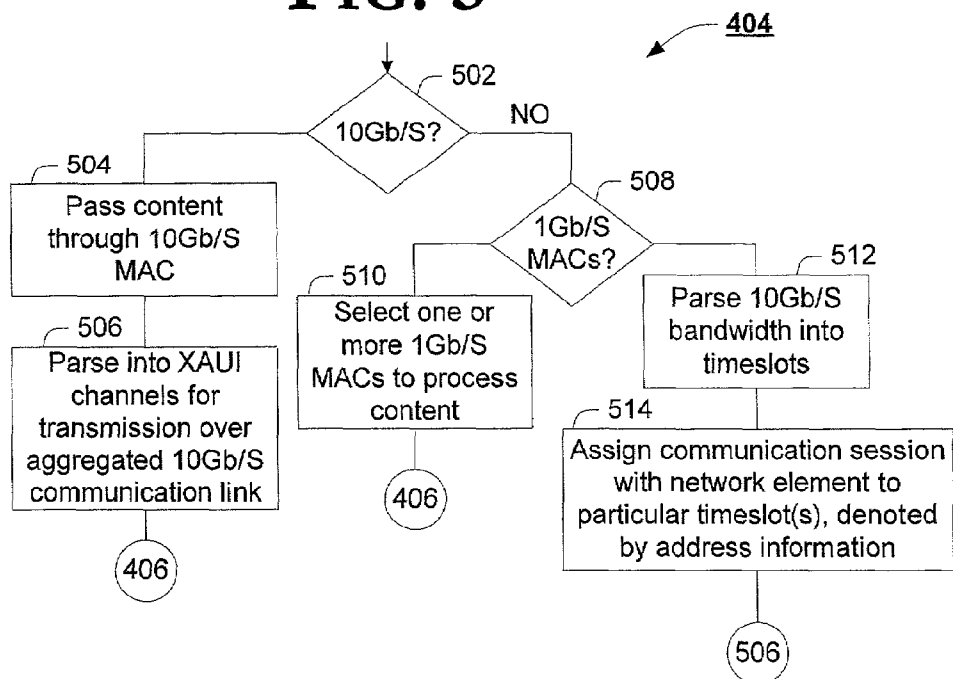
FIG. 4**FIG. 5**

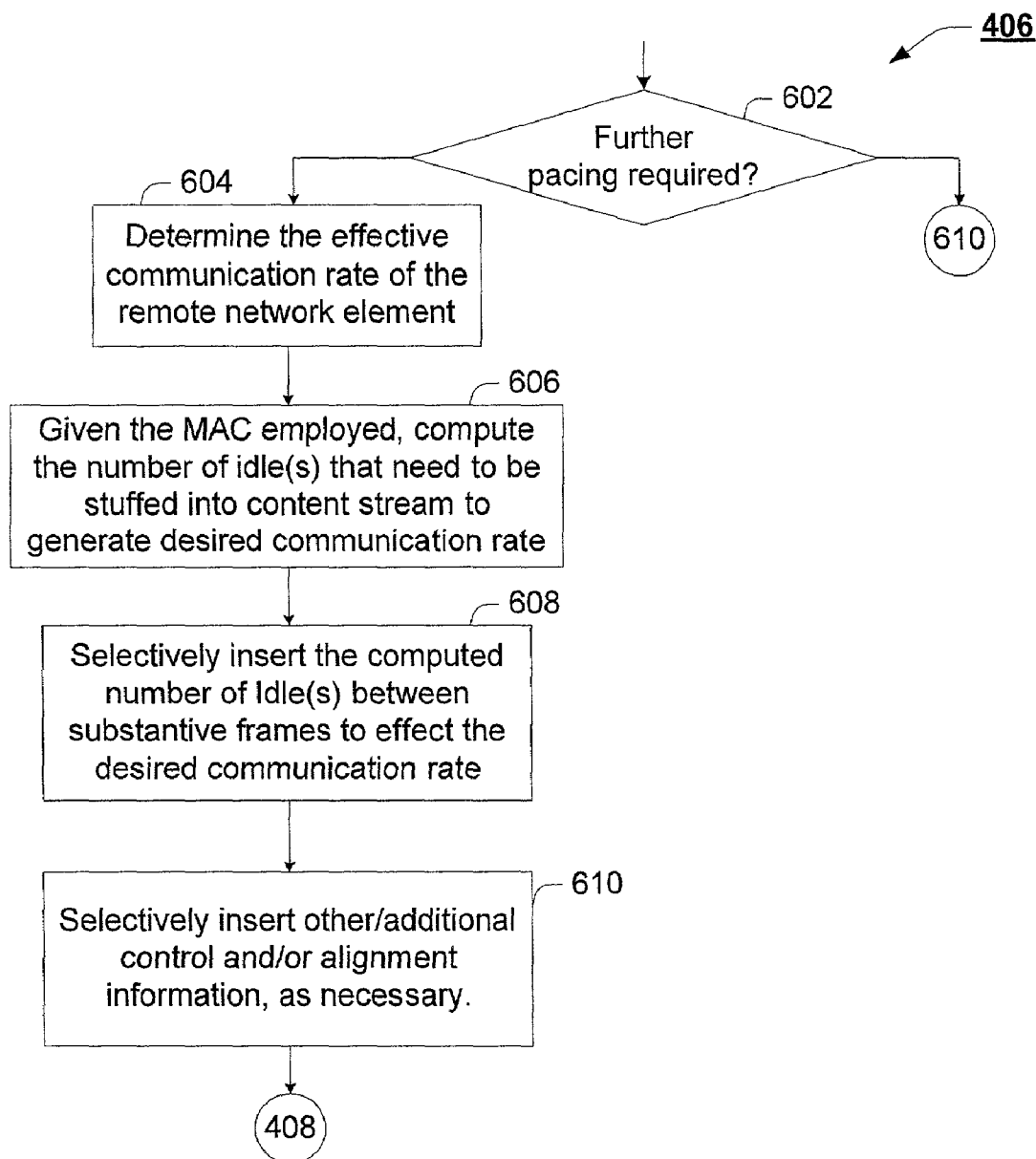
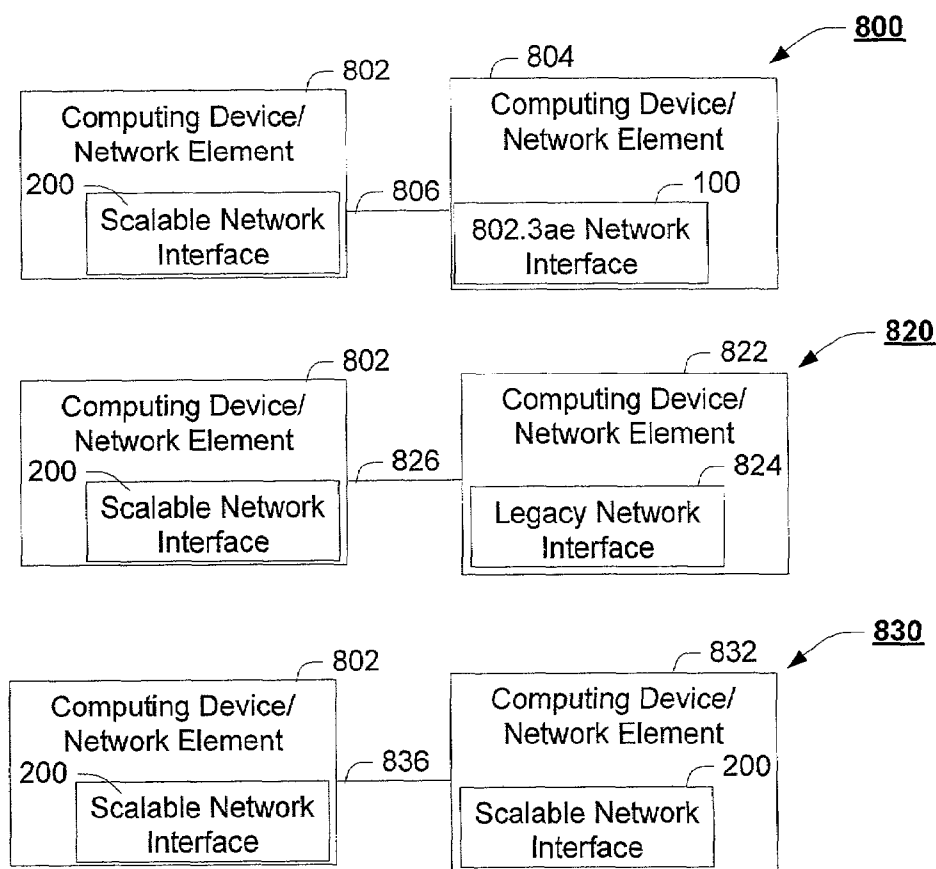
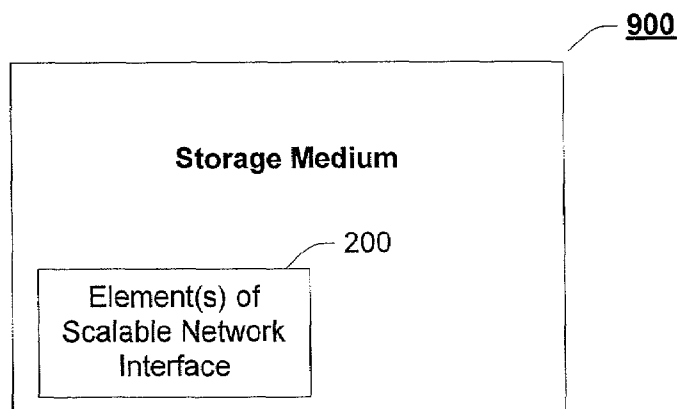
FIG. 6

FIG. 8**FIG. 9**

INTERFACE AND RELATED METHODS FOR RATE PACING IN AN ETHERNET ARCHITECTURE

TECHNICAL FIELD

The present invention generally relates to the field of data networks and, more particularly, to an interface and related methods for rate pacing in an Ethernet architecture.

BACKGROUND

As computer technology has evolved, so too has the use of networks which communicatively couple computer systems together enabling remote computer systems to exchange information. One example of just such a network topology is the Ethernet standard topology, defined within the 802.3 standards committee of the Institute of Electronic and Electrical Engineers (IEEE). Over the last decade, the Ethernet standard has evolved from a 10 Mb/S standard to a 100 Mb/S standard to a 1 Gb/s standard and, more recently, a 10 Gb Ethernet standard, IEEE 802.3ae entitled *Local and Metropolitan Area Networks—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications—Media Access Control Parameters, Physical Layers and Management Parameters for 10 Gb/s Operation* has been proposed, each of which are incorporated herein by reference.

As currently proposed, the 802.3ae Ethernet standard provides for a single, 10 Gb/s communication channel which is the aggregate of four lanes, each providing full-duplex data rate of 2.5 Gb/s of 8 b/10 b encoded data at a signaling rate of 3.125 Gb/s (or, 12.5 Gb/s for the aggregate channel). To place a 10 Gb/s data rate in context, the entire contents of a DVD could be transmitted through a 10 Gb/s link in less than six seconds. An example of an 802.3ae compliant network interface (NI) architecture is presented, with reference to FIG. 1.

Turning briefly to FIG. 1, a block diagram of a conventional 10 Gb/s network interface is presented. As shown, the conventional 802.3ae network interface includes a system bus interface **102**, one or more input/output buffer(s) **104**, an 802.3ae media access controller **106**, an encoder/decoder **108** coupled to a 10 Gb/s attachment unit interface (XAUI) **110**, and a 10 Gb/s transceiver **112**. As used herein, the system bus interface **102** and the I/O buffers **104** effectively couple the 802.3ae MAC to processing elements of a host system. Content is received from the processing elements of the host via the interface **102** and buffered, as required, to/from the 802.3ae MAC. The 802.3ae MAC processes received data to facilitate communication over the network communication link. In this regard, 802.3ae MAC packetizes data for transmission, and de-packetizes information received from the communication link for promotion to the host processing elements. The 802.3ae MAC is coupled to an Encoder/Decoder **108** to provide signaling for packing 2×1 G channels into a single 2.5G XAUI channel.

The 10G external attachment unit interface (XAUI) is depicted comprising four (4) channels, which establish four full-duplex communication “lanes”, which are aggregated to provide the 10 Gb/s communication link through a physical media interface **112** (e.g., an optical transceiver). The XAUI interface **112** is used to extend the effective transmission length of the 802.3ae MAC, facilitating more flexibility in connecting the 802.3ae MAC to the physical media interface. In this regard, the XAUI interface performs additional encoding using the 8 b/10 b encoding scheme such that each

of the four channels supports a data rate of 2.5 Gb/s over a signaling rate of 3.125 Gb/s (the difference allocated to encoding overhead). It will be appreciated that the physical media interface **112** may also perform additional coding (e.g., 64 b/66 b) in preparing the content for transmission over the physical medium.

While the impressive throughput of the 10 Gb Ethernet architecture offers the promise of eliminating network processing bottlenecks for a significant time to come, those skilled in the art will appreciate that current computing platforms cannot consume data at this rate. Thus, current implementations of a 10 G Ethernet architecture will necessarily require significant buffering between 802.3ae compliant devices and more traditional computing resources (e.g., client computers, host systems, servers, and the like) to enable the conventional computing device(s) to consume data in accordance with its processing capabilities.

Another significant limitation lies in the fact that, as proposed, 802.3ae devices will not interoperate with legacy Ethernet interface(s) at the link-level (i.e., in the parlance of the Open Systems Interconnect (OSI) communication model). That is to say, unlike legacy Ethernet standards which provide for link-level compatibility by having the device “fall back” to the lowest common communication denominator (e.g., 10 Mb, 100 Mb or 1 Gb data rates), the proposed 802.3ae standard does not provide for such link-level compatibility with conventional Ethernet devices. This lack of backwards compatibility fails to offer consumers a migration path that allows them to upgrade individual components of a network as the need arises. Given the popularity of past Ethernet architectures, consumers have a significant investment in their Ethernet networking architecture and, consequently, are not likely to simply replace such network elements wholesale to make this upgrade.

Thus, while the 802.3ae standard proposal provides a roadmap of the future of Ethernet, a number of limitations stand in the way of early acceptance and adoption in the marketplace of 802.3ae-compliant devices. First, the communication rate of 802.3ae devices can quickly overwhelm host systems without significant buffering at the interface. Those skilled in the art will appreciate that the memory elements and associated control to provide such buffering add significant cost to the conventional 802.3ae interface.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings in which like reference numerals refer to similar elements and in which:

FIG. 1 is a simplified block diagram of an example conventional network interface, representative of prior art network interfaces;

FIG. 2 is a block diagram of an example network interface incorporating the teachings of the present invention, in accordance with one example implementation of the present invention;

FIG. 3 is a more detailed block diagram of certain elements of the example network interface of FIG. 2, according to one example implementation of the present invention;

FIG. 4 is a flow chart of an example method of implementing a scalable network interface in accordance with the teachings of the present invention;

FIG. 5 is a flow chart of an example method for dynamic link channelization, in accordance with one aspect of the present invention;

FIG. 6 is a flow chart of an example method for rate pacing within a network channel, in accordance with one aspect of the present invention;

FIG. 7 is a graphical illustration of an example sequence of frames illustrating the rate pacing aspect of the present invention, according to one example implementation of the present invention;

FIG. 8 is a block diagram of example networking embodiments of the scalable network interface, in accordance with the teachings of the present invention; and

FIG. 9 is a block diagram of an example storage medium comprising a plurality of executable instructions which, when executed, cause an accessing machine to implement one or more aspects of the innovative communication agent of the present invention, in accordance with an alternate embodiment of the present invention.

DETAILED DESCRIPTION

The present invention is generally directed to an interface and related methods for dynamic channelization in an Ethernet architecture. In this regard, a scalable network interface is introduced which effectively enables an 802.3ae-compliant device to interface with host systems without the need for significant buffering, and also provides an element of backwards compatibility with legacy Ethernet devices. According to one example implementation, a scalable network interface is introduced that identifies the communication and/or processing capability of a remote network device, and dynamically creates a virtual channel within the 802.3ae physical channel to communicate with the remote network device in accordance with its identified capability. Alternate embodiments of the dynamic channelization feature will be developed more fully below. Those skilled in the art will appreciate, from the discussion to follow, that the dynamic channelization features of the scalable network interface provides an element of backwards compatibility with legacy network devices.

In accordance with another aspect of the present invention, the scalable network interface introduces further throttles the communication channel established with a remote network device based, at least in part, on the processing capability of the remote network device. In this regard, a rate pacing element is presented which effectively reduces the data rate of a (virtual/physical) communication channel to any level below the channel data rate. Those skilled in the art will appreciate that the rate pacing element may well be used in conjunction with the dynamic channelization feature to generate a virtual channel of any data rate to suit the network interface and/or processing capability of other network elements. In this regard, a scalable interface and related methods enabling an 802.3ae compliant network device to effectively interface with legacy equipment is presented.

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

EXAMPLE SCALABLE NETWORK INTERFACE

FIG. 2 provides a block diagram of an example scalable network interface in accordance with the teachings of the present invention. In addition to the elements found in the conventional 802.3ae network interface introduced above, the scalable network interface **200** is depicted comprising control logic **202**, a switch **204**, one or more 1 Gb/s MAC(s), a multiplexing encoder/decoder **208**, and legacy physical media interconnect devices **210**, each coupled as depicted. Although depicted as a number of disparate functional items, those skilled in the art will appreciate that one or more of such elements may well be combined into single functional entities. Alternatively, certain elements may be split into multiple functional elements. In this regard, alternate embodiments of greater or lesser complexity that nonetheless enables an 802.3ae compliant network interface to interact with legacy network elements is envisioned within the scope and spirit of the present invention.

As used herein, control logic **202** controls the scalability aspect of the network interface **200**. In this regard, control logic **202** determines whether the interface **200** is coupled to an 802.3ae network or some legacy network (e.g., 1 Gb/s, 100 Mb/s, 10 Mb/s). According to one example implementation, control logic **202** utilizes auto-negotiation features to identify the communication rate supported by the remote network device. Any of a number of auto-negotiation techniques may well be used by control logic **202** in this regard. In accordance with one aspect of the present invention, developed more fully below, once control logic **202** has identified the communication capability of the remote network device, control logic **202** enables select interface resources to establish a communication channel within the 10 Gb/s signaling rate of the communication link **112** that is commensurate with the communication capability of the remote device. Although depicted as a separate functional entity for purposes of clarity, those skilled in the art will appreciate that at least this aspect of the control logic **202** may well be embodied within other physical or logical elements of interface **200**. In one implementation, for example, the auto-negotiation features of control logic **202** are implemented within a physical media interface, such as the 10 G physical media interface (PMI) of 802.3ae compliant devices. In this regard, control logic **202** is intended to represent any of a wide variety of control logic known in the art such as, for example, microprocessor(s), microcontroller(s), programmable logic device(s) (PLD), field programmable gate arrays (FPGA), state machine(s) and the like. Alternatively, control logic **202** may well be content (e.g., executable instructions) which, when executed by a computing appliance, implement the control features described herein.

As depicted, switch **204** routes data to/from communicatively coupled system(s) through I/O buffer(s) **104**. According to one aspect of the present invention, switch **204** routes such information to/from one or more of the 802.3ae compliant MAC **106** and/or one or more of the 1 Gb/s MAC(s) **206**. According to one example implementation, switch **204** receives control information from control logic (e.g., **202**) to route content between the I/O buffer(s) **104** and the MAC(s) **106** and/or **206**. In accordance with the illustrate example Implementation, switch **204** is controlled via direct memory access (DMA) from control logic such as, e.g., control logic **202**.

In accordance with one example implementation of the present invention, interface **200** is endowed with one or more 1 Gb/s media access controller(s) (MAC) **206** to

Implement the dynamic channelization features of the present invention. That is, in accordance with one example Implementation, network interface **200** includes one or more 1 Gb/s MAC(S), which are selectively engaged to 1 Gb/s establish up to a sub-10 Gb/s data channel with a remote network device. In accordance with one example Implementation, the sub-10 Gb/s data channel is a virtual channel established within the 10 Gb/s bandwidth of an 802.3ae communication link. In accordance with one example implementation, the sub-10 Gb/s data channel is established over a sub-10 Gb/s communication link (e.g., a conventional 1 Gb/s Ethernet link). As shown, each of the 1 Gb MACs **206** depicted are dual, 1 Gb/s MACs, each with an input and an output. As used herein, such MAC(S) perform packetization and encoding functions to generate 802.3 compliant data-

grams for transmission to the receiving network device. In accordance with another example implementation, described more fully below, an enhancement is made to a conventional 802.3ae MAC **106** that enables the 802.3ae MAC to establish a sub-10 Gb/s data channel over a 10 Gb/s communication link. As will be developed more fully below, in accordance with this example implementation, the enhanced 802.3ae MAC (or, as referred to herein, an enhanced 10 G MAC (EXMAC)) selectively invokes a timeslicing mechanism (not particularly denoted) to establish a sub-10 Gb/s data channel (virtual channel) within the 10 Gb/s signaling channel. In accordance with one example aspect of this implementation of the present invention, the number of timeslots EXMAC invokes is based, at least in part, on the communication capability of the remote network device. According to one example implementation, EXMAC selectively parses the channel into ten (10) timeslots, each roughly approximating a 1 Gb/s data channel. EXMAC may utilize several of such timeslots to generate higher bandwidth data channel(s), or may well parse the 10 Gb/s bandwidth into more timeslots to effect lower bandwidth channel(s). According to one implementation, EXMAC receives 10 G data and parses the 10 G data in up to ten (10) 1 Gb/s virtual channels for delivery to communicatively coupled sub-10 Gb Ethernet interface(s).

In addition to that which is disclosed above, one or more of the 802.3ae MAC **106** or the 1 Gb/s MAC(s) **206** may be further enhanced with a rate pacing feature, in accordance with another aspect of the present invention. As will be developed more fully below, the rate pacing feature is selectively employed to lower the effective data channel rate within the 10 Gb/s signaling channel. According to one example implementation of the rate pacing feature (i.e., employed in conjunction with either the 10 Gb/s MAC or the 1 Gb/s MAC), the MAC selectively injects "idle" control indications between successive frames of content. In this regard, the one or more successive idle control elements separating the frames effectively reduces the rate of the data channel, e.g., to a rate that is acceptable to a receiving network element. Those skilled in the art will appreciate that a combination of the link channelization and the rate pacing elements of the present invention enables the innovative interface **200** to dynamically establish a data channel scaled to satisfy the communication capability of legacy network devices.

As introduced above, the 10 Gb/s attachment unit interface (XAUI) is comprised of four (4) full-duplex XAUI channels. As introduced above, each of the XAUI channels performs 8b/10b encoding to provide a 2.5 Gb/s data channel at a signaling rate of 3.125 Gb/s. In accordance with conventional implementations, the four lanes generated by the disparate channel(s) are aggregated to provide the 10

Gb/s data channel over a 12.5 Gb/s signaling rate. In accordance with one example implementation of the present invention, if the interface **200** is endowed with the 1 Gb/s MAC(s) **206**, the multiplexer encoder/decoder module **208** selectively routes content to/from individual XAUI channels. According to one example implementation, two 1 Gb/s MAC(s) **206** are paired with a single XAUI channel, where each of the MAC(s) **206** can consume up to 1 Gb/s each of the 2.5 Gb/s channel bandwidth provided by each XAUI channel. If the 802.3ae MAC is selected (e.g., by switch **204**), then all four channels are employed in support of the bandwidth requirements of the 802.3ae MAC **106**. If one or more 1 Gb/s MAC(s) are selected (e.g., by switch **204**), then one or more associated XAUI channels are employed in support of the bandwidth.

As introduced above, the multiplexer encoder/decoder module **208** selectively couples the XAUI interface **110** with one or more media access controller(s) (e.g., **106** and/or **206**). In addition, module **208** employs the encoding/decoding features of conventional 802.3ae compliant encoder/decoder modules.

With continued reference to FIG. 2, in addition to the 10 Gb/s physical media interface of a conventional 802.3ae compliant interface (e.g., interface **100**), the scalable network interface **200** may well include one or more physical media interface(s) **210**. In accordance with one example implementation, the innovative scalable network interface **200** includes one or more 1 Gb/s physical media interface(s) **210**, at least a subset of which are endowed with the same XAUI-channelization logic (not particularly denoted) on one and/or each end of the XAUI link, i.e. the PMI side, as well as the MAC side. This "logic" takes care of the mapping of 1 G channels onto XAUI and then back off XAUI and then sends them to the 1 G logic which would send data out onto individual 1 G channels. According to one example implementation, interface **200** comprises eight (8) 1 Gb/s physical media interface(s).

Those skilled in the art will appreciate, given the foregoing, that scalable network interface **200** enables an 802.3ae compliant network interface to interact and communicate with legacy equipment that conventional interface(s) do not provide. In this regard, the innovative interface provides a heretofore unavailable migration path from legacy Ethernet implementations to the exciting 10 Gb/s Ethernet architecture.

FIG. 3 illustrates a block diagram of an example architecture for implementing the teachings of the present invention, in accordance with but one example embodiment of the present invention. In accordance with the illustrated example of FIG. 3, a number of 1 Gb/s MAC(s) **206** are coupled through a control element **302** to a multiplexer encoder/decoder module **208**, which selectively applies content to/from one or more MAC(s) **106** and/or **206** to an appropriate one or more XAUI channels of XAUI interface **110**. Although depicted as a separate functional element, those skilled in the art will appreciate that control element **302** may well be embodied as a control input into the data stream from a 1 Gb/s MAC **206** to the encoder/decoder module **208**. As shown, control element **302** includes an Idle feature to facilitate selective invocation of the rate-pacing features introduced above.

In accordance with the illustrated example implementation, multiplexer **308** effectively selects either an 802.3ae compliant MAC **106** or one or more 1 Gb/s MAC(s) to implement the dynamic channelization features of the present invention. If a sub-10 Gb/s data channel is required, one or more 1 Gb/s MAC(s) **206** are employed and selec-

tively switched to encoder/decoder **108** using one or more multiplexing elements **304** through **306**. In such an implementation, the one or more 1 Gb/s MAC(s) are selectively applied to one or more XAUI channels of XAUI interface **110**, which establishes a virtual data channel within the physical 10 Gb/s data channel.

EXAMPLE IMPLEMENTATION AND OPERATION

Having introduced the operational and architectural elements of the present invention with reference to FIGS. **2** and **3**, above, reference is next directed to FIGS. **4-8**, wherein certain aspects of the present invention are developed in greater detail. For ease of explanation, the dynamic channelization features of the present invention will be developed in the context of preparing content for transmission to a remote network element. It will be appreciated by those skilled in the art, however, that the dynamic channelization features of the present invention are similarly invoked to enable the scalable network interface **200** to receive content from lower bandwidth, legacy network devices.

FIG. **4** is a flow chart of an example method of implementing a scalable network interface in accordance with the teachings of the present invention. In accordance with the illustrated example implementation of FIG. **4**, the method begins in block **402** wherein network interface **200** identifies the communication capability of a remote network element. As introduced above, network interface **200** includes control logic **202**, which selectively implements features to identify the communication capability of a remote network element. In accordance with one example implementation, control logic **202** communicates with the remote device to identify an acceptable communication rate. Alternatively, control logic **202** may well receive broadcast messages from the remote device advertising its communication capability.

In block **404**, network interface **200** selects an appropriate media access controller(s) **106** and/or **206**, and/or MAC attribute(s) to enable communication with the remote network device. In accordance with the teachings of the present invention, control logic **202** identifies the communication capability of the remote network device and, if the remote network device supports the 10 Gb/s data channel of the 802.3ae MAC, the 802.3ae MAC **106** is selected. If not, network interface **200** selectively invokes the dynamic channelization features of the present invention to facilitate communication with the legacy network device. A flow chart of an example method for implementing the dynamic channelization aspects of the present invention is detailed more fully below, with reference to FIG. **5**.

In block **406**, network interface **200** selectively inserts control and/or alignment features, as necessary, in support of the selected MAC interface(s) **106** and/or **206**. That is, network interface **200** provides for the interjection of control elements as well as alignment elements to facilitate communication over any of a number of data channel rates. The alignment content is introduced when multiple lanes are used to realize a desired data channel. In accordance with one example implementation, such alignment content is not required until the data channel implemented by network interface **200** exceeds 2 Gb/s, i.e., exceeds a single XAUI channel. As will be developed more fully below, such alignment features may well be introduced at the XAUI channel processing phase.

In accordance with one aspect of the present invention, network interface **200** may well implement rate-pacing features, wherein the effective data channel is further

reduced by introducing "idle" control elements in between successive packet(s) of substantive content. An example method for implementing the rate-pacing features of the present invention is presented more fully with reference to FIG. **7**.

In block **408**, the content is delivered to multiplexer encoder/decoder module **208**, wherein the content is encoded for transmission to the remote device. As introduced above, according to one example implementation, MUX encoder/decoder module **208** selects one or more lanes of the XAUI interface **110**, and encodes the content bound for the one or more XAUI channels. According to one example implementation, the number of XAUI channels selected is based, at least in part, on the bandwidth required of the virtual data channel to be established within the 10 Gb/s data channel.

In block **410**, the encoded content is selectively passed to one or more channels of the XAUI interface **110** to combine the encoded content from one or more MAC(s), as necessary, to facilitate communication with the identified network element. To facilitate a 10 Gb/s channel, mux encoder/decoder module **208** routes content from 10 Gb/s MAC through encoder **108** to each of the four XAUI channels of the XAUI interface **110**. To facilitate sub-10 Gb/s channel, mux encoder/decoder **208** selectively routes content from one or more 1 Gb/s MAC(s) through the encoder/decoder **108** to one or more XAUI channel(s) of XAUI interface **110**. In this regard, network interface **200** provides a flexible, scalable alternative to conventional 802.3ae network interfaces, providing a means through which an 802.3ae compliant network interface can facilitate communications with legacy devices.

Turning to FIG. **5**, a flow chart of an example method for dynamic link channelization, in accordance with one aspect of the present invention is presented. In accordance with the illustrated example implementation of FIG. **5**, the method of block **406** begins with block **502** wherein a determination is made of whether the remote network device will support a 10 Gb/s data channel. As introduced above, this determination is made by control logic **202** implementing any of a number of auto-negotiation features.

If the remote network device does, in fact, support 802.3ae compliant communication, content received from the host device is passed through a 10 Gb/s MAC **106** of the network interface in block **504**.

In block **506**, the content is encoded and multiplexed to multiple XAUI channels for transmission over the aggregated 10 Gb/s communication link. In accordance with the illustrated example implementation of FIG. **2**, the content is passed from the 10 G MAC **106** to the mux encoder/decoder module **208**, which encodes the content and parses it to the four (4) XAUI channels of XAUI interface **110**. In this regard, scalable network interface **200** is intended to represent the functionality of conventional 802.3ae compliant network interfaces.

Where the scalable network interface **200** deviates from conventional operation, however, is in its support of lower data channel rates. In this regard, if in block **502** the control logic detects that the remote network device does not support a 10 Gb/s data channel, a further determination is made of whether the network interface **200** is endowed with 1 Gb/s MAC(s) **206**, block **508**. If so, one or more of the 1 Gb/s MAC(s) **206** are dynamically selected to process content, block **510**. Such content is encoded and selectively multiplexed to one or more XAUI channel(s), as necessary, to support the sub-10 Gb/s data channel, as introduced above.

If, in block **508**, network interface **200** is not endowed with the 1 Gb/s MAC(s) **206** an otherwise conventional 802.3ae MAC may well be enhanced with timeslicing features to support establishment of a reduced-rate data channel within the 10 Gb/s channel, facilitating communication with legacy network devices. In this regard, the process continues with block **512**, where the enhanced 10 Gb/s MAC (the EXMAC, introduced above) parses the 10 Gb/s bandwidth into multiple timeslots. According to one example implementation, the number of timeslots generated is predetermined. In an alternate implementation, the EXMAC dynamically calculates the number of timeslots necessary to effect the reduced-rate data channel acceptable to the remote network device. If, for example, a 1 Gb/s data channel is supported by the remote network device, EXMAC selectively invokes timeslicing features and parses the 10 Gb/s bandwidth into ten (10) discrete timeslots, populating one of such timeslots with substantive content of the data channel.

In block **514**, EXMAC assigns a communication session with the network elements to particular timeslot(s), denoted by address information associated with at least the remote network element. According to one example implementation, the remaining timeslots are left empty. In alternate implementation, the remaining timeslots are stuffed with one or more of, e.g., control data, junk data denoting unused timeslots, etc.

In this regard, alternate methods of implementing the dynamic channelization features of the present invention have been described. As introduced above, however, additional modifications to the effective bandwidth of such virtual channels may be realized with selective invocation of the rate pacing aspect of the present invention. An example method of implementing rate pacing is presented with reference to FIG. 6, below.

FIG. 6 is a flow chart of an example method for rate pacing within a network channel, in accordance with one aspect of the present invention. In accordance with the illustrated example implementation of FIG. 6, the method begins with block **602** wherein control logic **202** determines whether additional rate pacing is required. In this regard, control logic **202** through, e.g., the auto-negotiation features determines that the remote network device is well-suited to communicate at a non-standard data rate.

As introduced above, a MAC (e.g., **106**, **206**) enhanced to include the rate pacing aspect of the present invention will "stuff" idle control elements (packets, frames, etc.) into a data stream between substantive frames (i.e., those frames carrying content associated with the actual communication between the elements), as necessary, to reduce the effective data rate of the communication link. Accordingly, in block **606** the enhanced MAC of substantive frames computes the number of idle control elements that are to be inserted between substantive frames to effect the desired data rate. This aspect of the present invention is graphically illustrated with reference to FIG. 7.

Turning briefly to FIG. 7, a graphical representation of the rate pacing element of the present invention is presented, in accordance with one aspect of the present invention. As introduced above, the rate pacing aspect of the present invention is implemented, e.g., within an enhanced MAC, which selectively inserts idle control datagrams in between consecutive datagrams comprising substantive content. More particularly, FIG. 7 denotes a series of datagrams (e.g., packets, frames, etc.) **700** wherein a first datagram **N 702** populated with substantive data associated with the communication session between the network devices is separated from a subsequent datagram **N+1 706** by one or more

intervening datagrams **704A . . . N** comprising idle control elements. The number of intervening idle control elements **704A . . . N** effectively slows that rate at which substantive datagrams **702**, **706**, etc. are received, thereby reducing the effective data rate of the communication channel below that otherwise provided by the MAC (e.g., 10 Gb/s, 1 Gb/s, etc.). In this regard, a MAC enhanced with the rate pacing aspect of the present invention may well support any standard or non-standard data rate requested by a remote network element.

Returning to block **608** in FIG. 6, the MAC selectively inserts the computed number of idle elements between substantive frames to effect the desired communication rate.

In accordance with network requirements, the process continues with block **610** wherein additional control/alignment control elements are introduced into the data stream, as necessary, as the process continues with block **408**.

EXAMPLE NETWORK IMPLEMENTATION(S)

Having introduced various innovative aspects of the present invention, above, a number of alternate network implementations of the innovative scalable network interface **200** are presented with reference to FIG. 8. In this regard, FIG. 8 illustrates block diagram(s) of example network implementations depicting the flexibility enabled by the scalable network interface, in accordance with the teachings of the present invention.

With reference to example implementation **800**, a computing device/network element **802** is endowed with the scalable network interface **200** incorporating one or more of the dynamic channelization and/or rate pacing aspects of the present invention. As shown, computing device/network element **802** is coupled to a remote computing device/network element **804** comprising a conventional 802.3ae compliant network interface **100** through a communication link **806**. As used herein, computing device/network elements **802**, **804** are intended to represent such computing appliances and/or network elements commonly known in the art including, but not limited to, a computer system, a server system, a network switch, a network hub, etc.

In accordance with the teachings of the present invention, scalable network interface **200** employs auto-negotiation feature(s) to identify the communication capability of remote network element **804**. In so doing, scalable network interface **200** identifies conventional network interface **100** as being 802.3ae compliant, capable of up to a 10 Gb/s data channel over communication link **806**. However, although endowed with an 802.3ae compliant network interface, computing device/network element **804** may not be able to consume data at such a rate. Accordingly, scalable network interface **200** selectively invokes the dynamic channelization and/or rate pacing features of the present invention to facilitate the processing capability of the remote network element **804**.

In network implementation **820**, computing device/network element **802** is communicatively coupled with computing device/network element **822** including a legacy network interface **824** via communication link **826**. As used herein, legacy network interface is intended to represent any of a wide variety of legacy Ethernet network interface(s) such as, for example, a 10 Mb/S interface, a 100 Mb/S interface and/or a 1 Gb/s interface.

In accordance with the teachings of the present invention, introduced above, scalable network interface **200** employs auto-negotiation feature(s) to identify the communication capability of remote network element **822**. In so doing,

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scalable network interface **200** identifies the communication capability of the legacy network interface **824** and selectively invokes one or more of dynamic channelization and/or rate pacing to establish a communication link **826** suited to the capability of the remote network device **822**. In this regard, implementation **820** graphically depicts the ability of scalable network interface **200** to establish a communication link with legacy devices.

Turning to network implementation **830**, a computing device/network element **802** is communicatively coupled to another computing device/network element **832** similarly endowed with a scalable network interface **200** via communication link **836**. In this regard, the scalable network interface(s) **200** invoke the auto-negotiation features introduced above to agree on an acceptable data rate for the communication link **836**. According to one implementation, introduced above, although the scalable network interface supports 10 Gb/s data rates, the host computing device/network element **832** may not. Accordingly, the scalable network interface(s) **200** agree, through auto-negotiation, on a virtual channel size that is suited to the processing and/or internal bus speeds of the host device(s) **802**, **832**, respectively.

ALTERNATE EMBODIMENT(S)

FIG. 9 is a block diagram of an example storage medium comprising a plurality of executable instructions which, when executed, cause an accessing machine to implement one or more aspects of the innovative scalable network interface **200** of the present invention, in accordance with an alternate embodiment of the present invention.

In the description above, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that the present invention may be practiced without some of these specific details. In other instances, well-known structures and devices are shown in block diagram form.

The present invention includes various steps. The steps of the present invention may be performed by hardware components, such as those shown in FIG. 2 or 3, or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor or logic circuits programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software. Moreover, although the invention has been described in the context of a network interface device, those skilled in the art will appreciate that such functionality may well be embodied in any of number of alternate embodiments such as, for example, integrated within a computing device, and is readily adaptable to wireless Ethernet implementations as well as the wired environment described herein.

The present invention may be provided as a computer program product which may include a machine-readable medium having stored thereon instructions which may be used to program a computer (or other electronic devices) to perform a process according to the present invention. The machine-readable medium may include, but is not limited to, floppy diskettes, optical disks, CD-ROMs, and magneto-optical disks, ROMs, RAMs, EPROMs, EEPROMs, magnet or optical cards, flash memory, or other type of media/machine-readable medium suitable for storing electronic instructions. Moreover, the present invention may also be downloaded as a computer program product, wherein the program may be transferred from a remote computer to a

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requesting computer by way of data signals embodied in a carrier wave or other propagation medium via a communication link (e.g., a modem or network connection).

Many of the methods are described in their most basic form but steps can be added to or deleted from any of the methods and information can be added or subtracted from any of the described messages without departing from the basic scope of the present invention. It will be apparent to those skilled in the art that many further modifications and adaptations can be made. The particular embodiments are not provided to limit the invention but to illustrate it. The scope of the present invention is not to be determined by the specific examples provided above but only by the claims below.

What is claimed is:

1. A method comprising:

identifying a processing capability of a remote device;
selecting at least one of a plurality of media access controllers (MACs) to use for a communication channel with the remote device, wherein at least two of the plurality of MACs are capable of transmission at different maximum rates; and
slowing an effective data rate within the communication channel with the remote device based at least in part on the processing capability of the remote device, wherein slowing the effective data rate comprises:
computing a ratio of processing capability of the remote device to a data rate of the communication channel; and
selectively inserting a number of frames of idle control elements between at least one frame of substantive content based, at least in part, based on the computed ratio.

2. A method according to claim 1, wherein identifying the processing capability of the remote device comprises:

sending a capability request; and
receiving a response to the request denoting at least the processing capability of the remote device.

3. A method according to claim 1, wherein identifying the processing capability of the remote device comprises:

receiving an indication from the remote device denoting at least the processing capability of the remote device.

4. A method according to claim 3, wherein the indication also denotes a communication capability of the remote device.

5. A method according to claim 1, further comprising:

establishing at least one virtual channel for the communication channel, each virtual channel having a data rate less than that of a maximum transmission rate of the selected at least one MAC and wherein the data rate of each virtual channel is based, at least in part, on the identified processing capability of the remote device.

6. A method according to claim 1, wherein at least the processing capability of the remote device is obtained through auto-negotiation.

7. A method according to claim 1, wherein the number of frames inserted reduces a rate at which substantive frames are received by the remote device to a level commensurate with the processing capability of the remote device.

8. An apparatus comprising:

control logic to identify a processing capability of a remote network device;

a plurality of media access controllers (MACs), responsive to the control logic, wherein each MAC is capable of use for a communication channel with the remote

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network device and wherein at least two of the plurality of MACs are capable of transmission at different maximum rates;

logic to select at least one of the plurality of MACs to use for the communication channel with the remote network device; and

logic to selectively reduce an effective data rate of the communication channel with the remote network device based, at least in part, on the identified processing capability of the remote network device, wherein to reduce the effective data rate, the logic to selectively reduce is to:

compute a ratio of processing capability of the remote device to a data rate of the communication channel; and

selectively insert a number of frames of idle control elements between at least one frame of substantive content based, at least in part, based on the computed ratio.

9. An apparatus according to claim 8, wherein the control logic sends a capability request to the remote device and receives a response to the request denoting at least the processing capability of the remote device.

10. An apparatus according to claim 8, wherein the control logic receives a broadcast indication from the remote device denoting at least the processing capability of the remote device.

11. A computer-readable storage medium comprising content which, when executed by an accessing computing device, causes the device to implement a scalable network interface to identify a processing capability of a remote network device, to select at least one of a plurality of media access controllers (MACs) to use for a communication channel with the remote network device, wherein at least two of the plurality of MACs are capable of transmission at different maximum rates, and to selectively reduce an effective data rate of a communication channel between the accessing computing device and the remote network device based, at least in part, on the processing capability of the remote network device, wherein to reduce the effective data rate, the scalable network interface is to: compute a ratio of processing capability of the remote device to a data rate of the communication channel and selectively insert a number of frames of idle control elements between at least one frame of substantive content based, at least in part, based on the computed ratio.

12. The method of claim 1, wherein the communication channel comprises an Ethernet compatible communications channel.

13. An apparatus of claim 8, wherein the communication channel comprises an Ethernet compatible communications channel.

14. An apparatus comprising:

control logic to identify a processing capability of a remote network device;

a media access controller (MAC), responsive to the control logic, to selectively reduce an effective data rate of a communication channel with the remote network device based, at least in part, on the identified processing capability of the remote network device; and

a plurality of MACs, wherein the plurality of MACs includes the MAC and a second MAC, wherein at least two of the MACs are capable of transmission to the remote network device at different maximum rates, wherein the control logic is to:

select a MAC for use in a communication channel with the remote network device based in part on the

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processing capability of the remote network device being approximately equal to the transmission rate of the selected MAC; and

if the selected MAC having a transmission rate approximately equal to the processing capability of the remote network device is not available, selecting a MAC having a transmission rate higher than the processing capability of the remote network device and providing a virtual channel within the transmission capabilities of the higher transmission rate MAC to provide the communication channel with the remote network device based at least in part on the processing capability.

15. A system comprising:

first and second network elements capable of intercommunicating, wherein the second network element comprises:

logic to identify receiving rate capability of the first network element;

a plurality of media access controllers (MACs), responsive to the logic to identify receiving rate capability of the first network element, wherein at least two of the plurality of MACs are capable of transmission at different maximum rates;

logic to select at least one of the plurality of MACs to use for a communication channel with the first network element; and

logic to selectively reduce a data rate within the communication channel with the first network element based, at least in part, on the identified processing capability of the first network element, wherein the logic to selectively reduce a data rate is to compute a ratio of processing capability of the first network element to a data rate of the communication channel and selectively insert a number of frames of idle control elements between at least one frame of substantive content based, at least in part, based on the computed ratio.

16. The system of claim 15, wherein the first network element includes a media access controller.

17. The system of claim 15, wherein the first network element includes a media access controller capable of processing transmissions at a speed less than that which the second network element is capable of transmitting.

18. The system of claim 15, wherein the first and second network elements apply auto-negotiation to determine an acceptable transmission rate for the communication session.

19. An apparatus comprising:

control logic to identify a processing capability of a remote network device; and

a media access controller (MAC), responsive to the control logic, to selectively reduce an effective data rate of a communication channel with the remote network device based, at least in part, on the identified processing capability of the remote network device;

a plurality of MACs, wherein the plurality of MACs includes the MAC and at least one other MAC, wherein at least two of the plurality of MACs are capable of transmitting to the remote network device at different maximum rates, wherein the control logic is to:

select at least one of the plurality of MACs for use in a communication channel with the remote network device, wherein a combined transmission rate of the selected at least one of the plurality of MACs is approximately equal to a receiving capability of the remote network device; and

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select one of the plurality of MACs for use in a communication channel with the remote network device, wherein the selected one of the plurality of MACs is capable of a transmission rate higher than the receiving capability of the remote network device and wherein the selected one of the plurality of MACs provides a virtual channel to provide the communication channel with the remote network device.

20. The apparatus of claim 19, further comprising a 10 Gb/s attachment unit interface (XAUI) communicatively coupled to at least one of the plurality of MACs.

21. The apparatus of claim 20, wherein the XAUI comprises multiple channels and wherein each of the plurality of MACs is capable to transmit over at least one of the multiple channels.

22. The apparatus of claim 21, further comprising logic to selectively inject alignment elements in response to more than one of the multiple channels being used to receive frames from at least one of the plurality of MACs.

23. The apparatus of claim 19, wherein the control logic sends a capability request to the remote device and receives a response to the request denoting at least the processing capability of the remote device.

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24. The apparatus of claim 19, wherein the control logic receives a broadcast indication from the remote device denoting at least the processing capability of the remote device.

25. The apparatus of claim 19, wherein the communication channel comprises an Ethernet compatible communications channel.

26. The apparatus of claim 19, wherein at least one MAC that is to transmit is to selectively insert at least one idle control element between at least one frame of substantive content associated with a communication with the remote device to reduce the effective data rate of the communication channel.

27. The apparatus of claim 19, wherein to reduce the effective data rate, at least one MAC is to:

compute a ratio of processing capability of the remote device to a data rate of the communication channel; and selectively insert a number of frames of idle control elements between at least one frame of substantive content based, at least in part, based on the computed ratio.

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