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(54) **TRANSMITTING DIGITAL VIDEO AND DATA OVER THE SAME WIRES**

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(52) **U.S. Cl.**

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(58) **Field of Classification Search**

None

See application file for complete search history.

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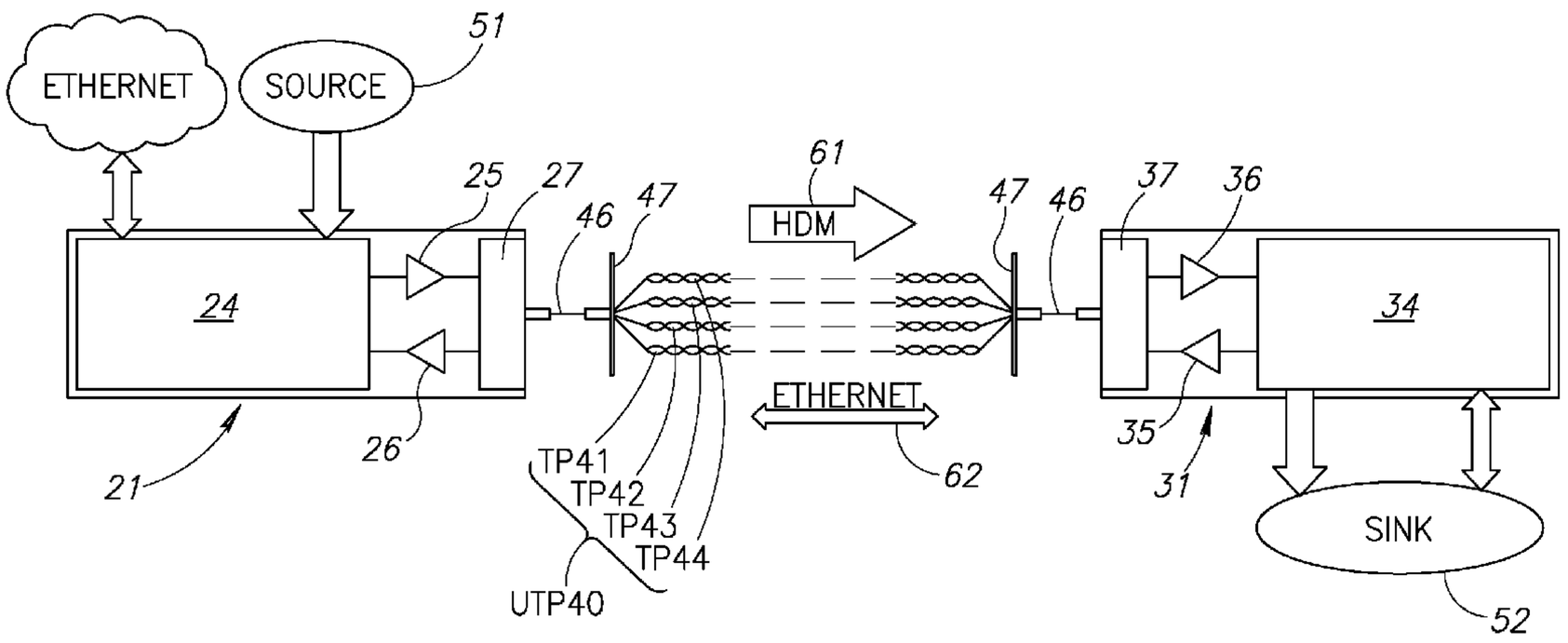
Primary Examiner — Donald Mills

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(57) **ABSTRACT**

A communication device configured to transmit and receive simultaneously, over the same wire, unidirectional high definition video and bidirectional data. The communication device includes a hybrid circuit coupled to a cable made of wires, and a transceiver. The transceiver is configured to transmit, over one of the cable's wires, Transition Minimized Differential Signaling (TMDS) data and source-to-sink direction of bidirectional data. The transceiver is further configured to receive the opposite direction of the bidirectional data over the same wire and simultaneously with the transmitting.

20 Claims, 4 Drawing Sheets



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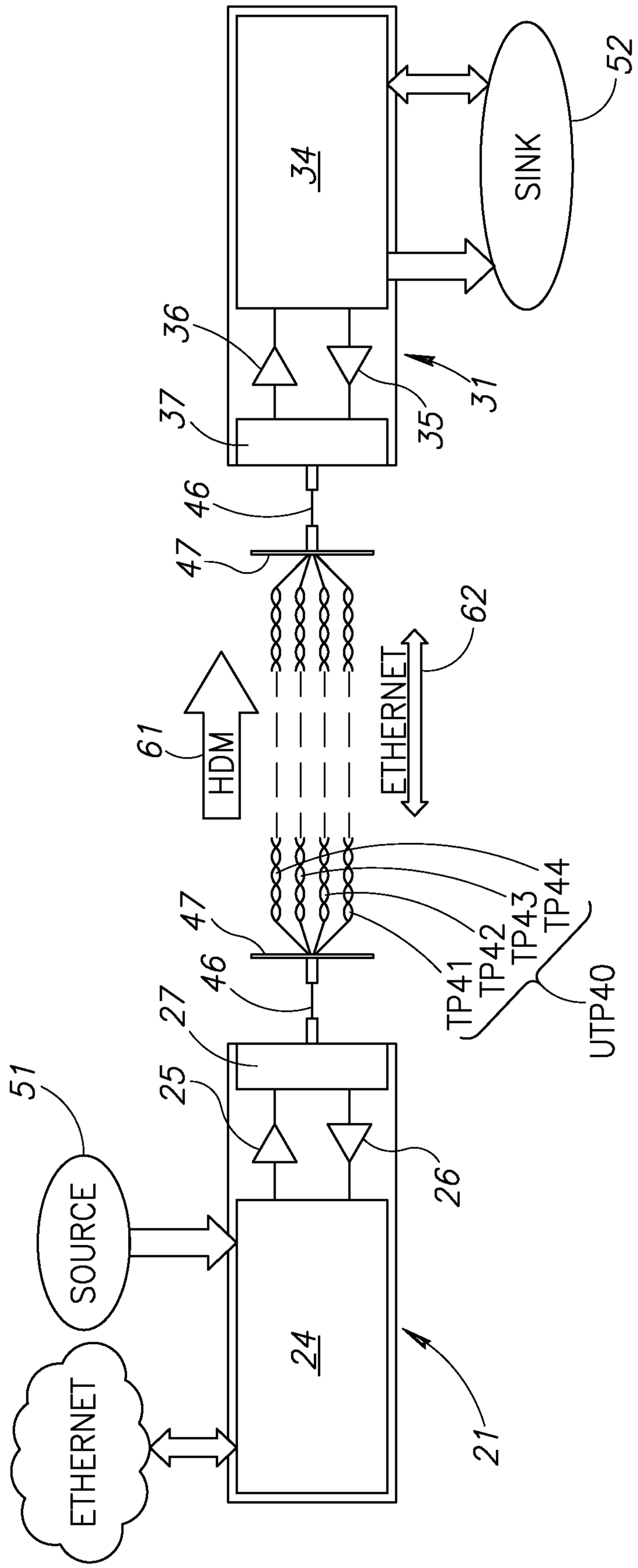

34
SINK
52
36
37
35
31
46
47
61
HDM
ETHERNET
62
47
46
27
TP41
TP42
TP43
TP44
UTP40
51
SOURCE
25
26
ETHERNET
24
21

FIG.1A

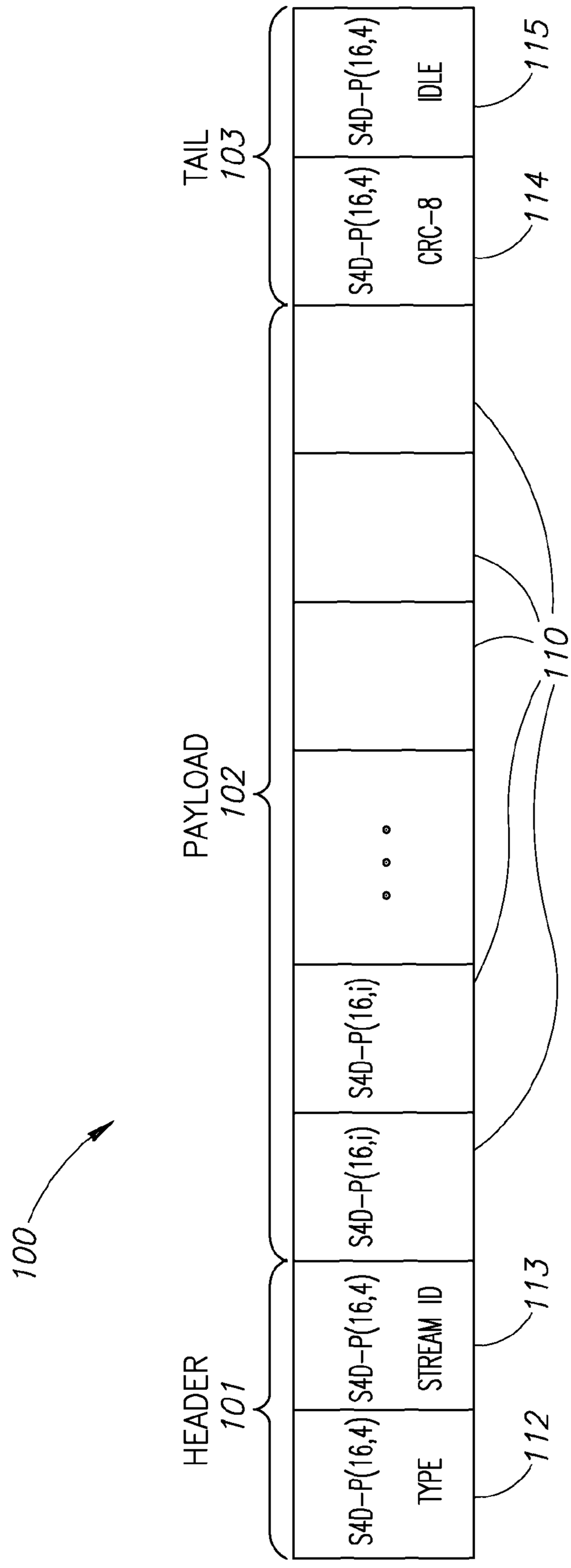

100
HEADER
101
TYPE
S4D–P(16,4)
112
S4D–P(16,4)
STREAM ID
113
S4D–P(16,i)
PAYLOAD
102
S4D–P(16,i)
110
TAIL
103
S4D–P(16,4)
CRC–8
114
S4D–P(16,4)
IDLE
115

FIG.1B

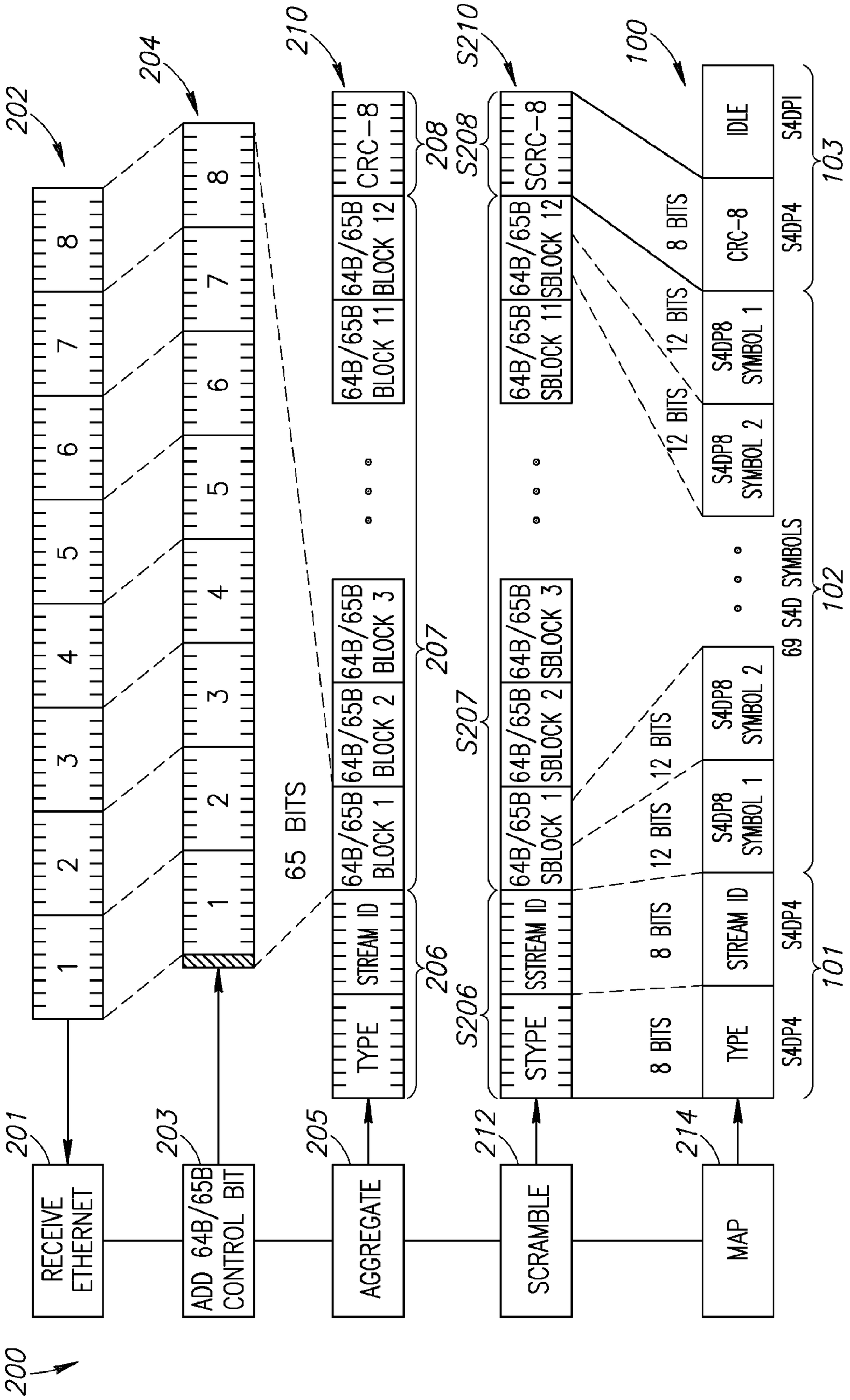

200
201
RECEIVE ETHERNET
202
203
ADD 64B/65B CONTROL BIT
204
205
AGGREGATE
206
207
208
210
212
214
S206
S207
S208
S210
100
101
102
103
1
2
3
4
5
6
7
8
65 BITS
STREAM ID
64B/65B BLOCK 1
64B/65B BLOCK 2
64B/65B BLOCK 3
64B/65B BLOCK 11
64B/65B BLOCK 12
CRC-8
TYPE
SSTREAM ID
64B/65B SBLOCK 1
64B/65B SBLOCK 2
64B/65B SBLOCK 3
64B/65B SBLOCK 11
64B/65B SBLOCK 12
SCRC-8
STYPE
8 BITS
12 BITS
S4DP8 SYMBOL 1
S4DP8 SYMBOL 2
S4DP4
69 S4D SYMBOLS
IDLE
S4DPI
SCRAMBLE
MAP

FIG.2

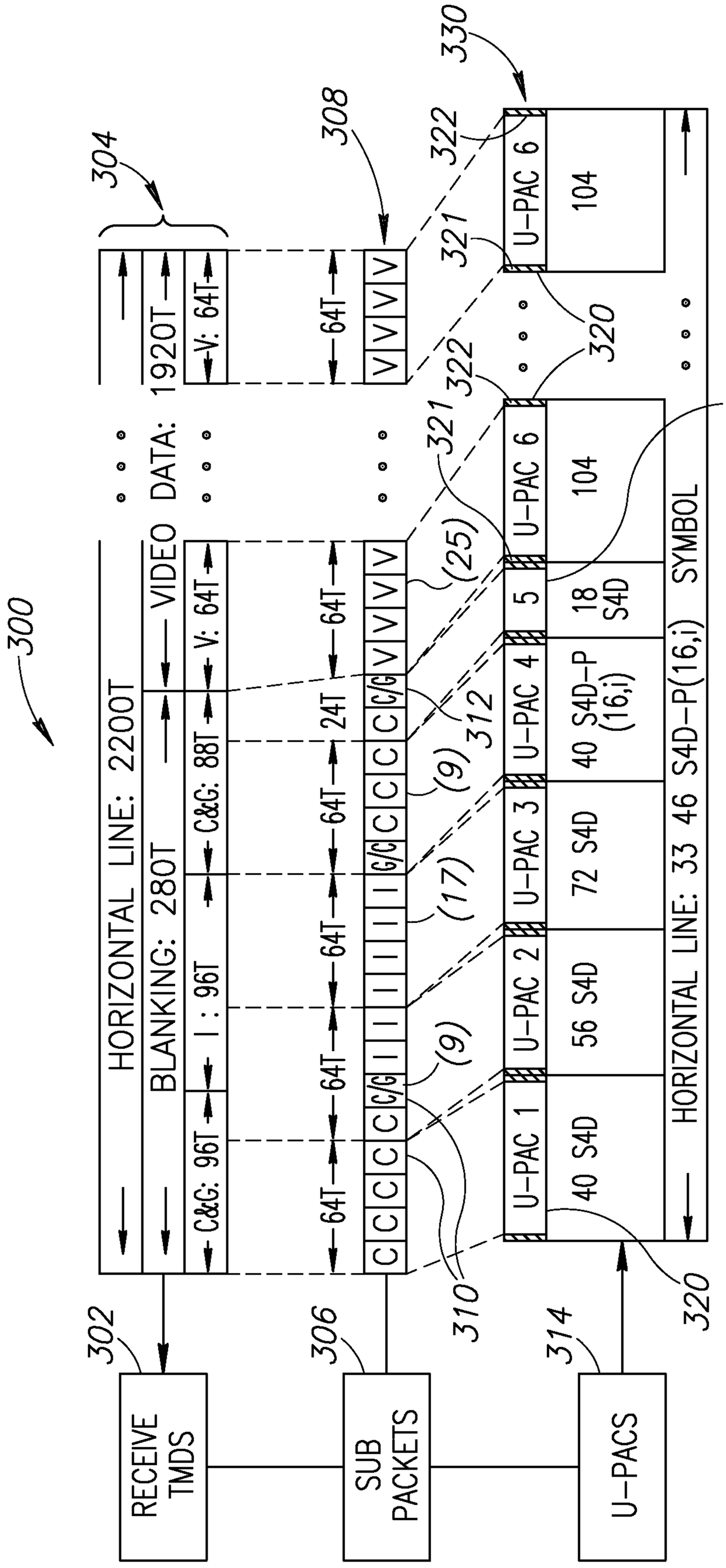

300
HORIZONTAL LINE: 2200T
BLANKING: 280T
VIDEO DATA: 1920T
304
308
330
322
321
320
324
312
310
314
302
306
V: 64T
C&G: 88T
C&G: 96T
I : 96T
64T
24T
(9)
(17)
(25)
U-PAC 1
U-PAC 2
U-PAC 3
U-PAC 4
U-PAC 5
U-PAC 6
56 S4D
72 S4D
40 S4D-P (16,i)
18 S4D
104
HORIZONTAL LINE: 33 46 S4D-P(16,i) SYMBOL
RECEIVE TMDS
SUB PACKETS
U-PACS

FIG.3

TRANSMITTING DIGITAL VIDEO AND DATA OVER THE SAME WIRES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of U.S. Ser. No. 13/936,191, filed on Jul. 7, 2013, and allowed on Mar. 31, 2014; Ser. No. 13/936,191 is a Continuation of U.S. Ser. No. 12/348,309, filed on Jan. 4, 2009, and published as U.S. Pat. No. 8,503,489 on Aug. 6, 2013; U.S. Ser. No. 12/348,309 is a Continuation of U.S. Ser. No. 11/703,080, filed on Feb. 7, 2007, and published as U.S. Pat. No. 8,565,337 on Oct. 22, 2013.

BACKGROUND

Today's work and play environments in the home and/or office are replete with numerous and various devices and appliances, hereinafter referred to generically as appliances, such as home entertainment systems, play stations, computers and surveillance equipment that people use for entertainment and work. The appliances actively interface and communicate with their users via video and/or audio displays to provide entertainment and/or to present information that they generate or receive. Behind the communication interface with human users, the appliances carry on a continuous chatter of digital communication among themselves, sending and receiving control, information and entertainment data that enable them to maintain the data processing and presentations they provide to the users.

Various digital communication systems and networks supported by different physical infrastructures and standards for their operation have been developed to provide the communication needs and demands of the appliances and the users who use them. The physical infrastructures may comprise coaxial cables, twisted pair cables, phone lines, and/or power lines and/or may comprise wireless communication channels. However, new appliances and configurations of appliances are constantly offering users new features and services that generally require digital communication networks having increased bandwidth. The continual flow of new features and services and demand for increased bandwidth have generated a "patch work" of different communication systems and networks and standards for managing the systems and networks aimed at satisfying the demand.

For example, the development of flat panel LCD digital displays stimulated the development of digital video interfacing (DVI) utilizing Transition Minimized Differential Signaling (TMDS) technology for high-speed transmission of uncompressed serial digital data. Different communication standards defining communication systems incorporating add on features and improvements for transmitting high definition multimedia content such as high definition video, digital music, digital photos and DVD entertainment from a Source of such content, e.g. a DVD or Set Top Box (STB), to a Sink of the content, such as a TV, material followed. Among the standards are High Definition Multimedia Interface (HDMI), Unified Display Interface (UDI) and DisplayPort.

Whereas the various multimedia communication standards and systems provide relatively high data transfer rates, they are generally configured to provide simplex data transmission of multimedia content at relatively high bit error rates (BER) from a Source of multimedia content to a Sink of the content over relatively short distances. The standards and systems generally require special dedicated connectors and cable assemblies and their transmission is generally limited to a

reach of less than about 15 meters. Duplex and half duplex transmission of control data between a Source and a Sink that the standards require is performed at relatively low bandwidth of up to 1 Mbps and is generally supported by a dedicated channel separate from the channel over which the simplex multimedia data is transmitted.

The noted multimedia standards and systems do not support high quality relatively low BER full duplex data transmission that is generally required by communication networks that support information exchange between various appliances, e.g. various computer platforms, in a household or office environment. For example, uncompressed high definition video may be streamed from Source to Sink by these systems at data rates of about a gigabit per second (Gbps) for each of the red green and blue (RGB) color channels used to provide video. At these rates, substantial noise and in particular echo and near end cross talk (NEXT) may be generated that interferes with data transmission and to provide information exchange at an acceptable BER, the exchanged information must generally be protected by a relatively large coding overhead of redundant bits. The increased overhead substantially increases complexity of coding and decoding software and hardware required to process the information and thereby the cost of the systems if they are configured to support full duplex communication.

Full duplex information exchange between appliances at the home and office that are characterized by relatively low BER are typically provided by networks such Ethernet 100 Base-T, WIFI, MOCA HOMEPNA or HOMEPLUG AV. The various Ethernet networks provide duplex information exchange over twisted pair wires at bandwidths that correspond to ratings of the twisted pairs. WIFI provides information exchange over wireless channels. MOCA provides communication over coaxial cable. HOMEPNA and HOMEPLUG AV support in-home networking over copper phone lines and power lines respectively that exist in the home.

The various information exchange networks do not in general provide sufficient bandwidth to support transmission of uncompressed multimedia content, which typically requires data transmission rates of about 1 Gbps for each of the R, G and B color channels of a video display. A latest Ethernet standard 10 Gbase-T, while having sufficient bandwidth for supporting transmission of uncompressed high definition multimedia content, is not configured to do so. It does not provide multimedia clock regeneration or support for Hot Plug Detection (HPD), Consumer Electronics Control (CEC) or Display Data Channel (DDC). 10 Gbase-T networks are designed to cope with echo, NEXT and alien cross talk (ANEXT) and comprise terminal equipment that implements relatively complex echo/cross talk cancellers and support processing relatively large error correction overheads. As a result, 10 Gbase-T terminal equipment and networks are relatively complicated and expensive.

Since none of the various multimedia communication systems and information exchange communication networks provide both satisfactory uncompressed multimedia transmission and information exchange, home and office environments that provide both are equipped with a complex of different hardware and software systems.

SUMMARY

An aspect of some embodiments of the invention relates to providing a single flexible format for transmitting different types of data over a same physical communication network. In accordance with an embodiment of the invention, data is

transmitted over the network in packets of waveforms and the uniform flexible format comprises a uniform format for the packet, hereinafter referred to as a "U-Pac", for encapsulating data for transmission over the physical communication network. The different types of data optionally comprise information exchange data such as Ethernet data and uncompressed multimedia audiovisual data such as HDMI 1.3, DVI 1.0, UDI and/or DisplayPort data.

An aspect of some embodiments of the invention, relates to providing resistance to noise for data transmitted over the same physical network responsive to the type of data transmitted and/or a desired degree of protection against noise. Different degrees of resistance to noise are provided by modulating different types of data that warrant different degrees of protection against noise onto waveform sets having different numbers of waveforms. Optionally, the waveform sets having different numbers of waveforms are chosen from waveform sets comprising a largest set having a largest number of waveforms and subsets of the largest set.

According to an aspect of some embodiments of the invention, in a data stream comprising data modulated onto a sequence of waveforms, choice of a waveform onto which given data is modulated is independent of choices of waveforms onto which other data in the data stream is modulated. For example, in some embodiments of the invention, in a data stream comprising data modulated onto a sequence of waveforms, temporally adjacent waveforms are, optionally, chosen from different waveform sets. If data in the data stream is modulated onto and transmitted in waveform packets, such as a U-Pac, a same waveform packet may contain waveforms chosen from different waveform sets.

By way of example, let a waveform set comprising i waveforms chosen from M waveforms comprised in a largest set of waveforms be represented by S(M,i), where the largest set of waveforms is represented by S(M,M) and i satisfies a relation $0<i\leq M$. Then, in accordance with an embodiment of the invention, if a first type of data is modulated onto a waveform set S(M,i), a second type of data warranting higher resistance to noise than the first type of data is modulated for transmission onto a waveform set S(M,j) where $j<i$. If data is encapsulated in U-Pacs, a same U-Pac optionally comprises encapsulated data modulated onto different symbol sets to provide different data in the U-Pac with different levels of protections against noise. Optionally, the different symbol sets are chosen from a set $\{S(M,i): 0<i\leq M\}$ of symbol sets.

It is noted that choosing waveform sets from a same largest waveform set can be advantageous in simplifying implementation of a communication network that transmits data in accordance with an embodiment of the invention. For example, if all waveforms onto which the data is modulated are chosen from a same largest waveform set, different slicers do not have to be used to slice waveforms from different waveform sets and substantially identical slicers may be used in all receivers in the network. The slicers optionally slice and generate error directions for all received waveforms assuming that the waveforms are waveforms in the largest waveform set, independent of the actual waveform set to which a given waveform belongs. In accordance with an embodiment of the invention, demodulation of a given received waveform to a correct waveform of a waveform set to which the given waveform belongs is performed using information carried in the data indicating the waveform set to which the given waveform belongs.

Hereinafter, a waveform onto which data is modulated for transmission is also referred to as a "symbol" and a set of waveforms onto which data is modulated is also referred to as a "symbol set". Modulating data onto waveform sets comprising different numbers of waveforms in accordance with an embodiment of the invention is referred to as dynamic waveform modulation (DWM). For convenience alphabetic and/or alphanumeric designations used to represent symbol sets may also be used in referencing symbols belonging to the symbol set. For example, the alphabetic symbol set designation S(M,i) may also be used in referencing a symbol belonging to the symbol set S(M,i). Similarly, a designation of a symbol may be used to designate a symbol set to which the symbol belongs.

Different types of waveforms, such as for example, frequency shift, phase shift or amplitude shift keyed waveforms, may be used in the practice of embodiments of the invention. Optionally, a largest waveform set S(M,M) comprises an M-ary pulse-modulation symbol set having $M=2^k$ different waveforms. In some embodiments of the invention, the pulse-modulation waveforms are pulse amplitude modulation (PAM) symbols. Optionally, the symbols are pulse-position modulation (PPM) symbols. Optionally, the symbols are pulse-duration modulation (PDM) symbols. For convenience of presentation, it is assumed hereinafter that symbols are PAM symbols, a largest set of PAM symbols is represented by P(M,M) and a subset of P(M,M) comprising i PAM symbols is represented by P(M,i).

In some embodiments of the invention, the symbols onto which data is modulated for transmission are transmitted over a twisted pair (TP) cable optionally comprising four pairs of twisted wires. Optionally, each symbol is a four-dimensional symbol comprising four substantially simultaneously transmitted "one dimensional" symbols, each transmitted over a different twisted pair of the TP cable.

Let, a four-dimensional symbol in accordance with an embodiment of the invention be represented by "S4D". In accordance with an embodiment of the invention, each of the one dimensional symbols that make up a four dimensional symbol S4D is chosen from a same set of one-dimensional symbols S(M,i). The index i is smaller for types of data warranting higher noise resistance than for types of data warranting lower noise protection. Let a four dimensional symbol comprising one dimensional symbols S(M,i) (i.e. symbols chosen from the S(M,i) symbol set) be represented by "S4D-S(M,i)". A four dimensional symbol comprising one dimensional PAM symbols $P(M)_i$ is represented by "S4D-P(M,i)".

In some embodiments of the invention, the TP cable is a Cat5e or Cat6 unshielded TP (UTP) cable comprising unshielded twisted pairs. Optionally, the TP cable is up to about 100 m in length and four-dimensional symbols S4D are transmitted over the TP cable at a rate of 250 Msym/s (mega-symbols per second) per TP. Assuming that each one dimensional symbol in a S4D symbol is a PAM(16,16) symbol (i.e. each PAM symbol is a four bit symbol) each TP transmits data at a rate of about 1 Gbps (a gigabit per second) for a total bandwidth of about 4 Gbps. In some embodiments of the invention, the TP cable is up to about 70 m in length and S4D symbols are transmitted over the cable at a rate of 500 Msym/s per TP for a total bandwidth of about 8 Gbps.

An aspect of some embodiments of the invention relates to providing a method of reducing noise generated in a communication channel over which both uncompressed multimedia data is transmitted from a Source to a Sink in simplex mode and over which data is exchanged between the Source and the Sink in full duplex mode.

The inventors have noted that for a communication channel transmitting uncompressed multimedia data in simplex and information data in duplex between a Source and Sink, relatively large amounts of noise at the Sink are due to Echo and

Near End Cross Talk (NEXT). In accordance with an embodiment of the invention, to reduce Echo and NEXT, information data from the Sink to the Source is transmitted at a lower symbol rate than a symbol rate at which the multimedia data is transmitted from the Source to the Sink. Optionally, the Source to Sink multimedia symbol rate is greater than about 10 times the Source to Sink information symbol rate. Optionally, the multimedia symbol rate is greater than 20 times the Source to Sink information symbol rate. Optionally, the multimedia symbol rate is greater than 30 times the Source to Sink information symbol rate. Optionally, the multimedia symbol rate about 40 times the Source to Sink information symbol rate. A network configured to transmit from Sink to Source in accordance with an embodiment of the invention can substantially reduce NEXT and Echo at the sink and as a result may enable relatively inexpensive terminal equipment to be used in the network.

There is therefore provided in accordance with an embodiment of the invention, a method of transmitting a data stream over a communication channel, the method comprising: providing symbol sets having different numbers of symbols; modulating data in the data stream that warrant different degrees of protection against noise onto symbols from symbol sets having different numbers of symbols, wherein which symbol set given data in the stream is modulated onto is independent of symbol sets onto which other data in the data stream is modulated onto; and transmitting the symbols.

Optionally, the symbol sets are chosen from symbol sets comprising a largest set having a largest number of symbols and subsets of the largest set. Additionally or alternatively, the method comprises configuring symbols into packets. Optionally, configuring symbols into packets comprises configuring symbols from symbol sets having different numbers of symbols into a same packet.

In some embodiments of the invention, temporally adjacent symbols are chosen from symbol sets having different numbers of symbols.

In some embodiments of the invention, each symbol is a multidimensional symbol comprising a plurality of symbols that are substantially simultaneously transmitted over the channel. Optionally, the multidimensional symbol is a four dimensional symbol comprising four symbols chosen from a same set of symbols.

In some embodiments of the invention, the symbols comprise frequency shift symbols. In some embodiments of the invention, he symbols comprise phase shift symbols. In some embodiments of the invention, the symbols comprise amplitude shift symbols. In some embodiments of the invention, the symbols comprise pulse-modulation symbols. In some embodiments of the invention, the symbols comprise pulse-position modulation (PPM) symbols. In some embodiments of the invention, the symbols comprise pulse-duration modulation (PDM) symbols. In some embodiments of the invention, the symbols comprise pulse amplitude modulation (PAM) symbols.

In some embodiments of the invention, the largest set comprises 16 symbols.

In some embodiments of the invention the method comprises transmitting the symbols at a transmission rate up to about 250 Msym/sec. In some embodiments of the invention the method comprises transmitting the symbols at a transmission rate up to about 500 Msym/sec.

In some embodiments of the invention the method comprises transmitting data comprises transmitting in simplex mode. Optionally, transmitting data comprises transmitting in full duplex mode over the channel. Optionally, transmitting in full duplex mode comprises transmitting data at different rates in different directions over the channel.

There is further provided in accordance with an embodiment of the invention, a method of transmitting data over a communication channel, the method comprising: transmitting data in simplex mode over the communication channel; and transmitting data in full duplex mode at different rates in different directions over the channel.

Alternatively or additionally, transmitting data in full duplex mode comprises transmitting data at a first rate in a direction in which the simplex data is transmitted and at a second rate lower than the first rate in a direction opposite the simplex direction.

In some embodiments of the invention, the data comprises Transition Minimized Differential Signaling (TMDS) data. In some embodiments of the invention, the data comprises DisplayPort data. In some embodiments of the invention, the data comprises uncompressed data. In some embodiments of the invention, the data comprises multimedia data. Optionally, the multimedia data comprises high definition multimedia data.

In some embodiments of the invention, the method comprises transmitting data in full duplex mode over the channel. In some embodiments of the invention, the data comprises Ethernet data.

In some embodiments of the invention, the channel comprises a twisted pair cable. Optionally, the twisted pair cable comprises four twisted pairs. Additionally or alternatively, the twisted pairs are unshielded. In some embodiments of the invention, the twisted pairs are shielded. In some embodiments of the invention, the cable is a Cat5e cable. In some embodiments of the invention, the cable is a Cat6 cable.

In some embodiments of the invention, simplex and full duplex data are transmitted over a same twisted pair.

There is further provided in accordance with an embodiment of the invention, a communication system comprising: a communication channel; and first and second transceivers that communicate with each other over the channel in simplex and in full duplex mode; wherein data in full duplex mode is transmitted at different rates in different directions over the channel.

Optionally, data in full duplex mode is transmitted at a first rate in a direction in which the simplex data is transmitted and at a second rate lower than the first rate in a direction opposite the simplex direction. Additionally or alternatively, the first transceiver transmits data in a data stream to the second transceiver and modulates data in the data stream that warrant different degrees of protection against noise onto symbols from symbol sets having different numbers of symbols. Optionally, the symbol sets are chosen from symbol sets comprising a largest set having a largest number of symbols and subsets of the largest set. Optionally, the first transceiver configures symbols into packets. Optionally, the first transceiver packets symbols from symbol sets having different numbers of symbols into a same packet. In some embodiments of the invention, the first transceiver packets symbols from symbol sets having different numbers of symbols temporally adjacent each other.

In some embodiments of the invention, the data comprises Transition Minimized Differential Signaling (TMDS) data. In some embodiments of the invention, the data comprises DisplayPort data. In some embodiments of the invention, the data comprises uncompressed data. In some embodiments of the invention, the data comprises multimedia data. Optionally, the multimedia data comprises high definition multimedia data. In some embodiments of the invention, the data comprises Ethernet data.

In some embodiments of the invention, the channel comprises a twisted pair cable. Optionally, the twisted pair cable comprises four twisted pairs. Additionally or alternatively, the twisted pairs are unshielded. In some embodiments of the invention, the twisted pairs are shielded. In some embodiments of the invention, the cable is a Cat5e cable. In some embodiments of the invention, the cable is a Cat6 cable. In some embodiments of the invention, simplex and full duplex data are transmitted over a same twisted pair.

There is further provided in accordance with an embodiment of the invention, a transceiver comprising: a receiver for receiving data transmitted over a communication channel; a transmitter for transmitting data over the communication channel; and circuitry for modulating data for transmission over the channel by the transmitter that modulates data that warrant different degrees of protection against noise onto symbols from symbol sets having different numbers of symbols. Optionally, the symbol sets are chosen from symbol sets comprising a largest set having a largest number of symbols and subsets of the largest set. Additionally or alternatively, the circuitry configures symbols into packets. In some embodiments of the invention, the circuitry packets symbols from symbol sets having different numbers of symbols into a same packet. In some embodiments of the invention, the circuitry packets symbols from symbol sets having different numbers of symbols temporally adjacent each other.

BRIEF DESCRIPTION OF FIGURES

Examples illustrative of embodiments of the invention are described below with reference to figures attached hereto. In the figures, identical structures, elements or parts that appear in more than one figure are generally labeled with a same numeral in all the figures in which they appear. Dimensions of components and features shown in the figures are generally chosen for convenience and clarity of presentation and are not necessarily shown to scale. The figures are listed below.

FIG. **1**A schematically illustrates transmitting uncompressed multimedia data and Ethernet data over a channel comprising a UTP cable, in accordance with an embodiment of the invention;

FIG. **1**B schematically shows a U-Pac comprising symbols, in accordance with an embodiment of the invention.

FIG. **2** schematically illustrates encapsulating Ethernet data in a U-Pac of the form shown in FIG. **1**B, in accordance with an embodiment of the invention; and

FIG. **3** schematically illustrates encoding multimedia Transition Minimized Differential Signaling (TMDS) data in a U-Pac of the form shown in FIG. **1**B, in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

FIG. **1** schematically shows first and second transceivers **21** and **31**, hereinafter referred to as DWM transceivers **21** and **31**, communicating using dynamic waveform modulation (DWM) to package data in U-Pacs, in accordance with an embodiment of the invention.

By way of example, DWM transceiver **21** is coupled to the Ethernet and at least one Source **51** of high definition uncompressed audiovisual (AV) multimedia data from which DWM transceiver receives data to transmit to a Sink **52** via DWM transceiver **31**. Optionally, the DWM transceivers **21** and **31** transmit data to each other over an unshielded twisted pair (UTP) cable **40**. Optionally, UTP cable **40** is a Cat5e or Cat6 cable comprising four twisted pairs, TP**41**, TP**42**, TP**43** and TP**44**. The multimedia data is assumed to be Transition Minimized Differential Signaling Audio Visual (TMDS-AV) data.

DWM transceiver **21** optionally comprises signal processing and control circuitry **24** for encoding/decoding and modulating/demodulating data it receives and for each twisted pair TP**41**, TP**42**, TP**43** and TP**44** of UTP cable **40**, a transmitter, receiver and hybrid circuit. The various transmitters, receivers and hybrid circuits are schematically represented by a transmitter **25**, a receiver **26** and a hybrid circuit **27** respectively. Optionally, an RJ45 patch **46** mounted to a wall plate **47** couples hybrid circuit **27** to each twisted pair TP**41**, TP**42**, TP**43** and TP**44**.

DWM transceiver **31** comprises signal processing and control circuitry **34** for encoding/decoding and modulating/demodulating data it receives and for each twisted pair TP**41**, TP**42**, TP**43** and TP**44** of UTP cable **40**, a transmitter, receiver and hybrid circuit. The various transmitters, receivers and hybrid circuits are schematically represented by a transmitter **35**, a receiver **36** and a hybrid circuit **37** respectively. Optionally, an RJ45 patch **46** mounted to a wall plate **47** couples hybrid circuit **37** to each twisted pair TP**41**, TP**42**, TP**43** and TP**44**.

DWM transceiver **21** receives Ethernet data from the Ethernet and TMDS-AV data and control data from Source **51** and its processing and control circuitry **24** encodes and modulates the data optionally onto symbol (i.e. waveform) sets S4D-S(M,i) of different size responsive to a degree of resistance to noise that is desired for the data. Circuitry **24** then controls transmitter **25** to transmit the symbols in packets, U-Pacs, having a same format. In accordance with an embodiment of the invention, the index i is smaller for data warranting higher noise resistance than for data warranting lower noise protection.

DWM transceiver **31** receives the U-Pacs and its processing and control circuitry **34** demodulates and decodes the symbols they comprise to un-packetize the data they contain and transmits the data to Sink **52**. Whereas TMDS-AV data is transmitted in simplex mode from Source **51** to Sink **52**, Ethernet and/or control data transmitted from the Sink to the Source in general requires that the Sink provide a response to the Source and Ethernet and control data is transmitted in full duplex between the Source and Sink, in accordance with an embodiment of the invention. Large block arrows **61** schematically represent simplex multimedia TMDS-AV data and double arrowhead block arrows **62** represent full duplex Ethernet and/or control data.

In responding to Ethernet and control data received from Source **51**, Sink **52** optionally packetizes its response in U-Pacs using symbol sets S4D-S(M,i) for transmission similarly to the way in which Source **51** packetizes its data for transmission. However, the inventors have noted that transmission of TMDS data and full duplex Ethernet data over a same channel, such as the twisted pair (TP), hybrid terminated channel shown in FIG. **1**A, at high transmission rates required by TMDS data can generate substantial amounts of noise in the channel. In particular, echo and near end cross talk (NEXT) generated by near end transmitters make substantial contributions to the noise. Both the near end transmitter Echo and Next can exhibit exponential growth with frequency of signal transmission over a TP channel similar to that shown in FIG. **1**A. For example, for a 50 m Cat6 cable, noise can increase by as much as about 30 dB for an increase in frequency of transmission from about 10 MHz to about 300 MHz. The inventors have further noted that full duplex transmission of Ethernet does not in general require a same data transmission rate as transmission of simplex TMDS data. Therefore, in some embodiments of the invention, whereas

transceiver **21** is configured to transmit both TMDS data and full duplex Ethernet and/or control data, at a relatively high transmission rate required by TMDS data, transceiver **31** is configured to transmit Ethernet and/or control data to transceiver **21** at a substantially lower transmission rate. The lower transmission rate at which transceiver **31** transmits data can substantially reduce echo and NEXT at transceiver **31**.

In some embodiments of the invention, DWM transceiver **21** transmits TMDS and Ethernet and/or control data to transceiver **31** at a transmission rate greater than about 10 times the transmission rate at which DWM transceiver **31** transmits Ethernet and/or control data to transceiver **21**. Optionally, DWM transceiver **21** transmits at a transmission rate 20 times greater than DWM transceiver **31**. Optionally, DWM transceiver **21** transmits at a transmission rate 30 times greater than DWM transceiver **31**. Optionally, DWM transceiver **21** transmits at a transmission rate 40 times greater than DWM transceiver **31**. For example, in some embodiments of the invention, DWM transceiver **21** transmits TMDS and Ethernet and/or control data to DWM transceiver **31** at 250 Msym/sec or 500 Msym/sec and DWM transceiver **31** transmits Ethernet and/or control data to transceiver **21** at 12.5 Msym/sec.

It is noted that the relatively low transmission rates at which DWM transceiver **31** transmits data to DWM transceiver **21** can generate significant base line wander (BLW) due to transformers that optionally couple each transceiver to TP cable **40**. To reduce possible BLW, DWM transceiver **31** optionally transmits data using "DC-balanced" waveform sets, i.e. DC-balanced symbol sets. Whereas, any suitable DC-balanced waveform set and methods of transmitting such waveform sets known in the art may be used by DWM transceiver **31** to transmit data, optionally DWM transceiver **31** is configured to transmit data using S4D-P(M,i) symbols.

Let a DC-balanced symbol set in accordance with an embodiment of the invention be represented by "±S4D-P(M, i)". In accordance with an embodiment of the invention, the set comprises positive and negative voltage level symbols S4D-P(M,i) and for each positive voltage level symbol, the set comprises a "mirror image" negative voltage level symbol having a same magnitude as the positive level symbol. Mirror image symbols represent identical data and are selectively transmitted by DWM transceiver **31** so that BLW generated by positive symbols is substantially neutralized by transmission of negative mirror image symbols. In accordance with an embodiment of the invention, DWM transceiver **31** uses symbols from a data set ±S4D-P(M,i) having a smaller value of i for data warranting higher noise resistance.

Optionally, the S4D-S(M,i) symbol sets are four dimensional PAM symbols sets S4D-P(M,i) and with each component one-dimension PAM(M,i) symbol of the four dimensional S4D-P(M,i) symbol transmitted substantially simultaneously over a different one of TP**41**, TP**42**, TP**43** and TP**44**. For convenience of presentation, it is assumed that the one dimensional PAM symbols are PAM(**16**,i) symbols and that $i=2^k$ where k is equal to a number of bits of information represented by a PAM(16,i) and satisfies a condition $1 \le k \le 4$. The index i has a value equal to 16 for the largest PAM set and assumes values 8, 4 or 2 for subsets of the largest set with symbols in subsets having smaller i and therefore smaller numbers of symbols being easier to distinguish one from the other and having improved symbol error rate (SER). For values of i equal to 16, 8, 4 and 2 each PAM symbol respectively contains 4, 3, 2 and 1 bit of information. Each symbol of the corresponding four-dimensional S4D-P(M,i) symbol sets contains 16, 12, 8 and 4 bits of information.

It is noted that for each decrease in k by 1, an amplitude difference between symbols in a symbol set S4D-P(M,i) is doubled, making it is easier to differentiate between symbols transmitted between transceiver **21** and **31** and improving the signal to mean squared error (MSE) ratio of slicers in the transceivers used in determining which symbols is received by the transceivers. Signal to MSE ratio (MSER) is defined by an expression $MSER=(10*\log_{10}((d/2)^2/E(e^2))$ where d is a minimal distance between slicer decision levels and $E(e^2)$ is a mean of the squared slicer error signal at the decision levels. As a result, for each decrease in k by 1, d doubles and the MSER improves by 6 dB. Assuming Additive White Gaussian Noise (AWGN), in the channel coupling transceivers **21** and **31**, for a given level of noise in the channel, improvement in MSER by 6 dB, substantially improves a symbol error rate (SER) in symbols transmitted between the transceivers. For example assuming a SER of 10^{-5} a 6 dB improvement in MSE improves the SER to 10^{-17} and SERs of 10^{-7} and 10^{-9} are improved to 10^{-25}, and 10^{-32} respectively. The inventors have determined that the improvement in SER provided by reducing i by 1 provides about a same improvement in SER for a AWGN channel as is provided by encoding data in accordance with a Reed-Solomon (RS) code having an error correction capability of up to 3 data symbols.

FIG. **1**B schematically shows a U-Pac **100** comprising S4D-P(16,i) symbols in accordance with an embodiment of the invention. U-Pac **100** comprises a header section **101**, a payload section **102** and a tail section **103**. Payload section **102** comprises a plurality of symbols **110** that encode "payload" data to be delivered from one to the other of Source **51** and Sink **52** (FIG. **1**A). The data in the payload section of U-Pac **100** is encoded and modulated onto S4D-P(16,i) symbols having index i which depends upon a level of protection against noise with which it is desired to protect the data. In accordance with an embodiment of the invention, different parts of payload **102** may have different values of i and thereby different levels of SER and anti-noise protection. Header **101** and tail **103** comprise management data used for processing information comprised in the packet and data in the header and tail is encoded and modulated onto S4D-P(16, 4) symbols each representing 8 bits to provide the data with relatively low SER. Optionally, the header comprises two symbols, a type symbol **112** and a Stream ID symbol **113**. Type symbol **112** is optionally configured to characterize up to 64 different types, examples of which are discussed below, of U-Pacs. Stream ID comprises data that identifies Source **51** and Sink **52**. Tail **103** optionally comprises a CRC-8 symbol **114** and an idle symbol **115** that marks the end of U-Pac **100**.

By way of example, FIG. **2** shows a flow chart **200** schematically illustrating encapsulating Ethernet data into a U-Pac **100**, in accordance with an embodiment of the invention.

In a process step **201** a stream of Ethernet data to be transmitted to Sink **52** is received by first transceiver **21**. A block **202** of eight (8) Ethernet octets in the stream of Ethernet data is schematically shown to the right of process step **201**. In a process step **203** a data/control bit shown shaded is added to the eight (8) Ethernet octets shown in block **202** to a form a "64 B/65 B" code block **204** of sixty-five (65) bits.

In a step **205** twelve sixty-five (65) bit code blocks **204** are aggregated to form a payload data section **207** that will become with further processing a payload section of U-Pac **100**. A header data section **206** and tail data section **208** are added to the payload section to form an aggregate code block **210**. Header data section **206** optionally comprises a "Type" octet that defines the type of data in the aggregate and U-Pac **100** as Ethernet data and a Stream ID octet. Tail **208** optionally comprises a CRC-8 octet. Aggregate code block **210** comprises **768** Ethernet payload bits and 36 control bits

(header and tale bits plus the control bit added in step **203**) for a total of 804 bits. Optionally, the data in aggregate block **210** is scrambled in a step **212** to provide a scrambled aggregate data block S**210** having header, payload and tail sections S**206**, S**207** and S**208** respectively. In a step **214**, the data in scrambled, aggregate code block S**210** is mapped onto a set of S4D-P(16,i) symbols and a symbol is added to tail S**208** to generate header **101**, payload **102** and tail **103** of a U-Pac **100**.

In accordance with an embodiment of the invention, data in header section S**206** and tail section S**208** of scrambled aggregate S**210** is mapped to S4D-P(16,4) symbols, each of which represents 8 bits of data, to provide the control data with a relatively low SER. Header **101** and tail **103** have two (2) S4D-P(16,4) symbols each. The Ethernet data in payload section S**207** is optionally mapped to S4D-P(16,8) symbols in payload **102**, each of which symbols represents 12 bits of data, so that payload **102** has sixty-five (65) S4D-P(16,8) symbols. U-Pac **100** therefore comprises a total of sixty-nine (69) S4D-P(16,i) symbols and comprises 768 bits of Ethernet payload data. Assuming the Ethernet data received by DWM transceiver **21** is 100 Mbps Ethernet, to support the data transmission rate the transceiver transmits an Ethernet U-Pac **100** of 69 S4D-P(16,i) symbols to Sink **52** via DWM transceiver **31**, in accordance with an embodiment of the invention, every 7.68 μs for a transmission rate of about 9 Mega-symbols of Ethernet data per second (Msym/sec). Optionally, Sink **52** (FIG. **1**A) responds to the Ethernet information it receives at a same rate, and transmits back to transceiver **21** via transceiver **31** about 9 Mega-symbols of Ethernet data per second (Msym/sec). Symbol transmission between DWM transceivers **21** and **31** in accordance with an embodiment of the invention, therefore operates in a full duplex mode that supports 100 Mbps full duplex Ethernet transmission.

FIG. **3** shows a flow chart **300** that schematically illustrates encapsulating TMDS-AV data from a TMDS-AV data stream used for generating an audiovisual display into U-Pacs, in accordance with an embodiment of the invention.

A stream of TMDS-AV data comprises three different types of data transmitted during periods, hereinafter referred to as "TMDS periods" or "T-periods", having fixed duration "T". During each TMDS period one of the three different types of data is transmitted for each of three TMDS channels. The types of data are video data ("V" data), control data ("C" data) and data-island packet data ("I" data). During video data periods, also referred to as a "V periods", each TMDS channel carries pixel color data encoded in 8 bits, for a total of 24 bits of video data per period. During data island TMDS periods, also referred to as "I periods", the TMDS channels carry audio data, which may comprise for example audio samples acquired at 192 kHz for each of 8 audio channels and information frames, "infoframes", comprising data that characterizes audio and video data in the TMDS-AV stream. During an I period each TMDS channel carries 4 bits of data so that the three TDMS channels carry a total of 12 bits of data during the I period. During control data TMDS periods, also referred to as "C periods", the TMDS channels carry inter alia horizontal and vertical synchronization data. Each TDMS channel typically carries 2 bits of control data during a C period for a total of 6 bits of control data during the period. Sequences of different types of TMDS periods in the TDMS-AV stream are generally separated from each other by "guard bands" that are 2 TDMS periods, "G periods", long.

In a process step **302** in FIG. **3** DWM transceiver **21** receives a TMDS-AV data stream to be transmitted to Sink **52** via DWM transceiver **31**. A data block **304** of data in the TMDS-AV stream encoding a single horizontal line of video data and accompanying audio data is schematically shown being received by the transceiver. The data is assumed, by way of example, to be used to generate a progressive video display that is refreshed at 60 Hz and comprises 1080 active and 45 blank horizontal lines, each having 1920 24 bit pixels and 280 blank pixels. The video display is assumed accompanied by eight 8 audio channels sampled at 192 kHz to provide 8 level samples. Data block **304** therefore is 2200 TMDS periods long, of which 1920 periods are video data periods, i.e. V periods, during each of which 24 bits of pixel data are transmitted and 280 TMDS periods are "blank" TMDS periods. In FIG. **3** a TMDS T-period is generically denoted by its duration "T". Of the **280** blank T-periods a first 96 T-periods comprise control, C periods, or guard band, G periods each carrying 6 bits of data, a middle 96 periods comprise data island, I periods each carrying 12 bits encoding audio data and a last 88 periods comprise control C or G periods.

In accordance with an embodiment of the invention, in a process block **306** each 16 T-periods of TMDS data in data block **304** are encoded into S4D-P(16,i) symbols, and a header, hereinafter a "sub-packet header", added to the symbols to form a sub-packet. The sub-packet header optionally comprises a S4D-P(16,4) symbol that characterizes the data in the sub-packet. For example, the sub-packet header optionally distinguishes between a sub-packet comprising only control data from a sub-packet comprising control and guard data or a sub-packet comprising only data island data. Sub-packets **310** generated in process step **306** from data in data block **304** are schematically shown in a data block **308** and are labeled with a letter or letters indicating the type of data they contain. Sub-packets **310** labeled "C", "I", or "V" comprise only control, data island or video pixel data respectively. "Mixed" sub-packets comprising more than one type of data are labeled by the letters of each of the data types they contain. For example, sub-packets **310** in block **308** that contain both control (C) data and guard (G) data are labeled by both G and C.

In accordance with an embodiment of the invention, V data, is encoded into S4D-P(16,16) symbols, and I data, C data and G data are encoded into S4D-P(16,8) symbols. Since each T-period of V data comprises 24 bits of data, each V period is encoded to 1.5 S4D-P(16,16) symbols. Similarly, each I data period comprises 12 bits of data and is encoded to 1 S4D-P(16,8) symbol and each C data or G period comprises 6 bits of data and is encoded to 0.5 S4D-P(16,8) symbols. With the addition of the sub-packet header comprising one S4D-P(16,4) symbol, each type of V data sub-packet **310** comprises 25 S4D-P(16,16) symbols, each I data sub-packet comprises 17 S4D-P(16,8) symbols and each C or CG sub-packet **310** comprises 9 S4D-P(16,8) symbols. The number of S4D-P(16,i) symbols in each type of sub-packet **310** in FIG. **3** is shown in parentheses for at least one of the type of sub-packet below the sub-packet.

In accordance with an embodiment of the invention, V data is always encapsulated in sub-packets **310** comprising only V data in addition to the sub-packet header. Therefore, if data in a sequence of 16 T-periods that is to be encapsulated in a sub-packet includes T-periods having data other than V data followed by T-periods having V data, the sub-packet is a "shortened sub-packet" generated only from data in the non-V data T-periods and includes data in less than 16 T-periods. V data in the remaining T-periods are encapsulated in a next sub-packet. A shortened sub-packet **310** comprising data from only 8 T-periods is distinguished by a reference numeral **312**.

In a process step **314**, sub-packets **310** are encapsulated in U-Pacs **320** having a configuration shown for U-Pac **100**

(FIG. **1**B). U-Pacs **320** encapsulating sub-packets **310** generated in process step **314** are shown in a U-Pac data block **330**. In accordance with an embodiment of the invention, each U-Pac **320** typically comprises, 4 sub-packets **310** (data from 64 T-periods of data block **304**), a U-Pac header **321** comprising two S4D-P(16,4) symbols and a U-Pac tail **322** comprising two S4D-P(16,4) symbols. Similar to the case of sub-packets **310**, optionally, a U-Pac **320** does not "mix" sub-packets **310** having V data with sub-packets **310** comprising other than V data. In accordance with an embodiment of the invention, a sub-packet **310** comprising V data is encapsulated in a same U-Pac **320** only with other sub-packets **310** comprising V data. As a result, to satisfy the non-mixing constraint, a U-Pac **310** such as for example a U-Pac **320** distinguished in FIG. **3** by a reference numeral **324**, may comprise less than 4 sub-packets **310**.

A total of 35 U-Pacs **320**, labeled U-Pac **1**-U-Pac **35**, generated as described above are required to encapsulate all the TMDS data comprised in data block **304** that defines a single 1080p 24 bpp+8 L-PCM audio sampled at 192 KHz. Of the 35 U-Pacs **320**, 30 U-Pacs comprise pixel defining D data and 5 U-Pacs comprise control and/or audio data. Since different sub-packets **310** may comprise different numbers of S4D-P (16,i) symbols and as noted above, different U-Pacs **320** may comprise different numbers of sub-packets, different U-Pacs **320** may comprise different numbers of S4D-P(16,i) symbols. A number of S4D-P(16,i) symbols in each U-Pac **320** in U-Pac data block **330** is shown for each U-Pac **320**. A total of 3346 S4D-P(16,i) symbols are used to encapsulate the TMDS data for data block **304**.

In order to support the refresh rate of 60 Hz, DWM transceiver **21** must transmit 60×1125 lines of 3346 S4D-P(16,i) symbols to DWM transceiver **31** every second for a transmission rate of about 226 Msym/sec. In an embodiment of the invention, DWM transceivers **21** and **31** operate at transmission rates of 250 Msym/sec, which readily supports the bandwidth required for 226 Msym/sec simplex transmission of TMDS data plus 9 Msym/sec full duplex Ethernet transmission noted above between the transceivers. In an embodiment of the invention, the transceivers operate at transmission rates of 500 Msym/sec which supports simultaneous transmission of two TMDS streams plus full duplex Ethernet.

In the description and claims of the application, each of the words "comprise" "include" and "have", and forms thereof, are not necessarily limited to members in a list with which the words may be associated.

The invention has been described using various detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments may comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the invention utilize only some of the features or possible combinations of the features. Variations of embodiments of the invention that are described and embodiments of the invention comprising different combinations of features noted in the described embodiments will occur to persons with skill in the art. It is intended that the scope of the invention be limited only by the claims and that the claims be interpreted to include all such variations and combinations.

What is claimed is:

1. A communication device configured to transmit and receive simultaneously, over the same wire, unidirectional high definition video and bidirectional data, comprising:

a hybrid circuit coupled to a cable made of wires;

a transceiver configured to transmit, over a wire comprised in the cable, Transition Minimized Differential Signaling (TMDS) data and source-to-sink direction of bidirectional data; wherein the TMDS data comprises: video pixel data, and horizontal and vertical video synchronization data; and

the transceiver is further configured to receive, over the same wire and simultaneously with the transmitting, opposite direction of the bidirectional data.

2. The communication device of claim **1**, wherein the transceiver is further configured to provide a better signal protection to the bidirectional data compared to the signal protection provided to the TMDS data.

3. The communication device of claim **2**, wherein the bidirectional data is transmitted using a first modulation and the TMDS data is transmitted using a second modulation.

4. The communication device of claim **3**, wherein the first and the second modulations are pulse amplitude modulations using at least partially overlapping subsets of same symbol set.

5. The communication device of claim **1**, wherein the transceiver is further configured to transfer bidirectional High Definition Multimedia Interface (HDMI) control data.

6. The communication device of claim **5**, wherein the HDMI control data comprises one or more of the following: Inter-Integrated Circuit (I2C), Consumer Electronics Control (CEC), Hot Plug Detection (HPD), or 5V indication.

7. The communication device of claim **1**, wherein the cable is selected from the group of: Category 5 cable (CAT5), CAT5e, CAT6, CAT6a, and CAT7.

8. The communication device of claim **1**, wherein the transceiver is further configured to transmit two or more TMDS streams.

9. The communication device of claim **1**, wherein the transceiver is further configured to transmit two or more High Definition Multimedia Interface (HDMI) streams, including their controls.

10. The communication device of claim **1**, wherein the transceiver is further configured to transmit one or more of the following: Digital Video Interfacing (DVI) control signal data, High Definition Multimedia Interface (HDMI) control signal data, Inter-Integrated Circuit (I2C), Consumer Electronics Control (CEC), Hot Plug Detection (HPD), 5V indication, or a combination thereof.

11. The communication device of claim **1**, wherein the bidirectional data comprises full duplex Ethernet.

12. A communication device configured to transfer simultaneous transmissions of a Transition Minimized Differential Signaling (TMDS) data and bidirectional data, comprising:

a hybrid circuit coupled to a cable made of wires; and

a transceiver configured to transmit and receive, over the same wire simultaneously, the TMDS data and source-to-sink direction of the bidirectional data, and opposite direction of the bidirectional data; wherein the TMDS data comprises: video pixel data, and horizontal and vertical video synchronization data;

the transceiver is further configured to modulate the source-to-sink direction of the bidirectional data using a first modulation; and

the transceiver is further configured to modulate the TMDS data, which is also in the source-to-sink direction, using a second modulation;

wherein the first modulation provides the source-to-sink direction of the bidirectional data a higher protection against noise compared to protection against noise provided to the source-to-sink direction of the TMDS data by the second modulation.

13. The communication device of claim **12**, wherein the first and second modulations are pulse amplitude modulations.

14. The communication device of claim **12**, wherein the first and second modulations use at least partially overlapping subsets of same symbol set.

15. The communication device of claim **12**, wherein the transceiver is further configured to transfer bidirectional High Definition Multimedia Interface (HDMI) control data.

16. The communication device of claim **15**, wherein the HDMI control data comprises one or more of the following: Inter-Integrated Circuit (I2C), Consumer Electronics Control (CEC), Hot Plug Detection (HPD), or 5V indication.

17. The communication device of claim **12**, wherein the cable is selected from the group of: Category 5 cable (CAT5), CAT5e, CAT6, CAT6a, and CAT7.

18. The communication device of claim **12**, wherein the transceiver is further configured to transfer two or more TMDS streams.

19. The communication device of claim **12**, wherein the transceiver is further configured to transfer two or more High Definition Multimedia Interface (HDMI) streams, including their controls.

20. The communication device of claim **12**, wherein the transceiver is further configured to transmit one or more of the following: Digital Video Interfacing (DVI) control signal data, High Definition Multimedia Interface (HDMI) control signal data, Inter-Integrated Circuit (I2C), Consumer Electronics Control (CEC), Hot Plug Detection (HPD), 5V indication, or a combination thereof.

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