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(54) **DMT SYMBOL REPETITION IN THE PRESENCE OF IMPULSE NOISE**

DMT-SYMBOLWIEDERHOLUNG BEI VORHANDENSEIN VON STÖRSPANNUNGSSPITZEN
REPETITION DE SYMBOLES DMT EN PRESENCE DE BRUIT IMPULSIF

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Description

Field of the Invention

[0001] This invention generally relates to communication systems. More specifically, this invention relates to a communication system initialization method, to a communication system or to means for communication system initialization. An exemplary embodiment of this invention relates to an initialization technique for communication systems. Another exemplary embodiment relates to error detection and correction during initialization.

Description of Related Art

[0002] Communication systems often operate in environments with impulse noise. Impulse noise is a short-term burst of noise that is higher than the normal noise that typically exists in the communication channel. For example, DSL systems operate on telephone lines and experience impulse noise from many external sources including telephones, AM radio, HAM radio, other DSL services on the same line or in the same bundle, other equipment in the home, etc. It is common practice for communication systems to use interleaving in combination with Forward Error Correction (FEC) to correct the errors caused by the impulse noise during user data transmission, i.e., SHOWTIME.

SUMMARY

[0003] Standard initialization procedures in xDSL systems, such as those specified in ADSL ITU G.992 standards and VDSL ITU G.993 standards, are designed to optimize performance, such as data rate/reach, in the presence of "stationary" crosstalk or noise. Impulse noise protection is handled with Interleaving/FEC during data transmission mode, known as "SHOWTIME" in ADSL and VDSL systems, but the current xDSL initialization procedures, also known as "training procedures," are not designed to operate in an environment with high levels of impulse noise. As an example, there are several messages exchanged during initialization in ADSL and VDSL ITU standards that are not designed to work well in an environment with high levels of impulse noise. For example, in the ADSL2 G.992.3 standards, there are initialization messages such as R-MSG-FMT, C-MSG-FMT, R-MSG-PCB, C-MSG-PCB, R-MSG1, C-MSG1, R-MSG2, C-MSG2, R-PARAMS, C-PARAMS, etc., which use modulation techniques that do not provide high levels of immunity to impulse noise. Likewise, for example, in the VDSL1 G.993.1 standards, there are initialization messages such as O-SIGNATURE, O-UODATE, O-MSG1, O-MSG2, O-CONTRACT, O-B&G, R-B&G, R-MSG1, R-MSG2, etc., which use modulation techniques that do not provide high levels of immunity to impulse noise. Additionally, G.994.1 (G.hs), which is used as part of the initialization procedure for most xDSL standards,

uses modulation techniques that do not provide high levels of immunity to impulse noise. In particular, a receiver will not be able to correctly demodulate/decode the message information when only 1 DMT symbol is corrupted by impulse noise. This is especially problematic because xDSL systems are generally designed to be able to pass steady-state ("SHOWTIME") data without errors in the presence of impulse noise by configuring a parameter called Impulse Noise Protection (INP). INP is defined in the ADSL2 and VDSL2 standards as the number of consecutive DMT symbols that, when completely corrupted by impulse noise, can be completely corrected by the receiver using FEC and interleaving during SHOWTIME. For example, if TNP=2, then if 2 (or less) SHOWTIME DMT symbols are corrupted by impulse noise, the interleaving and FEC coding will be configured to be able to correct all the resulting bit errors. This means that with the current initialization procedures defined in the VDSL and ADSL standards, even though the xDSL system could operate in SHOWTIME in an impulse noise environment where 2 DMT symbols are being corrupted, the transceivers would not be able to reach SHOWTIME because initialization would fail due to initialization message failure.

US 6,243,414 B1 relates to a method for a high bit rate DMT system providing information on a plurality of DMT tones. In particular, single tones that provide a signal-to-noise ratio that is too low for using the individual tone in data transmission are combined in order to achieve a sufficiently high signal-to-noise ratio for carrying data. Alternatively or additionally, a DMT symbol is repeated to increase the probability of receiving the correct symbol. Although an initialization procedure can be used to initialize the method, the method is not applied to the initialization procedure itself.

Object of the present invention is to provide an improved initialization procedure for communication systems that operate in environments with high level of impulse noise. This object is achieved by a communication system initialization method according to claim 1, by a communication system according to 9 or by means for communication system initialization according to claim 16. Preferred embodiments are subject of the subclaims.

[0004] Accordingly, an exemplary aspect of this invention relates to an improved initialization procedure for communication systems that operate in environments with higher levels of impulse noise.

[0005] More specifically, an exemplary aspect of this invention relates to an initialization sequence where the messages exchanged during initialization are designed to operate in environments with higher levels of impulse noise.

[0006] Additional exemplary aspects of the invention relate to repeating DMT symbols within initialization messages.

[0007] Additional exemplary aspects of the invention relate to duplicating and repeating DMT symbols within initialization message(s).

[0008] Additional exemplary aspects of the invention relate to copying and repeating DMT symbols within initialization message(s).

[0009] Additional exemplary aspects of the invention relate to repeating the transmission of DMT symbols that are used to modulate initialization message information bits to correctly receive the messages in an environment with impulse noise.

[0010] Further exemplary aspects of the invention relate to using forward error correction to encode and decode initialization messages during initialization.

[0011] Aspects of the invention further relate to using forward error correction and interleaving to encode and decode initialization messages during initialization.

[0012] Still further aspects of the invention relate to using error detection techniques such as Cyclic Redundancy Checksum (CRC) on portions of an initialization message during initialization.

[0013] Additional exemplary aspects of the invention relate to using error detection techniques, such as CRC on portions of the bits in an initialization message to correctly determine which DMT symbols are corrupt.

[0014] Aspects of the invention also relate to utilizing error detection techniques, such as CRC, on portions of the bits in an initialization message to determine which bits are in error in a long message.

[0015] Aspects of the invention also relate to analyzing initialization message length to dynamically determine the type(s) of initialization message error detection and correction to be used.

[0016] Further aspects of the invention relate to using error detection techniques, such as CRC, on portions of the bits in an initialization message and message retransmission to correctly receive messages during initialization.

[0017] Additional exemplary aspects of the invention also relate to utilizing error detection techniques such as CRC on portions of the bits in any message or signal to determine which DMT symbols are corrupted by impulse noise during initialization.

[0018] Additional exemplary aspects of the invention relate to transmitting and/or receiving repeated DMT symbols with at least one CRC bit on each DMT symbol.

[0019] These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the exemplary embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The exemplary embodiments of the invention will be described in detail, with reference to the following figures wherein:

[0021] Fig. 1 is a functional block diagram illustrating an exemplary embodiment of this invention;

[0022] Fig. 2 is a flowchart outlining an exemplary embodiment for initializing a communication system according to this invention; and

[0023] Fig. 3 is a flowchart outlining a second exemplary embodiment for initializing a communication system according to this invention;

[0024] Fig. 4 is a flowchart outlining a third exemplary embodiment for initializing a communication system according to this invention;

[0025] Fig. 5 is a flowchart outlining a fourth exemplary embodiment for initializing a communication system according to this invention; and

[0026] Fig. 6 is a flowchart outlining a fifth exemplary embodiment for initializing a communication system according to this invention;

DETAILED DESCRIPTION

[0027] The exemplary embodiments of this invention will be described in relation to initialization in a wired and/or wireless communications environment, such as a DSL communication system. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system or protocol in any environment.

[0028] The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as DSL modems and VDSL modems, and associated communications hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

[0029] For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

[0030] Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a telecommunications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), a DSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a

modem and an associated computing device.

[0031] Furthermore, it should be appreciated that the various links, including communications channel 5, connecting the elements can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. Transmitting modem and transmitting transceiver as well as receiving modem and receiving transceiver are used interchangeably herein.

[0032] Fig. 1 illustrates an exemplary communication system. Communication system 10 comprises a first transceiver 100 and a second transceiver 200. The transceivers 100 and 200 each comprise a DMT symbol reception/determination module 110, a majority voting module 120, a DMT symbol inspection and selection module 130, a DMT symbol repetition module 140, a FEC/interleaving module 150, an INP determination type module 160, a CRC module 170, a modulation/demodulation module 180 and a transmitter/receiver module 190. It should be appreciated that numerous components of the transceiver have been omitted for clarity. However, the transceivers 100 and 200 can also include the standard components of a typical communications device(s).

[0033] In general, the systems and methods of this invention will be described in relation to transceivers in a DSL communications environment. However, it should be appreciated that the techniques illustrated herein can be implemented into any wired or wireless communication system.

[0034] In accordance with a first exemplary embodiment, DMT symbols that are used to modulate initialization messages are sent a plurality of times. Due to this repeated transmission, if one or more of the DMT symbols are corrupted by impulse noise, the transceiver receiving the DMT symbols can still recover the information therefrom. More specifically, and in cooperation with the DMT symbol repetition module 140, the majority voting module 120 and the modulation/demodulation module 180, a DMT symbol is repeated without modification with the receiving transceiver using a variety of detection/demodulation schemes to recover the message information bits. For example, the receiving transceiver could use a "majority voting" scheme where each DMT symbol is demodulated independently and then the message information bits recovered by examining how many DMT symbols carry the same bit pattern. Alternatively, for example, the DMT symbols could be examined by the DMT symbol inspection and selection module 130 prior to demodulation in the frequency or time domain and based on these signals, the transceiver that received the DMT symbols,

in cooperation with the DMT symbol inspection selection module 130, selects the most likely DMT symbol to be correct. For example, if a DMT symbol was repeated four times and one DMT symbol was corrupted by impulse noise, then the receiving transceiver could examine the four DMT symbols in the frequency domain and clearly detect that one of the four symbols has very different phase and/or amplitude characteristics than the other three DMT symbols. Based on this difference, the receiving transceiver could discard the one DMT symbol that is corrupt and use the remaining three DMT symbols to demodulate and recover the information. Moreover, in order to randomize the signal transmitted from the transmitting transceiver, the repeated DMT symbols can use phase or bit scrambling. With phase scrambling, the repeated DMT symbols can use different phase shifts on the subcarriers in order to randomize the signal. With bit scrambling, the information bits can be scrambled prior to modulating the bits on the repeated DMT symbols.

[0035] In accordance with another exemplary embodiment, the number of repeated symbols can be determined based on the SHOWTIME Impulse Noise Protection (INP) requirements. For example, if the SHOWTIME INP=2, then DMT symbols carrying initialization messages would be repeated during initialization at least $INP*2+1=5$ times. This way, even if two DMT symbols were corrupted by impulse noise, there would be three remaining uncorrupted DMT symbols received by the receiving transceiver. Then, for example, and with the cooperation of the majority voting module 120, a majority voting scheme could be applied to correctly demodulate and recover the DMT symbol(s) without errors. Other algorithms could also be used to derive the number of repeated DMT symbols from the INP value. For example, the number of repeated DMT symbols could be set to $A*INP+B$ where A and B are integers.

[0036] In accordance with an exemplary embodiment, and with the cooperation of the DMT symbol repetition/determination module 110, a receiving modem determines the number of repeated DMT symbols and informs the transmitting modem thereof. For example, the receiving modem could receive an INP value from one or more of a second transceiver or a management system. Based on this received INP value, and in cooperation with the DMT symbol repetition module 140, the number of repeated DMT symbols (M) for initialization messages is determined. This determination may be based on impulse noise measurements made by the receiving transceiver or may be based on the received INP value or both. For example, if the INP value is used, M may be equal to $INP*2+1$. The message indicating the determined number of repeated DMT symbols (M) is then transmitted to a second transceiver. Therefore, during initialization, the message bits are modulated onto the M repeated DMT symbols.

[0037] For example, in an alternative embodiment, a transmitting modem, with the cooperation of the DMT symbol repetition/determination module 110, could de-

termine the number of repeated DMT symbols and send a message to the receiving modem indicating the value. This determination can be based on impulse noise measurements, based on a received INP value, or both. Moreover, a management system 205 could determine one or more of the INP value and the number of repeated DMT symbols and configure the transceivers for their use. This determination could be based on impulse noise measurements or may be based on the received INP value or both.

[0038] DSL systems often use FEC and interleaving during SHOWTIME to correct errors from impulse noise. In accordance with an exemplary embodiment of this invention, and with the cooperation of the FEC/Interleaving module 150, FEC can be utilized with or without interleaving to correct impulse noise that may corrupt messages during the initialization process. For example, prior to modulating information bits of an initialization message, the message information bits could be encoded using any FEC technique, such as Reed Solomon codes, hamming codes, convolution codes, trellis codes, turbo codes, LDPC codes, or the like. At the receiving modem, the FEC coding could be used to correct errors from impulse noise. For example, initialization messages could be encoded with a Reed Solomon code using the code-word size $N=K+R$ bytes, containing K message information bytes and R FEC check bytes. This code can correct $R/2$ bytes. For example, if each DMT symbol is used to modulate 1 byte, and a R-S code with $N=6$ and $R=4$ is used, then the decoder at the receiving modem would be able to correct $R/2=2$ bytes in each codeword. This corresponds to correcting two DMT symbols, assuming each DMT symbol carries one byte. This would lead to the ability of the receiving modem being able to correctly recover the message information bits even if impulse noise corrupted two DMT symbols. Additionally, interleaving could be used to provide better immunity to impulse noise. For example, interleaving of multiple codewords could be used to spread the errors from impulse noise over multiple codewords thereby enabling the receiving transceiver to correct impulse noise events that corrupt even more DMT symbols.

[0039] For example, two DMT symbols with $N=6$ and $R=4$ could be interleaved, in cooperation with the FEC/interleaving module 150, by transmitting one byte from the first codeword and then transmitting one byte from the second codeword and continuing to alternate transmission in this manner. In this case, assuming each DMT symbol carries one byte, an impulse noise that corrupted four consecutive DMT symbols would be correctable by the receiver because four consecutive DMT symbols would always be divided between two codewords with each codeword having the ability to correct two bytes, or two DMT symbols.

[0040] During initialization, messages of various lengths are transmitted between the two transceivers 100 and 200. Some of these messages are longer than others with longer messages, due to their length, being more

susceptible to impulse noise corruption. In accordance with another example, and in cooperation with the INP determination type module 160, the type of impulse noise protection can be determined based, for example, on the length of the message being transmitted. For example, long initialization messages, such as C/R-PARAMS in ADSL, C/R-B&G in VDSL and G.994.1 messages are particularly problematic when transmitted in the presence of impulse noise. This is because when a message is long, it is very likely that some portion of the message will be corrupted by impulse noise and not be correctly recovered by the receiving modem. Although conventional DSL systems use standard error detection methods, such as CRC, CRC covers the entire message and does not provide any information regarding which bits, or DMT symbols, were corrupted by the impulse noise. Thus, when a CRC error is detected in a message in conventional DSL systems, the whole message is simply resent by the transmitting modem. However, in an environment with high impulse noise, the retransmitted message could be received in error as well and the retransmission process repeated without success. With the cooperation of the CRC module 170, additional error detection capability can be added to messages to enable the location of bit errors in longer messages. For example, and in cooperation with the CRC module 170, a one-byte CRC could be determined for each byte of the message. The CRC byte and the information could be modulated and transmitted, with the cooperation of the modulation/demodulation module 180 and transmitter/receiver module 190, on one DMT symbol. In this example, one DMT symbol is carrying two bytes.

[0041] At the receiving modem, the two bytes are demodulated and the CRC byte is used to detect if there was impulse noise corrupting the associated DMT symbol. If the CRC indicates there are no errors, then the receiving modem correctly received the message byte. If the CRC shows that there are errors, then the receiving modem needs to receive the DMT symbol again, with the cooperation of the DMT symbol reception module 140, in order to correctly recover the information. In this example, one CRC byte is transmitted with one information byte on each DMT symbol and the receiver can demodulate the entire message in this manner.

[0042] If impulse noise has corrupted some of the DMT symbols in the longer message, the message can be retransmitted and the receiving modem perform a CRC check on the previously corrupted DMT symbols to determine if they are now received without errors. Since impulse noise is typically uncorrelated with the transmitted message signal, it is highly likely that different DMT symbols will be corrupted when the signal is retransmitted, which means that the receiving modem will probably receive the previously corrupted DMT symbols without errors the second time that the message is transmitted. In the unlikely event that the same DMT symbols are still in error, the message could be retransmitted over and over until all DMT symbols are received without errors.

It is possible upon retransmission that the impulse noise will cause errors in different DMT symbols than in the previous transmission. Therefore, the receiving modem could store the correctly recovered message bits for DMT symbols from the previously received message. The receiver can also store all the previously received message bits that were received without error and simply utilize the retransmitted message to correctly determine the message bits and the DMT symbols that were in error previously.

[0043] For example, the receiving modem can send a message to the transmitting modem requesting the transmitting modem to retransmit only a portion of the message that was previously received in error.

[0044] While the examples above describe computing a CRC and adding a CRC byte to each byte in the message, a plurality of CRC bits could be computed for any number of bits in the message and transmitted to a receiving modem. Moreover, although the examples above describe modulating two bytes in each DMT symbol, any number of bits can be modulated on each DMT symbol. Although the examples above describe transmitting one CRC byte in every DMT symbol, any number of CRC bits can be modulated on each DMT symbol including, but not limited to, CRC bits being carried on only a subset of the DMT symbols. For this case, some DMT symbols may not have any CRC bits. As an example, one CRC byte could be computed for each four message bytes and each DMT symbol could carry one byte. In this case, the first four DMT symbols would be used to modulate the message bytes and the fifth DMT symbol would carry the CRC byte. At the receiving modem, the CRC would be used to detect if any of the five DMT symbols were corrupted by impulse noise. If the CRC showed an error has occurred, then the retransmission techniques described above could be used.

[0045] In another example, the DMT symbol repetition and error detection capabilities are combined to combat impulse noise on the communications line. For example, if a DMT symbol is repeated M times, and a CRC byte is transmitted with every DMT symbol, then the receiving modem could use the CRC byte to determine if each DMT symbol was being correctly demodulated. In this case, a majority voting scheme, or other frequency/time domain impulse noise detection method, such as those discussed above, would not necessarily be required. One advantage of this method is that it may require repeating a fewer number of DMT symbols. For example, if the impulse noise corrupts one DMT symbol, a majority-voting scheme, in conjunction with the majority voting module 120, would require at least three DMT symbols to make a decision. However, if a CRC byte was sent with each DMT symbol, then only two repeated DMT symbols would be necessary since the CRC, with the assistance of the CRC module 170, would correctly identify the uncorrupted DMT symbol and discard the corrupted DMT symbol. If the INP value was being used to determine the number of repeated DMT symbols, then this method

may require repeating a fewer number of DMT symbols. For example, it may be necessary to only repeat $INP+1$ DMT symbols, as opposed to $2*INP+1$ in the case where a CRC is not used. Illustratively, if $INP=2$, then it may be necessary to only transmit $INP+1=3$ repeated DMT symbols since the CRC byte could be used to detect the one correct DMT symbol and discard the two corrupted DMT symbols.

[0046] In accordance with an exemplary embodiment, the receiving modem determines the number of repeated DMT symbols and informs the transmitting modem thereof. In this exemplary embodiment, an INP value is received from a second transceiver or a management system 205. The number of repeated DMT symbols (M) is determined for the initialization messages in cooperation with the DMT symbol repetition module 140. This determination may be based on impulse noise measurements made by, for example, a receiving transceiver, or may be based on the received INP value or both. For example, if the INP value is used, M may be equal to $INP+1$. A message is then transmitted, with the cooperation of the transmitter/receiver module 190 to the transmitting modem indicating the determined number of repeated DMT symbols (M). Therefore, during initialization, the modem would receive messages wherein the message bits are modulated onto the M repeated DMT symbols with each DMT symbol containing at least one CRC bit for error detection.

[0047] For the transmitting modem, the transmitting modem would receive a message indicating the determined number of repeated DMT symbols and, during initialization, modulate at least one message bit onto a DMT symbol and transmit the DMT symbol (M) times, wherein each DMT symbol contains at least one CRC bit for error detection.

[0048] Alternatively, the transmitting modem could determine a number of repeated DMT symbols and send a message to the receiving modem. As described above, this determination could be based on impulse noise measurements or may be based on the received INP value or both.

[0049] Still alternatively, a management system could determine the number of DMT symbols and configure the transceivers accordingly. As described above, this determination may be made based on impulse noise measurements made by the receiving transceiver or may be based on the received INP value or both. While the above-described exemplary embodiments are illustrated independently of one another, it should be appreciated the various techniques can be combined in whole or in part.

[0050] Fig. 2 illustrates an exemplary initialization methodology and communication between first and second transceivers. More specifically, for the first transceiver, control begins in step S 100 and continues to step S110. In step S110, an INP value is determined or, for example, received from a management system or another transceiver.

[0051] Next, in step S120, the INP value is transmitted to the second transceiver. Then, in step S 130, a value M is received by the first transceiver where M is the number of repeated DMT symbols for initialization messages. Control then continues to step S 140.

[0052] In step S 140, and during initialization, the first transceiver modulates at least one message bit onto the M repeated DMT symbols. Next, in step S 150, the M number of DMT symbols are transmitted to the second transceiver. Control then continues to step S 160 where the control sequence ends.

[0053] For the second transceiver, control begins in step S105 and continues to step S115. In step S115 an INP value is received. Next, in step S125, the number of repeated DMT symbols (M) is determined for use in initialization and the value M transmitted to the first transceiver. Then, in step S 135, the second transceiver receives the M number of repeated DMT symbols. Control then continues to step S145 where the control sequence ends.

[0054] As with the previously discussed embodiments, and while not specifically illustrated in the flowchart, additional error detection capability can also be added to initialization message(s) to enable the location of bit errors. For example, each DMT symbol could also include at least one CRC bit, which can be used to detect if the DMT symbol is received correctly or in error. However, this embodiment is not limited thereto and any error detection technique in any configuration will work with the invention.

[0055] Fig. 3 illustrates a second exemplary methodology and communication between transceivers for initialization. More specifically, for the first transceiver, control begins in step S200 and continues to step S210. In step S210, an INP value is determined or, for example, received from a management system or another transceiver. Next, in step S220, the number repeated DMT symbols (M) for initialization messages is determined and transmitted to a second transceiver. Then, in step S230, and during initialization, at least one message bit is modulated onto the M repeated DMT symbols. Control then continues to step S240.

[0056] In step S240, the M symbols are transmitted to the second transceiver. Control then continues to step S250 where the control sequence ends.

[0057] For the second transceiver, control begins in step S205 and continues to step S215. In step S215, the value for M is received. Next, in step S225, the M number of DMT symbols are received. Control then continues to step S235 where the control sequence ends.

[0058] As with the previously discussed embodiments, and while not specifically illustrated in the flowchart, additional error detection capability can also be added to initialization message(s) to enable the location of bit errors. For example, each DMT symbol could also include at least one CRC bit, which can be used to detect if the DMT symbol is received correctly or in error. However, this example is not limited thereto and any error detection

technique in any configuration will work with the invention.

[0059] Fig. 4 illustrates another exemplary initialization methodology and communication between transceivers. More specifically, for the first transceiver, control begins in step S202 and continues to step S204. In step S204, an INP value is determined or, for example, received from a management system or another transceiver. Next, in step S206, the number of repeated DMT symbols (M) for initialization messages is determined and transmitted to a second transceiver. Then, in step S208, the M number of DMT symbols are received. Control then continues to step S209 where the control sequence ends.

[0060] For the second transceiver, control begins in step S201 and continues to step S203. In step S203, M is received. Next, in step S205, and during initialization, at least one message bit is modulated onto the M repeated DMT symbols. Then, in step S207, the M number of DMT symbols are transmitted. Control then continues to step S211 where the control sequence ends.

[0061] As with the previously discussed embodiments, and while not specifically illustrated in the flowchart, additional error detection capability can also be added to initialization message(s) to enable the location of bit errors. For example, each DMT symbol could also include at least one CRC bit, which can be used to detect if the DMT symbol is received correctly or in error. However, this example is not limited thereto and any error detection technique in any configuration will work with the invention.

[0062] Fig. 5 illustrates another exemplary initialization methodology according to this invention. In particular, control begins in step S300 and continues to step S310. In step S310, the CRC to byte ratio is determined. Next, in step S320, one or more CRC bits are determined for a number of bytes or bits. Then, in step S330, the one or more CRC bits are modulated in addition to additional information on a DMT symbol. Control then continues to step S340.

[0063] In step S340, the DMT symbol is demodulated and the one or more CRC bits are used to detect errors. Next, in step S350, a determination is made whether the CRC bits have revealed errors. If errors are present, control continues to step S360. Otherwise, control jumps to step S380 where the control sequence ends.

[0064] In step S360, retransmission of one or more DMT symbols or portions thereof are requested. Then, in step S370, the errored DMT symbols are discarded. Control then continues back to step S350.

[0065] Fig. 6 illustrates another example for communication initialization according to this invention. In particular, control begins in step S400 and continues to step S410. In step S410, an INP value is determined or, for example, received from a management system or another transceiver. Next, in step S420, the number of repeated DMT symbols M is determined for initialization messages. Then, in step S430, the value for the number of repeated DMT symbols is transmitted to, or received

from, as appropriate, a second transceiver. Control then continues to step S440.

[0066] In step S440, one or more initialization messages are transmitted or received, as appropriate, wherein at least one message bit is modulated onto a DMT symbol and the DMT symbol(s) is repeated M times with each DMT symbol including at least one CRC bit. Next, in step S450, the combination of CRC bit(s) and repeated DMT symbols are utilized to insure integrity of the initialization message(s). Control then continues to step S460 where the control sequence ends.

[0067] While the above-described flowcharts have been discussed in relation to a particular sequence of events, it should be appreciated that changes to this sequence can occur without materially effecting the operation of the invention. Additionally, the exact sequence of events need not occur as set forth in the exemplary embodiments, but rather the steps can be performed by one or the other transceiver in the communication system provided both transceivers are aware of the technique being used for initialization. Additionally, the exemplary techniques illustrated herein are not limited to the specifically illustrated embodiments but can also be utilized with the other exemplary embodiments.

[0068] The above-described system can be implemented on wired and/or wireless telecommunications devices, such a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

[0069] Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

[0070] Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design.

Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

[0071] Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

[0072] It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for initializing transceivers.

Claims

1. A communication system initialization method comprising:

determining, based on an impulse noise protection value, a number M of DMT symbols to be repeated during initialization, wherein the number M of DMT symbols to be repeated is computed as $M=A*INP+B$, where A and B are integers and INP is the impulse noise protection value, the impulse noise protection value being defined as the number of consecutive DMT symbols that, when completely corrupted by impulse noise, can be corrected at least using Forward Error Correction during showtime; and repeatedly transmitting, during the DMT transceiver initialization, a DMT symbol M times.

2. Method of claim 1, wherein a transmitting modem performs the determining step, or wherein a receiving modem performs the determining step,
3. Method of claim 1 or 2, wherein $A=2$ and $B=1$,

4. Method according to anyone of the preceding claims, further comprising:

modulating at least one bit onto the repeated DMT symbols; and
transmitting the number of repeated DMT symbols.

5. Method according to anyone of the preceding claims, further comprising:

receiving the number of repeated DMT symbols; and
demodulating at least one bit from the repeated DMT symbol,

6. Method according to anyone of the preceding claims, wherein the repeated DMT symbols are consecutive, identical DMT symbols, or a sequence of identical DMT symbols.

7. Method according to anyone of the preceding claims, wherein the Forward Error Correction includes Reed Solomon codes, hamming codes, convolution codes, trellis codes, turbo codes or LDPC codes.

8. Method according to anyone of the preceding claims, wherein FEC is utilized with interleaving to correct impulse noise.

9. A communication system comprising:

a DMT symbol repetition module (140) determining, during initialization based on an impulse noise protection value, a number M of DMT symbols to be repeated, wherein the number M of DMT symbols to be repeated is computed as $M=A*INP+B$, where A and B are integers and INP is an impulse noise protection value, the impulse noise protection value being defined as the number of consecutive DMT symbols that, when completely corrupted by Impulse noise, can be corrected at least using Forward Error Correction during showtime; and repeatedly transmitting, during the DMT transceiver initialization, a DMT symbol M times.

10. The system of claim 9, wherein the DMT symbol repetition module (140) is in a transmitting modem, or in a receiving modem and/or wherein $A=2$ and $B=1$,

11. System of claim 9 or 10, further comprising:

a modulation module (180) capable of modulating at least one bit onto the repeated DMT symbols; and
a transmitter module (190) capable of transmitting the number of repeated DMT symbols.

12. System according to anyone of claims 9 to 11, further comprising:

a receiver module (190) capable of receiving the number of repeated DMT symbols; and
a demodulation module (180) capable of demodulating at least one bit from the repeated DMT symbol.

13. System according to anyone of claims 9 to 12, wherein the repeated DMT symbols are consecutive, identical DMT symbols, or a sequence of identical DMT symbols.

14. System according to anyone of claims 9 to 13, wherein the Forward Error Correction includes Reed Solomon codes, hamming codes, convolution codes, trellis codes, turbo codes or LDPC codes.

15. System according to anyone of claims 9 to 14, wherein FEC is utilized with interleaving to correct impulse noise.

16. Means for communication system initialization comprising:

means for determining, during initialization based on an impulse noise protection value, a number M of DMT symbols to be repeated, wherein the number M of DMT symbols to be repeated is computed as $M=A*INP+B$, where A and B are integers and INP is an impulse noise protection value, the impulse noise protection value being defined as the number of consecutive DMT symbols that, when completely corrupted by impulse noise, can be corrected at least using Forward Error Correction during showtime; and
means for repeatedly transmitting, during the DMT transceiver initialization, a DMT symbol M times.

17. The means of claim 16, wherein a transmitting modem performs the determining step, or wherein a receiving modem performs the determining step.

18. The means of claim 16 or 17, wherein $A=2$ and $B=1$.

19. The means according to anyone of claims 16-18, further comprising:

means for modulating at least one bit onto the repeated DMT symbols; and
means for transmitting the number of repeated DMT symbols.

20. The means according to anyone of claims 16-19, further comprising:

means for receiving the number of repeated DMT symbols; and
means for demodulating at least one bit from the repeated DMT symbol.

21. The means according to anyone of claims 16-20, wherein the repeated DMT symbols are consecutive, identical DMT symbols, or a sequence of identical DMT symbols,
22. The means according to anyone of claims 16-21, wherein the Forward Error Correction includes Reed Solomon codes, hamming codes, convolution codes, trellis codes, turbo codes or LDPC codes.
23. The means according to anyone of claims 16-22, wherein FEC is utilized with interleaving to correct impulse noise.

Patentansprüche

1. Kommunikationssystem-Initialisierungsverfahren, umfassend:
- Bestimmen einer Anzahl M von während einer Initialisierung zu wiederholenden DMT-Symbolen auf der Basis eines Impulsrausch-Schutzwerts, wobei die Anzahl M von zu wiederholenden DMT-Symbolen als $M=A*INP+B$ berechnet wird, wobei A und B ganze Zahlen sind und INP der Impulsrausch-Schutzwert ist, wobei der Impulsrausch-Schutzwert als die Anzahl aufeinanderfolgender DMT-Symbole definiert ist, die, wenn sie vollständig durch Impulsrauschen verfälscht sind, mindestens unter Verwendung von Vorwärtsfehlerkorrektur während der Showtime korrigiert werden können; und wiederholtes M-maliges Senden eines DMT-Symbols während der DMT-Sender-/Empfängerinitialisierung.
2. Verfahren nach Anspruch 1, wobei ein Sendemodem den Bestimmungsschritt durchführt oder wobei ein Empfangsmodem den Bestimmungsschritt durchführt.
3. Verfahren nach Anspruch 1 oder 2, wobei $A=2$ und $B=1$.
4. Verfahren nach einem der vorhergehenden Ansprüche, ferner umfassend:
- Modulieren mindestens eines Bit auf die wiederholten DMT-Symbole; und Senden der Anzahl wiederholter DMT-Symbole.
5. Verfahren nach einem der vorhergehenden Ansprüche

che, ferner umfassend:

Empfangen der Anzahl wiederholter DMT-Symbole; und Demodulieren mindestens eines Bit aus dem wiederholten DMT-Symbol.

6. Verfahren nach einem der vorhergehenden Ansprüche, wobei die wiederholten DMT-Symbole aufeinanderfolgende, identische DMT-Symbole oder eine Sequenz identischer DMT-Symbole sind.
7. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Vorwärtsfehlerkorrektur Reed-Solomon-Codes, Hamming-Codes, Faltungscodes, Trellis-Codes, Turbo-Codes oder LDPC-Codes umfasst.
8. Verfahren nach einem der vorhergehenden Ansprüche, wobei FEC mit Verschachtelung verwendet wird, um Impulsrauschen zu korrigieren.
9. Kommunikationssystem, umfassend:
- ein DMT-Symbolwiederholungsmodul (140), das während einer Initialisierung auf der Basis eines Impulsrausch-Schutzwerts eine Anzahl M von zu wiederholenden DMT-Symbolen bestimmt, wobei die Anzahl von zu wiederholenden DMT-Symbolen als $M=A*INP+B$ berechnet wird, wobei A und B ganze Zahlen sind und INP der Impulsrausch-Schutzwert ist, wobei der Impulsrausch-Schutzwert als die Anzahl aufeinanderfolgender DMT-Symbole definiert ist, die, wenn sie vollständig durch Impulsrauschen verfälscht sind, mindestens unter Verwendung von Vorwärtsfehlerkorrektur während der Showtime korrigiert werden können; und wiederholtes M-maliges Senden eines DMT-Symbols während der DMT-Sender-/Empfängerinitialisierung.
10. System nach Anspruch 9, wobei sich das DMT-Symbolwiederholungsmodul (140) in einem Sendemodem oder in einem Empfangsmodem befindet und/oder wobei $A=2$ und $B=1$.
11. System nach Anspruch 9 oder 10, ferner umfassend:
- ein Modulationsmodul (180), das in der Lage ist, mindestens ein Bit auf die wiederholten DMT-Symbole zu modulieren; und ein Sendermodul (190), das in der Lage ist, die Anzahl wiederholter DMT-Symbole zu senden.
12. System nach einem der Ansprüche 9 bis 11, ferner umfassend:
- ein Empfängermodul (190), das in der Lage ist,

- die Anzahl wiederholter DMT-Symbole zu empfangen; und
ein Demodulationsmodul (180), das in der Lage ist, mindestens ein Bit aus dem wiederholten DMT-Symbol zu demodulieren.
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13. System nach einem der Ansprüche 9 bis 12, wobei die wiederholten DMT-Symbole aufeinanderfolgende, identische DMT-Symbole oder eine Sequenz von identischen DMT-Symbolen sind.
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14. System nach einem der Ansprüche 9 bis 13, wobei die Vorwärtsfehlerkorrektur Reed-Solomon-Codes, Hamming-Codes, Faltungscodes, Trellis-Codes, Turbo-Codes oder LDPC-Codes umfasst.
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15. System nach einem der Ansprüche 9 bis 14, wobei FEC mit Verschachtelung verwendet wird, um Impulsrauschen zu korrigieren.
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16. Mittel zur Kommunikationssystem-Initialisierung, umfassend:
- Mittel zum Bestimmen einer Anzahl M von zu wiederholenden DMT-Symbolen während einer Initialisierung auf der Basis eines Impulsrausch-Schutzwerts, wobei die Anzahl M von zu wiederholenden DMT-Symbolen als $M=A*INP+B$ berechnet wird, wobei A und B ganze Zahlen sind und INP der Impulsrausch-Schutzwert ist, wobei der Impulsrausch-Schutzwert als die Anzahl aufeinanderfolgender DMT-Symbole definiert ist, die, wenn sie vollständig durch Impulsrauschen verfälscht sind, mindestens unter Verwendung von Vorwärtsfehlerkorrektur während der Showtime korrigiert werden können; und
Mittel zum wiederholten M-maligen Senden eines DMT-Symbols während der DMT-Sender-/Empfängerinitialisierung.
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17. Mittel nach Anspruch 16, wobei ein Sendemodem den Bestimmungsschritt durchführt oder wobei ein Empfangsmodem den Bestimmungsschritt durchführt.
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18. Mittel nach Anspruch 16 oder 17, wobei $A=2$ und $B=1$.
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19. Mittel nach einem der Ansprüche 16-18, ferner umfassend:
- Mittel zum Modulieren mindestens eines Bit auf die wiederholten DMT-Symbole; und
Mittel zum Senden der Anzahl wiederholter DMT-Symbole.
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20. Mittel nach einem der Ansprüche 16-19, ferner umfassend:

Mittel zum Empfangen der Anzahl wiederholter DMT-Symbole; und
Mittel zum Demodulieren mindestens eines Bit aus dem wiederholten DMT-Symbol.

21. Mittel nach einem der Ansprüche 16-20, wobei die wiederholten DMT-Symbole aufeinanderfolgende, identische DMT-Symbole oder eine Sequenz identischer DMT-Symbole sind.
22. Mittel nach einem der Ansprüche 16-21, wobei die Vorwärtsfehlerkorrektur Reed-Solomon-Codes, Hamming-Codes, Faltungscodes, Trellis-Codes, Turbo-Codes oder LDPC-Codes umfasst.
23. Mittel nach einem der Ansprüche 16-22, wobei FEC mit Verschachtelung verwendet wird, um Impulsrauschen zu korrigieren.

Revendications

1. Procédé d'initialisation d'un système de communication comprenant :
- la détermination, sur la base d'une valeur de protection contre un bruit impulsionnel, d'un nombre M de symboles à tonalités multiples discrètes, DMT, à répéter pendant une initialisation, dans lequel le nombre M de symboles DMT à répéter est calculé comme étant $M = A * INP + B$, où A et B sont des nombres entiers et INP est la valeur de protection contre le bruit impulsionnel, la valeur de protection contre le bruit impulsionnel étant définie comme étant le nombre de symboles DMT consécutifs qui, lorsqu'ils sont complètement corrompus par le bruit impulsionnel, peuvent être corrigés au moins en utilisant une correction d'erreur sans voie de retour (FEC) pendant une transmission de données utilisateur (« showtime »), et
la transmission d'un symbole DMT répétée M fois, pendant l'initialisation de l'émetteur-récepteur de symboles DMT.
2. Procédé selon la revendication 1, dans lequel un modem d'émission effectue l'étape de détermination, ou dans lequel un modem de réception effectue l'étape de détermination.
3. Procédé selon la revendication 1 ou 2, dans lequel $A = 2$ et $B = 1$.
4. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre :
- la modulation d'au moins un bit sur les symboles DMT répétés, et

- la transmission du nombre de symboles DMT répétés.
5. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre :
- la réception du nombre de symboles DMT répétés, et
la démodulation d'au moins un bit à partir du symbole DMT répété.
6. Procédé selon l'une quelconque des revendications précédentes, dans lequel les symboles DMT répétés sont consécutifs, sont des symboles DMT identiques ou une séquence de symboles DMT identiques.
7. Procédé selon l'une quelconque des revendications précédentes, dans lequel la correction d'erreur sans voie de retour inclut des codes de Reed Solomon, des codes de Hamming, des codes de convolution, des codes par treillis, des turbo codes ou des codes de contrôle LDPC.
8. Procédé selon l'une quelconque des revendications précédentes, dans lequel la correction FEC est utilisée avec un entrelacement afin de corriger le bruit impulsionnel.
9. Système de communication comprenant :
- un module de répétition de symboles DMT (140) qui détermine, pendant une initialisation, sur la base d'une valeur de protection contre un bruit impulsionnel, un nombre M de symboles DMT à répéter dans lequel le nombre M de symboles DMT à répéter est calculé comme étant $M = A * INP + B$, où A et B sont des nombres entiers et INP est la valeur de protection contre le bruit impulsionnel, la valeur de protection contre le bruit impulsionnel étant définie comme étant le nombre de symboles DMT consécutifs qui, lorsqu'ils sont complètement corrompus par le bruit impulsionnel, peuvent être corrigés au moins en utilisant une correction d'erreur sans voie de retour (FEC) pendant une transmission de données utilisateur (« showtime »), et
la transmission d'un symbole DMT répétée M fois, pendant l'initialisation de l'émetteur-récepteur de symboles DMT.
10. Système selon la revendication 9, dans lequel le module de répétition de symboles DMT (140) se trouve dans un modem d'émission ou dans un modem de réception et/ou dans lequel $A = 2$ et $B = 1$.
11. Système selon la revendication 9 ou 10, comprenant en outre :
- un module de modulation (180) pouvant moduler au moins un bit sur les symboles DMT répétés, et
un module émetteur (190) pouvant transmettre le nombre de symboles DMT répétés.
12. Système selon l'une quelconque des revendications 9 à 11, comprenant en outre :
- un module récepteur (190) pouvant recevoir le nombre de symboles DMT répétés, et
un module de démodulation (180) pouvant démoduler au moins un bit à partir du symbole DMT répété.
13. Système selon l'une quelconque des revendications 9 à 12, dans lequel les symboles DMT répétés sont consécutifs, sont des symboles DMT identiques ou une séquence de symboles DMT identiques.
14. Système selon l'une quelconque des revendications 9 à 13, dans lequel la correction d'erreur sans voie de retour inclut des codes de Reed Solomon, des codes de Hamming, des codes de convolution, des codes par treillis, des turbo codes ou des codes de contrôle LDPC.
15. Système selon l'une quelconque des revendications 9 à 14, dans lequel la correction FEC est utilisée avec un entrelacement afin de corriger le bruit impulsionnel.
16. Moyen d'initialisation d'un système de communication, comprenant :
- un moyen permettant de déterminer, pendant une initialisation sur la base d'une valeur de protection contre un bruit impulsionnel, un nombre M de symboles DMT à répéter dans lequel le nombre M de symboles DMT à répéter est calculé comme étant $M = A * INP + B$, où A et B sont des nombres entiers et INP est la valeur de protection contre le bruit impulsionnel, la valeur de protection contre le bruit impulsionnel étant définie comme étant le nombre de symboles DMT consécutifs qui, lorsqu'ils sont complètement corrompus par le bruit impulsionnel, peuvent être corrigés au moins en utilisant une correction d'erreur sans voie de retour (FFC) pendant une transmission de données utilisateur (« showtime »), et
un moyen permettant de transmettre un symbole DMT de manière répétée M fois, pendant l'initialisation de l'émetteur-récepteur de symboles DMT.
17. Moyen selon la revendication 16, dans lequel un modem d'émission effectue l'étape de détermination,

ou dans lequel un modem de réception effectue l'étape de détermination.

- 18.** Moyen selon la revendication 16 ou 17, dans lequel
A = 2 et B = 1. 5
- 19.** Moyen selon l'une quelconque des revendications
de 16 à 18, comprenant en outre :
- un moyen permettant de moduler au moins un 10
bit sur les symboles DMT répétés, et
un moyen permettant de transmettre le nombre
de symboles DMT répétés.
- 20.** Moyen selon l'une quelconque des revendications 15
16 à 19, comprenant en outre :
- un moyen permettant de recevoir le nombre de
symboles DMT répétés, et 20
un moyen permettant de démoduler au moins
un bit à partir du symbole DMT répété.
- 21.** Moyen selon l'une quelconque des revendications
16 à 20, dans lequel les symboles DMT répétés sont 25
consécutifs, sont des symboles DMT identiques ou
une séquence de symboles DMT identiques.
- 22.** Moyen selon l'une quelconque des revendications
16 à 21, dans lequel la correction d'erreur sans voie 30
de retour inclut des codes de Reed Solomon, des
codes de Hamming, des codes de convolution, des
codes par treillis, des turbo codes ou des codes de
contrôle LDPC.
- 23.** Moyen selon l'une quelconque des revendications 35
16 à 22, dans lequel la correction FEC est utilisée
avec un entrelacement afin de corriger le bruit im-
pulsionnel.

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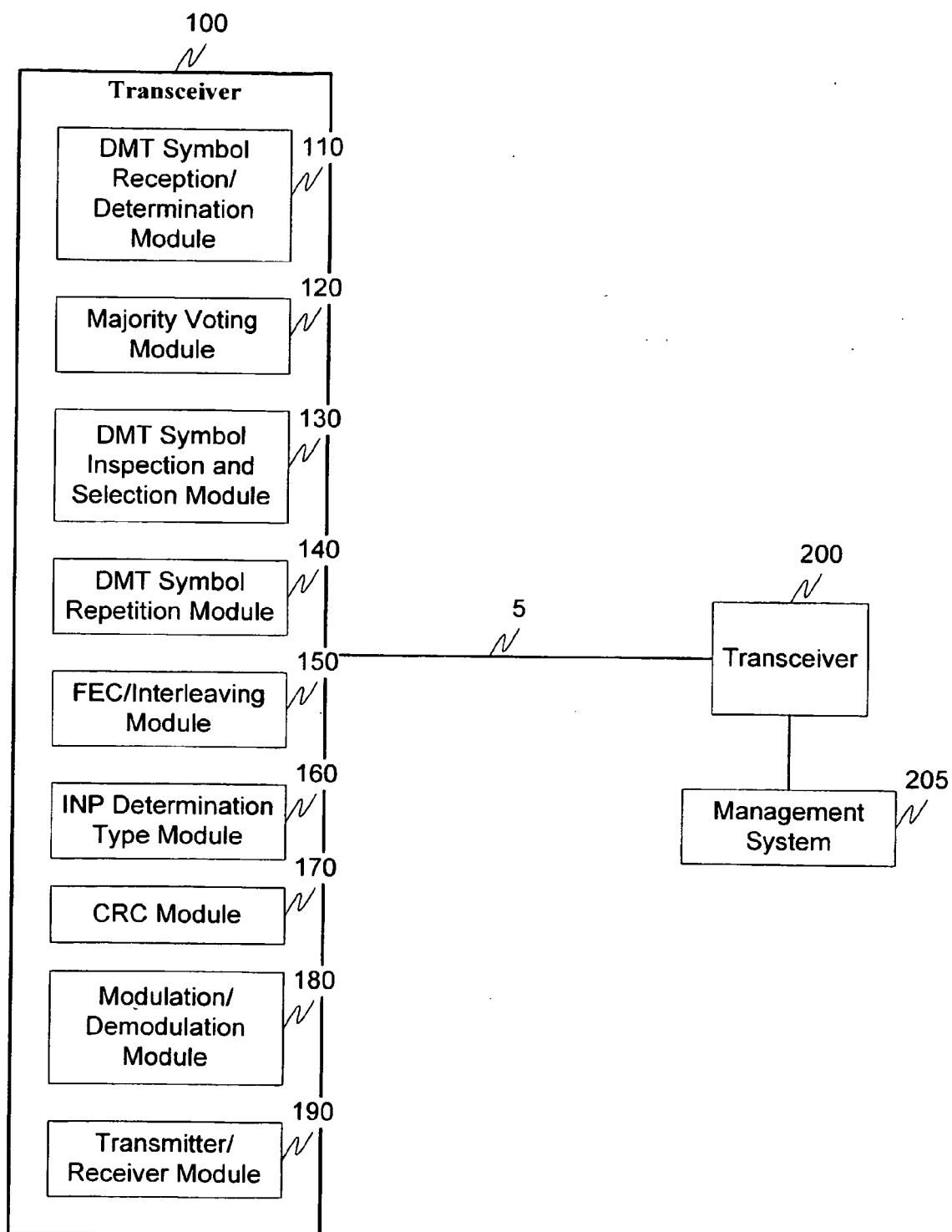
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Fig. 1

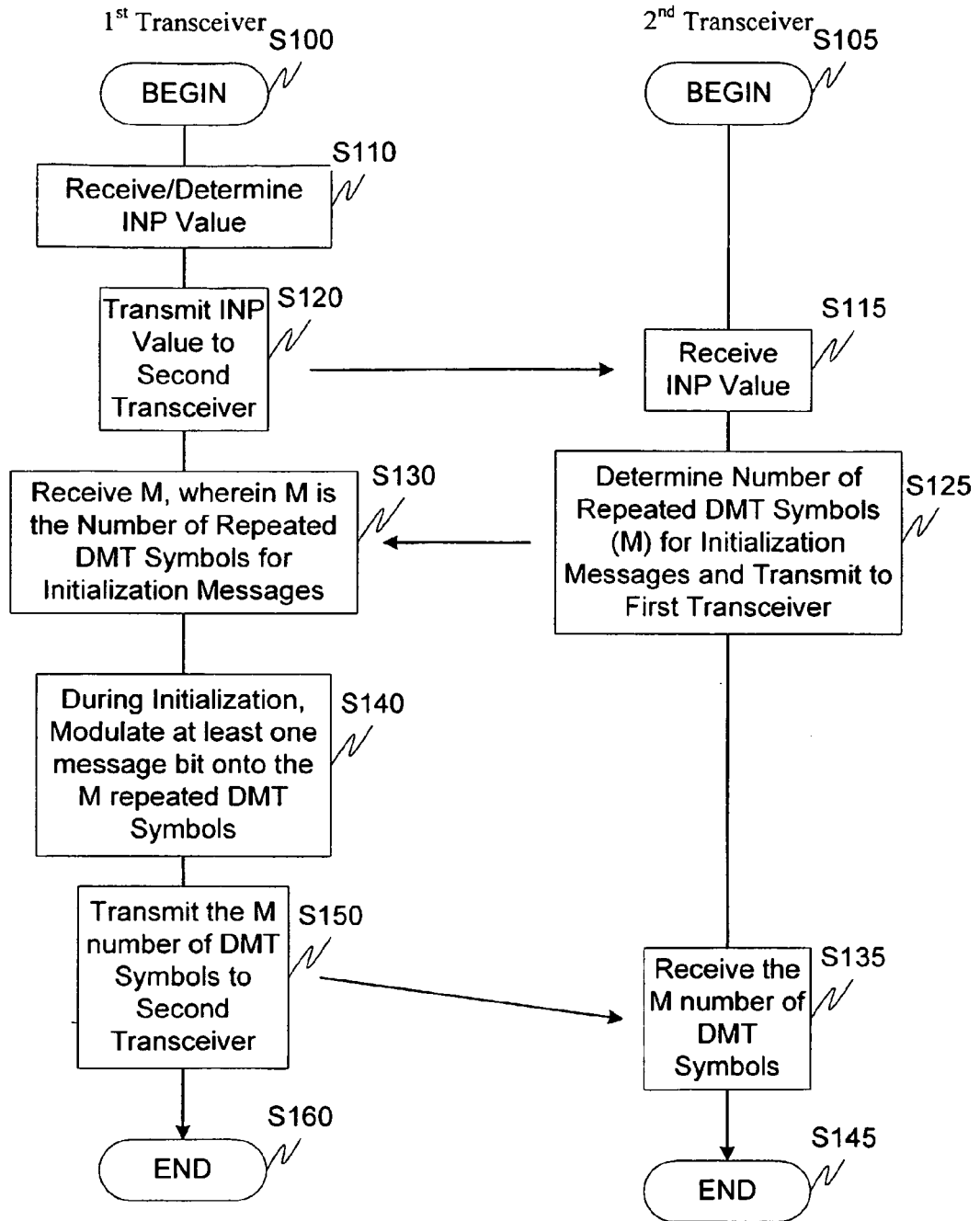


Fig. 2

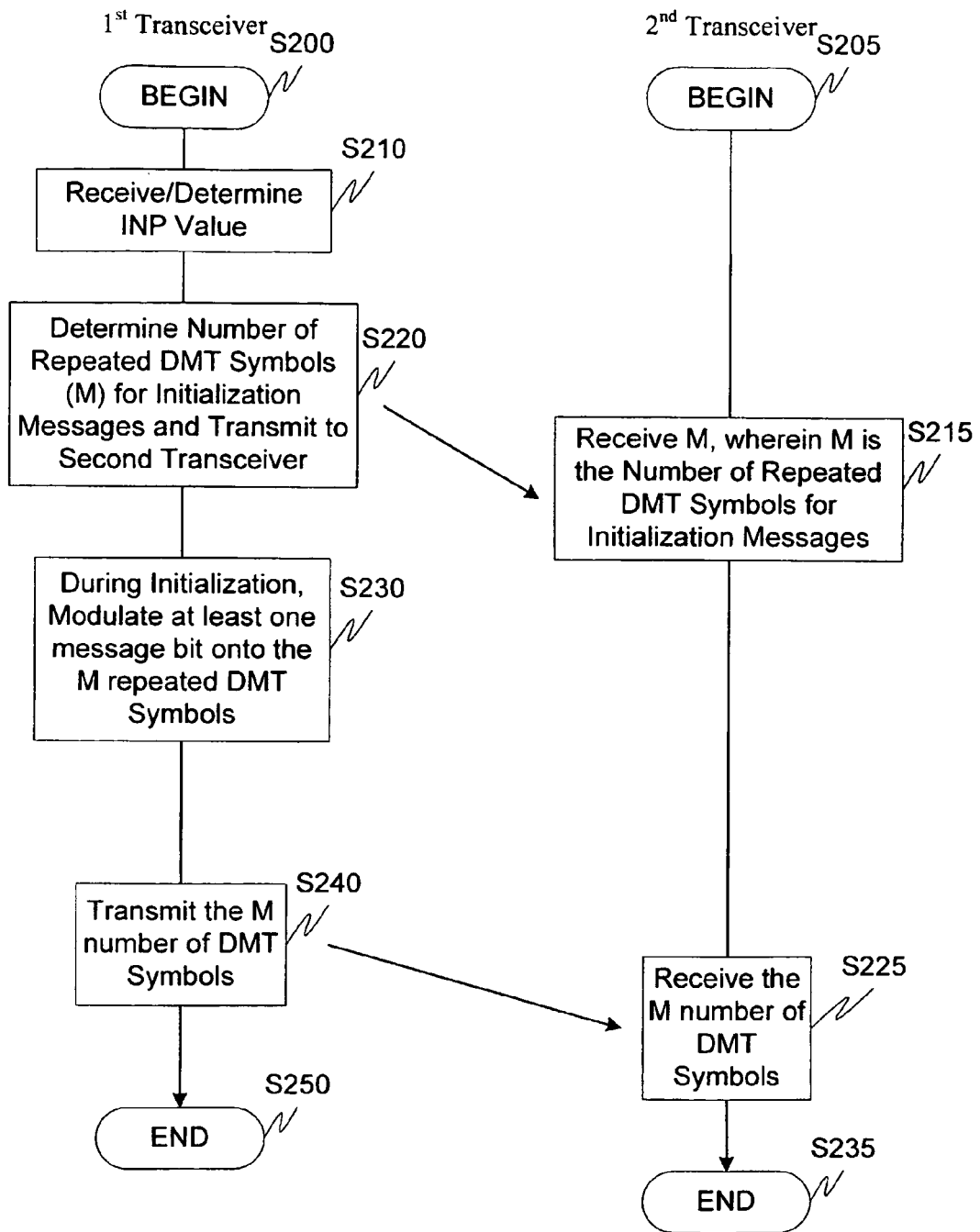


Fig. 3

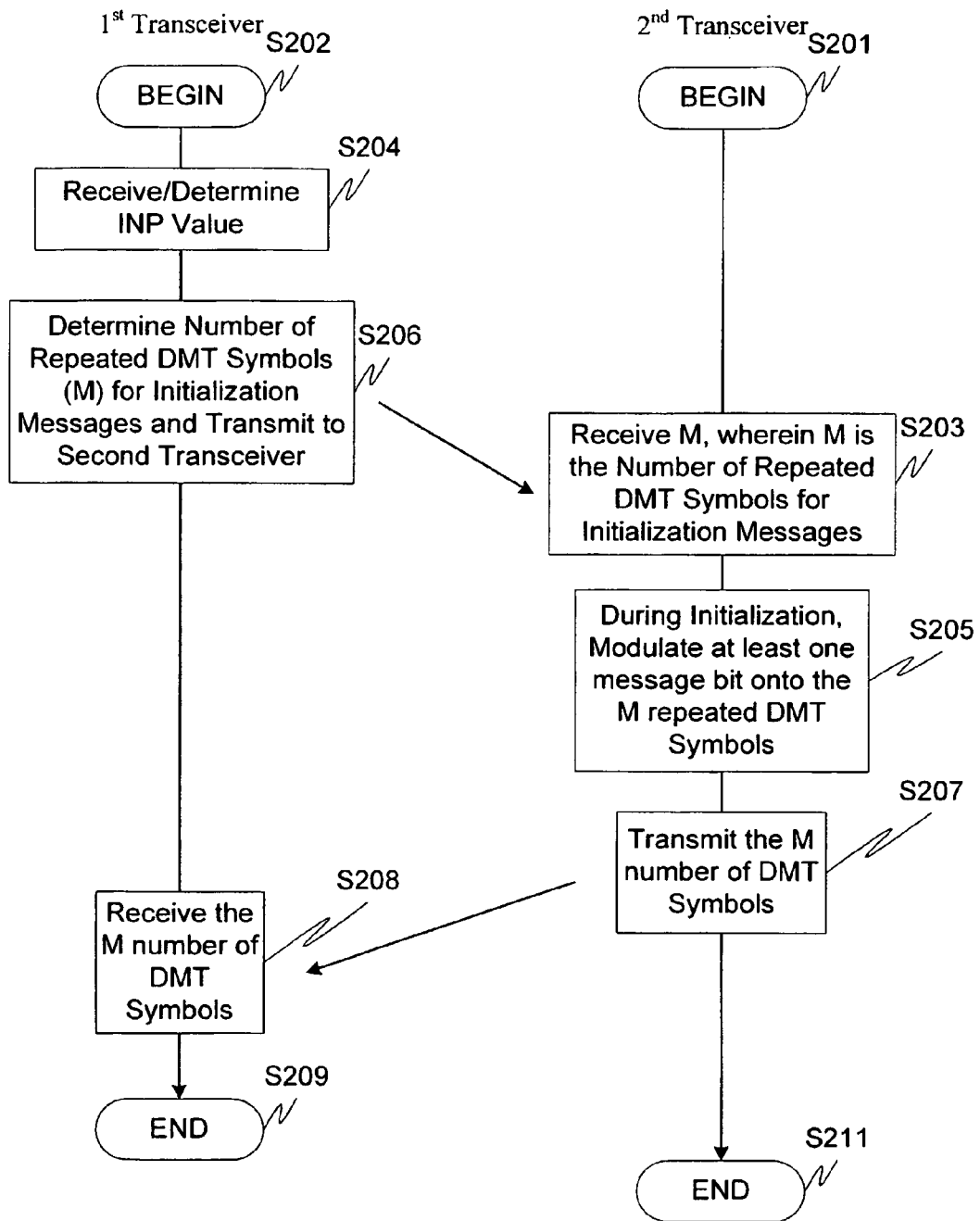


Fig. 4

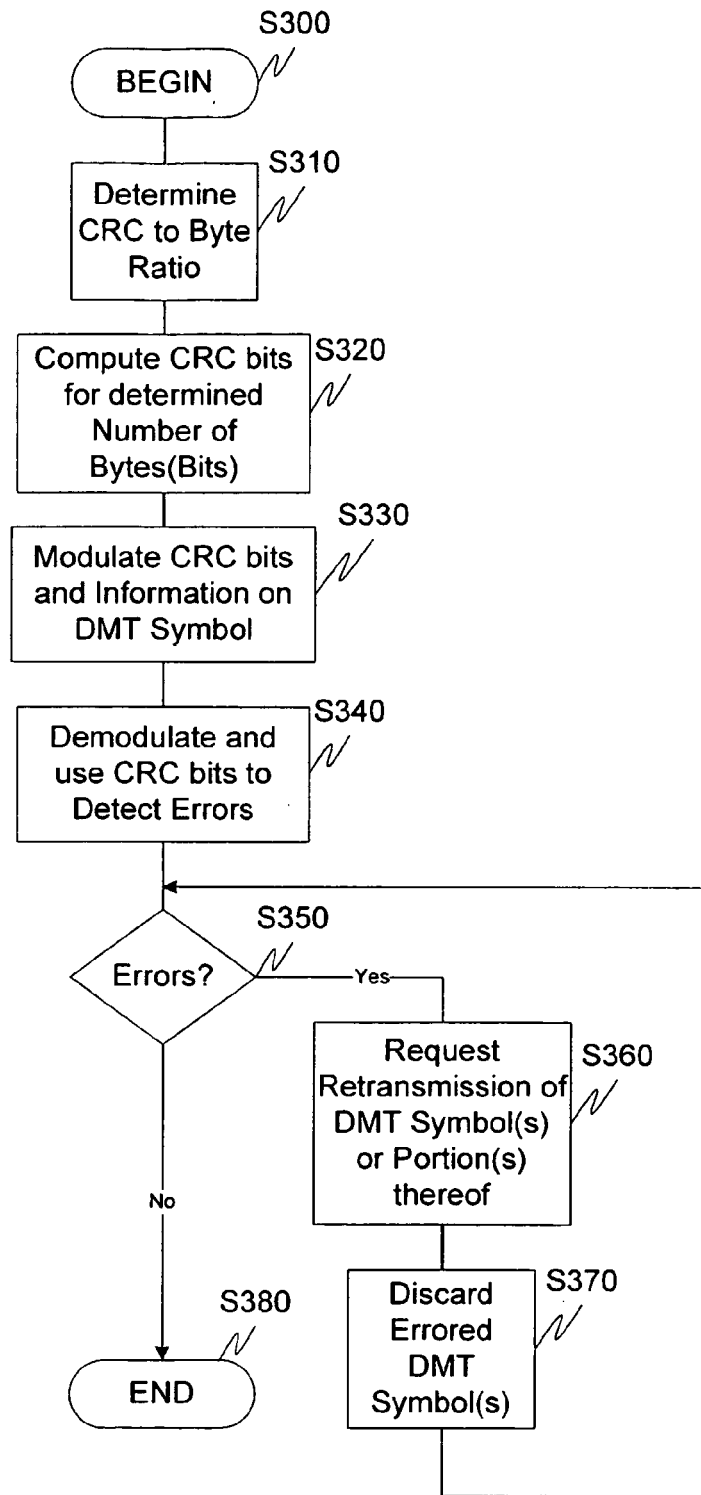


Fig. 5

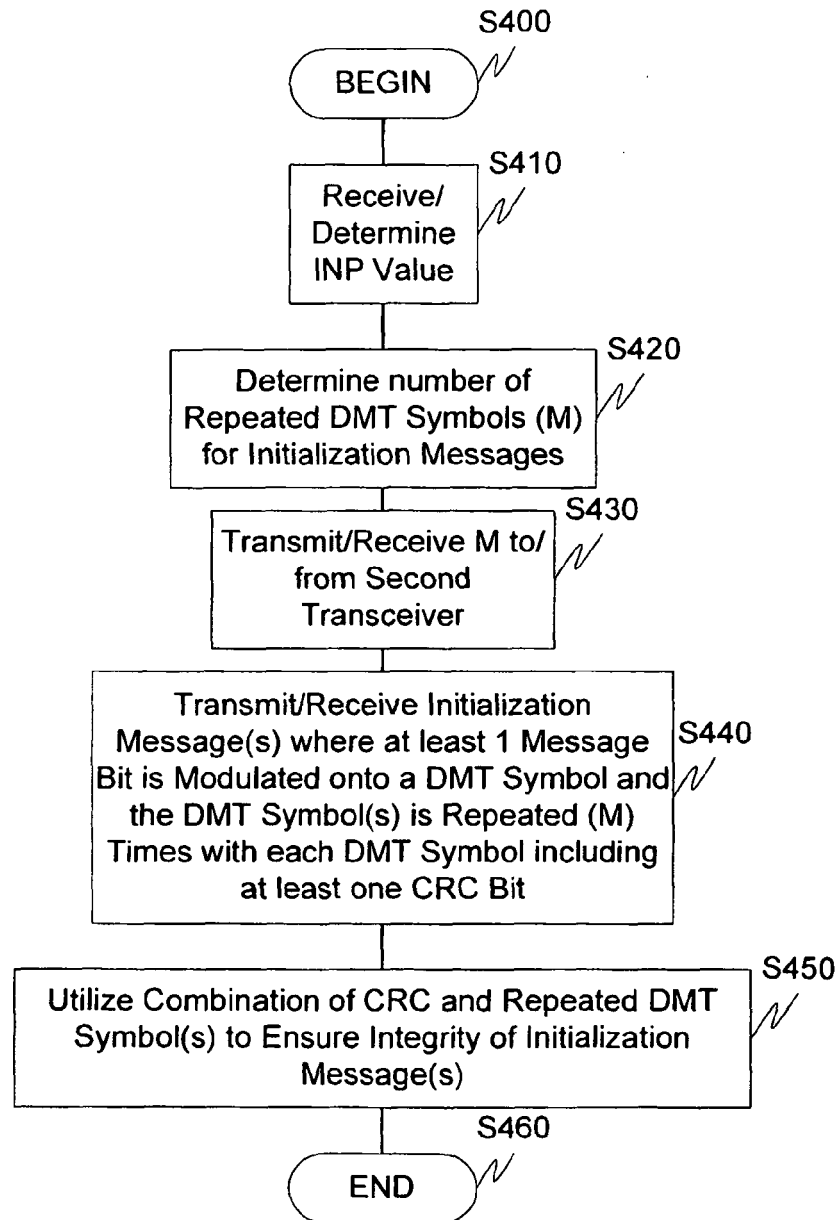


Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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