US 20090150537A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2009/0150537 A1

(43) Pub. Date: Jun. 11, 2009

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(54) DATA COMMUNICATION METHOD FOR A SET OF HARD-REAL TIME APPLICATIONS WITHIN A NETWORK

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(21) Appl. No.: 11/953,711

(22) Filed: Dec. 10, 2007

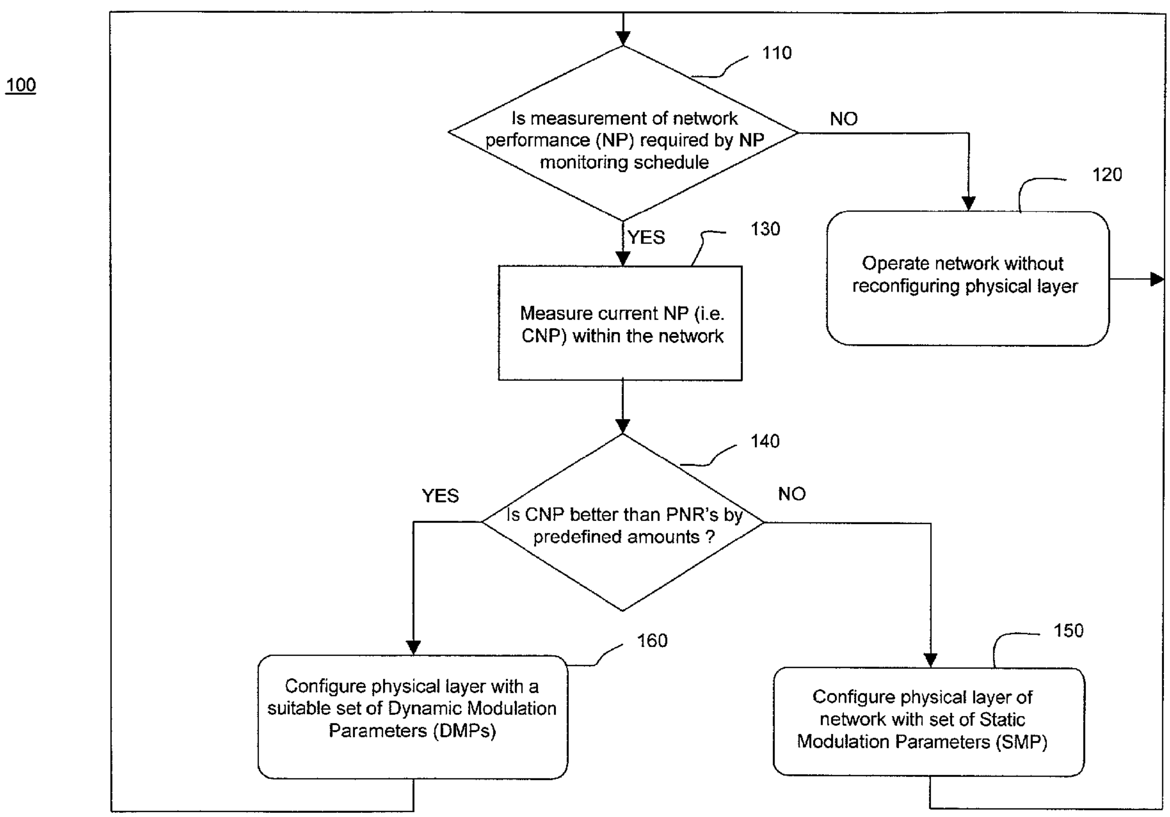
Publication Classification

(51) Int. Cl.
G06F 15/16 (2006.01)

(52) U.S. Cl. 709/224

(57) ABSTRACT

A data communication method for a set of hard real-time applications with an associated set of predefined network requirements (PNR) is provided. The method comprises configuring the physical layer of the network with a set of static modulation parameters (SMPs) to guarantee the PNRs are met at worst-case operating conditions for the network. The method further comprises measuring the current network performance within the network based on a given network performance monitoring schedule and, whenever the current network performance exceeds the PNRs by predefined amounts, adjusting the physical layer of the network by selecting a set of dynamic modulation parameters (DMP's) to increase the bandwidth availability within the network. Advantageously, the invention further allows for the allocation of the excess bandwidth to a set of non-hard real-time applications, whenever the current network performance exceeds the PNR.



100

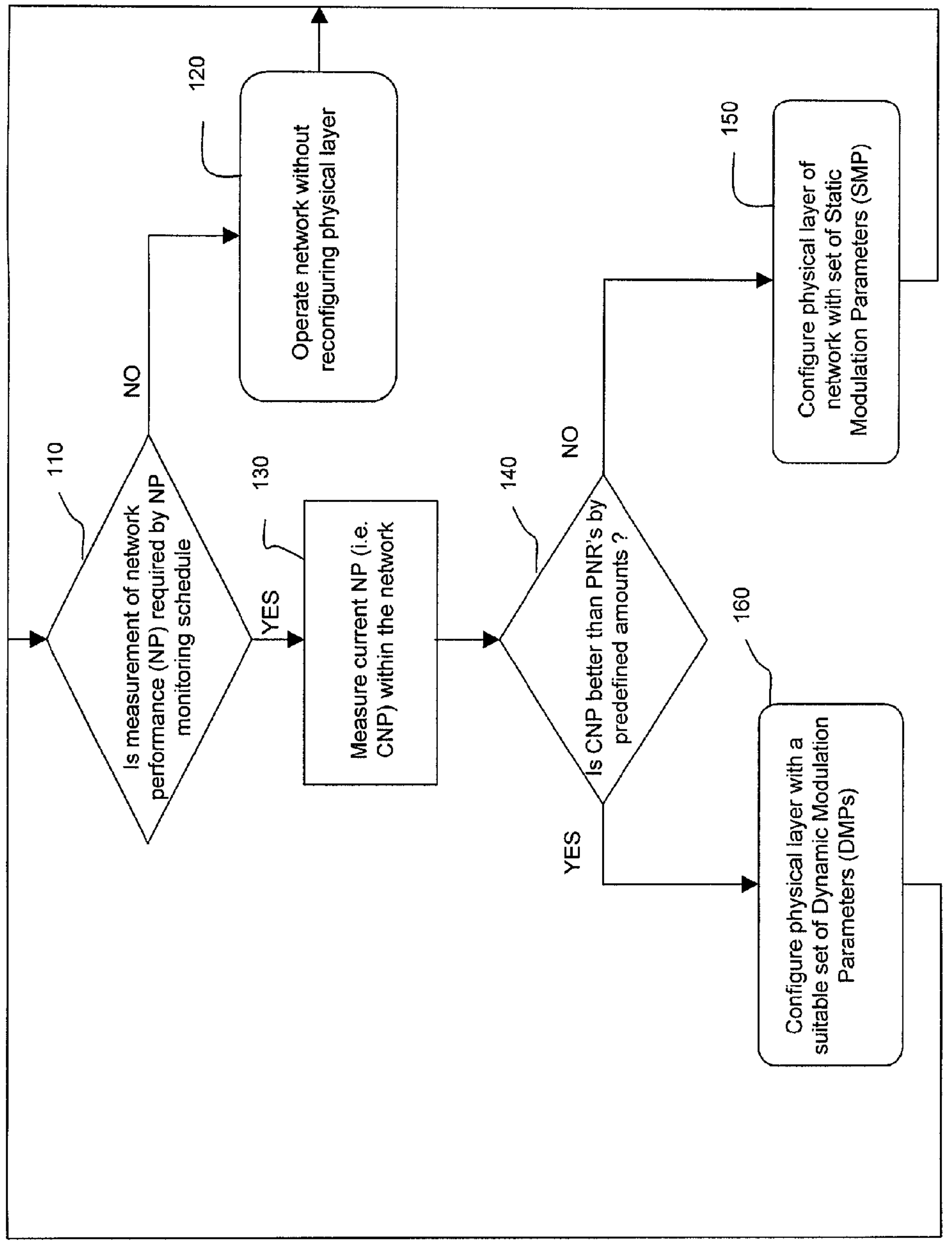
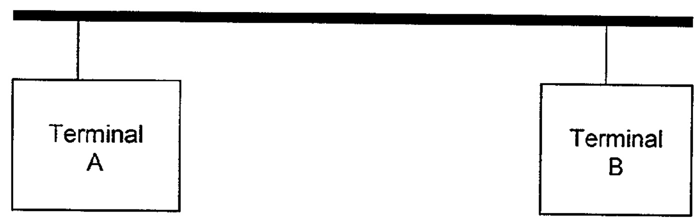
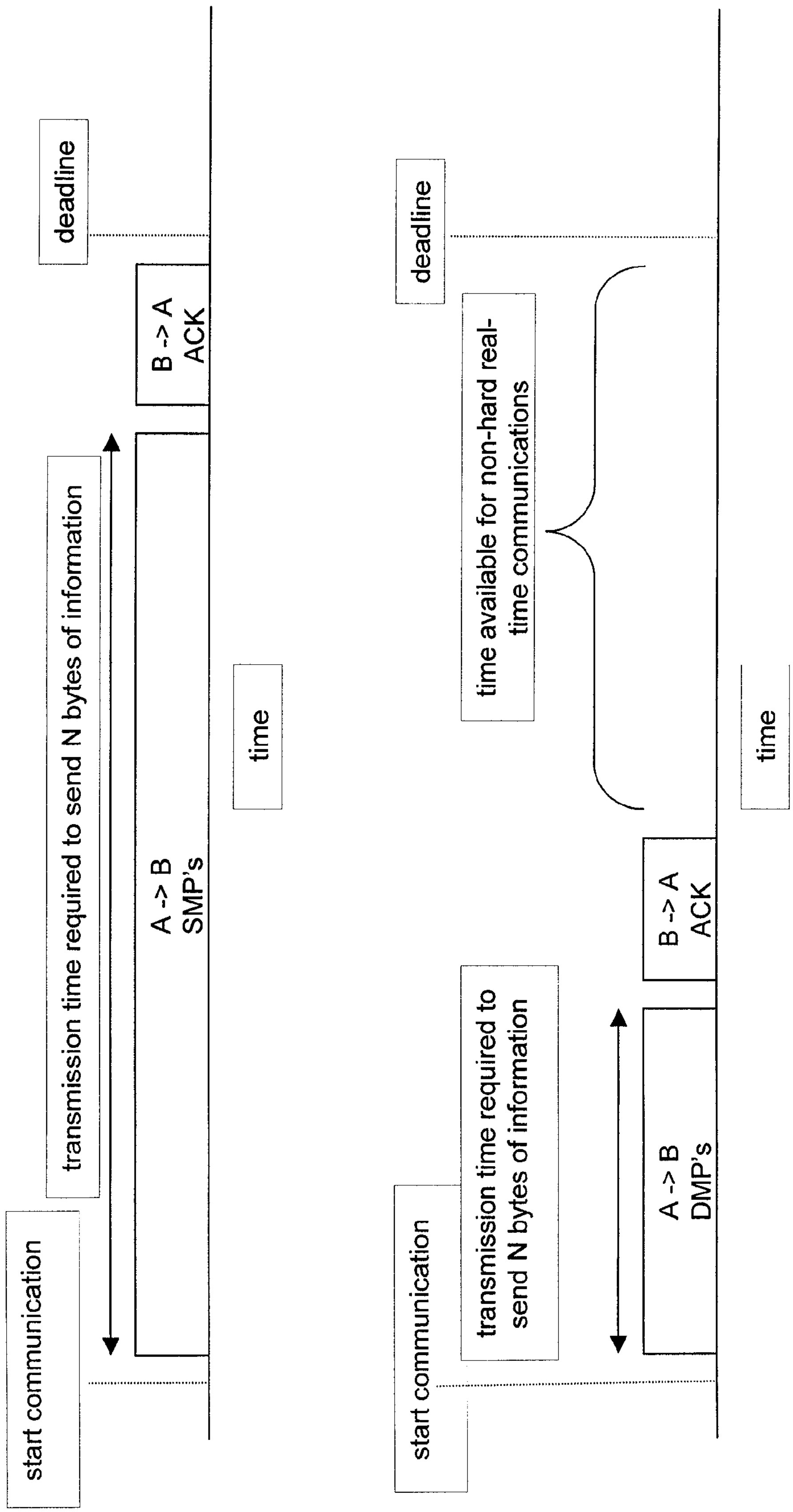

110
Is measurement of network performance (NP) required by NP monitoring schedule
NO
120
Operate network without reconfiguring physical layer
YES
130
Measure current NP (i.e. CNP) within the network
140
Is CNP better than PNR's by predefined amounts ?
NO
150
Configure physical layer of network with set of Static Modulation Parameters (SMP)
YES
160
Configure physical layer with a suitable set of Dynamic Modulation Parameters (DMPs)

FIGURE 1



Transmitting Terminal/Application	Receiving Terminal//Application	Packet Error Rate	Static Modulation Parameters (SMP)	Static Capacity (SC)
A	B	PER1	SMP1	SC1
B	A	PER2	SMP2	SC2

FIGURE 2



start communication
transmission time required to send N bytes of information
A -> B
SMP's
time
B -> A
ACK
deadline
start communication
transmission time required to send N bytes of information
A -> B
DMP's
B -> A
ACK
time
time available for non-hard real-time communications
deadline

FIGURE 3

DATA COMMUNICATION METHOD FOR A SET OF HARD-REAL TIME APPLICATIONS WITHIN A NETWORK

BACKGROUND OF THE INVENTION

[0001] A hard real-time application within a data network is a type of data communication in which a message is transmitted and successfully received over the network prior to a certain known deadline and with sufficient degree of certainty. An example of this would be control of a wing flap over an avionics bus. Thus, a minimum data rate and a maximum packet error rate must be guaranteed, under all operating conditions of the network. For multiple hard real-time applications, aggregate minimum data rate and maximum packet error rate requirements guaranteeing performance of the applications under all operating conditions can be defined. The set of these aggregate rates for a given set of hard real-time applications will be referred herein as the associated set of predefined network requirements (PNRs).

[0002] Similarly, a non-hard real-time application refers to a data communication process where there is no real-time constraint or deadline.

[0003] Current network performance of a given network is defined herein as a metric indicative of the data rate and bit error rate for each node pair in the network, at a given point in time. It is assumed to be substantially constant from the moment it is measured over a given period of time, following which a new current network performance measurement may be required.

[0004] Hard real time systems can be constructed using different media access protocols including a command/response protocol or a priority based protocol. Among others, the MIL-STD-1553 or simply 1553 is generally utilized for hard real time communication. 1553 is an approximately 30 year old technology that defines the electrical and signaling characteristics for 1 Mbps data rate communications over an asynchronous serial, command/response digital data bus on which messages are time division multiplexed among users. The United States Department of Defense ("DoD") requires the use of 1553 as the standard for all inter and intra-subsystem communications on all military airplanes, helicopters, ships and land vehicles. Originally used only in mission avionics, 1553 is now used in flight critical avionics, flight control, weapons, electrical power control, and propulsion control. 1553 specifies all of the electrical characteristics of the receivers, transmitters, and cable used to implement the bus, as well as the complete message transmission protocol. The messages are generally highly repetitive, and their content and periodicity are all pre-planned. The data capacity of 1 Mbps also comes with an associated bit error rate. Various notices, such as 1553a, 1553b, up to 1553e of the standard are available. For 1553b, there is a requirement to have a word or packet error rate of 1 in 10,000,000. In a lot of cases the bus will in fact support much higher communications rates at the same or lower packet error rate.

[0005] MIL-STD-1553B utilizes a primitive Manchester II bi-phase signaling scheme over shielded twisted pair cabling. This modulation scheme is bandwidth inefficient with most of its signal energy concentrated around 1 MHz. MIL-STD-1553b has little remaining capacity for existing applications and leaves little opportunity to enable additional communication capabilities.

[0006] Notice 5 of MIL-STD-1553 or 1553e provides an overlap of 1553 signals with signals based on Orthogonal Frequency Division Multiplexing (OFDM), for increased bandwidth availability for additional applications and without impact to the existent 1553 communication.

[0007] OFDM communication systems are generally designed to be rate adaptive in order to take advantage of the higher communications capacity of a particular channel at a particular time. Examples include technologies such as: 802.11a, HomePlug, HomePNA, WiMax, etc. Rate adaptation is usually implemented based on metric calculations from exchanging signals between two or more nodes on a network. These metrics are generally related to the signal to noise ratio (SNR) at the receiving device with the transmitter agreeing to use suitable modulation and coding to maximize the throughput for particular bit error rate for the channel. For OFDM communications, the number of bits assigned to an OFDM sub-carrier can be adapted independently for all sub-carriers.

[0008] A managed network (like a 1553b avionics network) refers to a controlled network where a network designer would configure and specify the number of communications devices as well as the details of the communications taking place. For 1553b, every message that is transmitted is specified according to a schedule delivered by a bus controller.

SUMMARY OF THE INVENTION

[0009] An object of the invention is to provide a data communication method for a set of hard real-time applications with an associated set of predefined network requirements (PNR). The method comprises configuring the physical layer of the network with a set of static modulation parameters (SMPs) to guarantee the PNRs are met at worst-case operating conditions for the network. The method further comprises measuring the current network performance within the network based on a given network performance monitoring schedule and, whenever the current network performance exceeds the PNRs by predefined amounts, adjusting the physical layer of the network by selecting a set of dynamic modulation parameters (DMP's) to increase the bandwidth availability within the network. Advantageously, the invention further allows for the allocation of the excess bandwidth to a set of non-hard real-time applications, whenever the current network performance exceeds the PNR.

[0010] Advantageously, the invention provides a robust and efficient communication method for hard real-time and non-hard real-time applications over a network.

BRIEF DESCRIPTION OF DRAWINGS

[0011] The following detailed description, given by way of example and not intended to limit the present invention solely thereto, will best be appreciated in conjunction with the accompanying drawings, wherein like reference numerals denote like elements and parts, where:

[0012] FIG. **1** is a flow chart of a data communication method for a given set of hard-real time applications, within a network, according to an embodiment of the invention;

[0013] FIG. **2** is a diagram of a two node network using the method in FIG. **1**;

[0014] FIG. **3** is a timing diagram for data communication occurring within the network in FIG. **2**, according to a preferred embodiment of the invention;

DETAILED DESCRIPTION OF THE INVENTION

[0015] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

[0016] FIG. **1** illustrates a flow chart of a data communication method **100** for a given set of hard-real time applications, within a network, according to an embodiment of the invention. The hard-real time applications have an associated set of predefined network requirements (PNRs) guaranteeing the applications are supported by the data network under any network operating conditions. To arrive at a set of PNR's, required maximum packet error rates and minimum data rates are first specified for each link direction within the network, for each hard real-time application to be supported. Following, aggregate packet error rates and aggregate data rates for all links in the network, for all hard real-time applications to be supported, can be deduced analytically or by measurement.

[0017] Within method **100**, a check whether a measurement of the network performance (NP) is required by an NP monitoring schedule, is initially performed, at step **110**. If such a measurement is not required, then the network is operated without reconfiguring its physical layer, as indicated by step **120**. If a measurement of the NP is required by the NP monitoring schedule, than it is performed, at step **130**, and a new current network performance (CNP) value is available. Following the measurement of the CNP, a determination as to whether the CNP is better than the set of PNR's by predefined amounts is carried out, at step **140**. A CNP better than the set of PNR's is indicative of excess signal-to-noise ratio (SNR). If the answer to step **140** is negative, the physical layer of the network is configured with a set of Static Modulation Parameters (SMP's), step **150**. Use of the set of SMP's at all nodes in the network will result in a network performance that meets the set of PNR's for all network operating conditions. If the answer to step **140** is positive, the physical layer of the network is configured with a suitable set of Dynamic Modulation Parameters (DMP's), step **160**. DMP's are designed to take advantage of the more favorable current network performance in the network by increasing bandwidth while keeping the error rates as required by the set of PNR's. Generally, specific steps of method **100** may be carried out either in a centralized, a distributed manner, or a combination of these, within the network. In the preferred embodiment, method **100** is carried out at each node in the network.

[0018] The data communication method **100** may further comprise, in case of a positive answer to step **140**, allowing the excess bandwidth to be assigned to non-hard real time applications.

[0019] The data communication method **100** can be carried over any network that can support hard real-time applications and monitoring of the network performance. The networks can be constructed using different media access protocols including a command/response protocol or a priority based protocol. According to the preferred embodiment of the invention, the network is a 1553 network, comprising a bus controller (BC) and remote terminals RT's communicating over a data bus. The data communication occurs via 1553 and OFDM signaling as described in co-pending U.S. application Ser. No. 11/419,742. In addition, messaging within the network occurs based on a schedule transmitted by a bus controller (BC) to all remote terminals (RTs).

[0020] Operating conditions can be any factors that may affect network performance, and may include, without limitation, environmental factors such as pressure, temperature, refractive index of propagating medium, in the case of an avionics data bus altitude, airplane velocity, as well as various operating modes such as combat, sitting on the tarmac in the case of a military airplane, etc.

[0021] The monitoring of network performance can be carried out based on various SNR-related performance metrics for bus conditions such as Bit Error Rate (BER), receiver power etc. Such metrics could be monitored periodically, as well as averaged over appropriate time intervals, according to specific system topologies and communication requirements.

[0022] Configuring the physical layer with various sets of modulation parameters implies setting the various terminals within the network, or their modems, to communicate data according to various modulation parameters. Without limitation, physical layer modulation parameters include transmitter power, modulation scheme such as OFDM, modulation level such as BPSK, QPSK, 16 QAM for M-QAM systems, error correction scheme, bits/tone of modulation scheme subcarriers, convolutional code rate such as ½, ¾, ⅞, transmitter digital scaling, power spectral density etc. Advantageously, in addition to physical layer parameters, other higher layer parameters, such as Media Access Control (MAC) parameters, may be used. For example, the preferred embodiment also uses frame length as a modulation parameter. Likewise, overhead size, or other subframe size, could be used.

[0023] While a unique set of SMPs is defined in connection with a default mode of communication and allowing for the required set of hard real-time applications to be supported under any circumstances, several sets of DMP's may be available for selection, each of them supporting the given set of hard real-time applications within associated amounts of excess bandwidth. The number of the DMP sets available can be dependent, among others, on the desired granularity of the excess bandwidth, non-hard application bandwidth requirements, etc.

[0024] An example of using the method **100** of FIG. **1** for a two node network is detailed next.

[0025] The two node network **50** of FIG. **2** comprises Terminal A and Terminal B linked by a data bus. For this example, a first hard real-time application that has to transmit data from Terminal A to Terminal B and a second hard real-time application that has to transmit data from Terminal B to Terminal A. The set of predefined network requirements for the two applications are, respectively packet error rates, PER**1** and PER**2**, and data rates or static capacities, SC**1** and SC**2**. Note that there is a data rate associated with each direction of the link as it is generally assumed that the channel capacity is not reciprocal.

[0026] A set of SMP's that guarantee the set of PNR's is met for the two applications under all operating conditions of network **50** can be determined. In practice, it may be difficult to ascertain the SMP's under all conditions and a margin of error may be built in for safety. Furthermore, all additional overhead for the protocols used and the overhead associated with the network performance monitoring schedule are advantageously taken into account when determining the set of SMP's. Even further, in a managed network such as a 1553 network, the fact that communication occurs on a scheduled basis must also be taken into account when determining the set of SMP's.

[0027] It is assumed that the operating conditions are time varying and there will be a significant amount of time in which the current network performance is more favorable than the set of PNR's, allowing for communication to occur at a higher rate and still satisfy the packet error rate requirements. Under these more favorable conditions, terminals A and B can negotiate a suitable set of the Dynamic Modulation Parameters (DMP) to achieve a higher communication rate.

[0028] The current network performance or communication quality can be monitored between terminals by exchanging signals periodically.

[0029] In using DMP's, the network capacity is improved and the time it takes to transmit and receive hard-real time messages is reduced. If the capacity of the network was previously fully utilized, this would free up time to send more messages. The additional bandwidth can be used to allow for non-hard-real time applications. An example is illustrated in FIG. **3**. An acknowledgement (ACK) frame is included to indicate proper decoding of the transmitted message.

[0030] It has to be noted that in some instances, due to changing operating conditions, using only the set of SMPs may lead to a current network performance better than the set of PNRs. The excess bandwidth available in these situations can also be used for additional non-hard real time applications, without a change from the set of SMPs to a DMPs set.

[0031] When operating based on a set of DMPs, the conditions where the network capacity drops back to the worst case must be taken into account. If a message is transmitted using DMP's and it is decoded incorrectly, a message retry (retransmit) scheme may either attempt to re-transmit the message using the DMP's or drop back immediately to the set of SMP's, in order to guarantee that the communications requirements are met. In the first scenario, the overhead of the retries should preferably be taken into account.

[0032] Although the present invention has been described in considerable detail with reference to certain preferred embodiments thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred embodiments contained herein.

What is claimed is:

1. Within a network, a data communication method comprising

i. for a set of hard real-time applications with an associated set of predefined network requirements (PNR), configuring the physical layer of the network with a set of static modulation parameters (SMPs) to guarantee the PNRs are met at worst-case operating conditions for the network;

ii. measuring the current network performance within the network based on a given network performance monitoring schedule; and

iii. whenever the current network performance exceeds the PNRs by predefined amounts, adjusting the physical layer of the network by selecting a set of dynamic modulation parameters (DMP's) to increase the bandwidth availability within the network.

2. The data communication method of claim **1**, further comprising: whenever the current network performance exceeds the PNR, allocating the excess bandwidth to a set of non-hard real-time applications.

3. The data communication method of claim **1** wherein the communication within the network is based on a command/response protocol based on bus control.

4. The data communication method of claim **1** wherein the communication within the network is based on a priority signaling scheme among terminals of the network.

5. The data communication method of claim **1** wherein the monitoring schedule is periodic.

6. The data communication method of claim **3** wherein the command/response protocol is according to the 1553 standard.

7. The data communication method of claim **1** wherein the SMP's and the DMP's are OFDM parameters.

8. The data communication method of claim **1** wherein the adjustment of the physical layer of the network comprises adjustment of data modems of terminals within the network.

9. The data communication method of claim **1** wherein modulation parameters are selected from the group consisting of transmitter power, transmitter digital scaling, power spectral density, modulation level, modulation scheme, bits/tone of OFDM subcarriers, error correction scheme and convolutional code rate.

10. The data communication method of claim **1** further comprising whenever the current network performance exceeds the PNRs by predefined amounts, adjusting a network layer above the physical layer by selecting a set of higher layer dynamic modulation parameters (DMP's) to increase the bandwidth availability within the network.

11. The data communication method of claim **10** wherein the network layer above the physical layer is a Media Access Control layer.

12. The data communication method of claim **11** wherein the higher layer dynamic modulation parameters are selected from the group of frame size and overhead size.

13. The data communication method of claim **1** wherein the network is a managed network.

14. The data communication method of claim **1** further comprising using a message retransmit scheme whenever current network performance does not exceed the PNRs by predefined amounts and the network is configured based on dynamic modulation parameters.

15. The data communication method of claim **4**, wherein the message retransmit scheme comprises retransmiting signals within the network based on the set of DMP's in use, for a predetermined number of retries.

16. The data communication method of claim **15**, wherein the predetermined number of retries is dependent on the overhead of retries.

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