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(54) **DIGITAL SUBSCRIBER LINE MODEM WITH BITLOADING USING CHANNEL CONDITION MODEL**

(75) Inventors: **Danny Edgard Josephine Van Bruyssel**, Temse (BE); **Sigurd Jan Maria Schelstraete**, Mountain View, CA (US)

Correspondence Address:
SUGHRUE MION, PLLC
2100 PENNSYLVANIA AVENUE, N.W.
SUITE 800
WASHINGTON, DC 20037 (US)

(73) Assignee: **ALCATEL**

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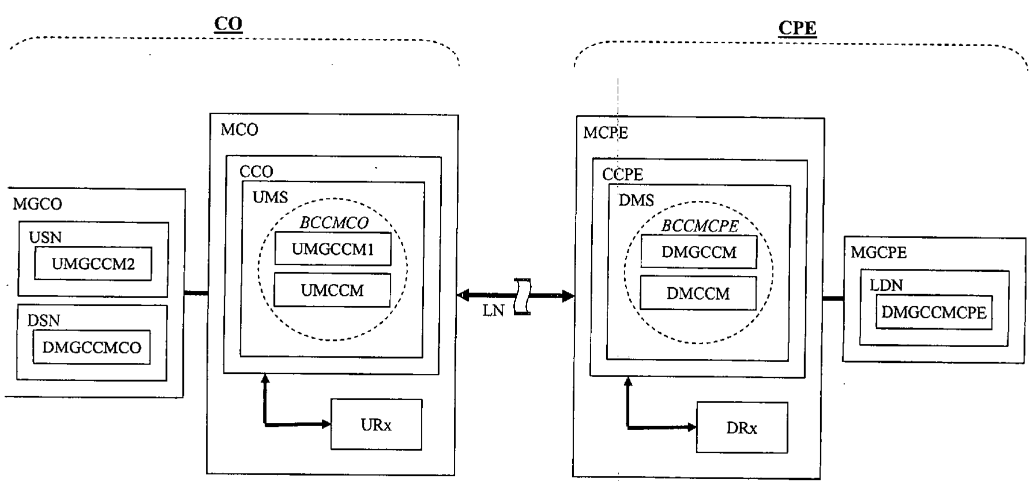
(57) **ABSTRACT**

A telecommunication arrangement with modems (MCO; MCPE) having a receiving module (URx; DRx) able to receive channels of signals via a communication line (LN). The arrangement preferably operates according to the xDSL protocol. The receiving module of each modem is associated to storage means (USN, DSN; LDN) storing a "channel condition model" corresponding to operational conditions of the channel, preferably to the "worst case". The channel condition model is determined by previously measured operational conditions of this channel and/or by a channel condition model managed externally to the modem, and which is stored in the storage means before the initialization of the modem. In different variants, the channel condition model is a model of the noise level, the signal-to-noise ratio, the actual or the maximum bitloading (b_i) per carrier of the channel and/or mathematical operations on these. The channel condition model is further updated at regular time intervals during initialization or showtime. The modem may be located at the Central Office (CO) or at the Customer Premises Equipment (CPE). The receiving module (URx) of the CO modem (MCO) may receive the channel condition model from the central office management device via a management interface. The channel condition model may also be transmitted from the central office management device to the receiving module (DRx) of the CPE modem (MCPE), and channel condition measurement information may even be fed back.



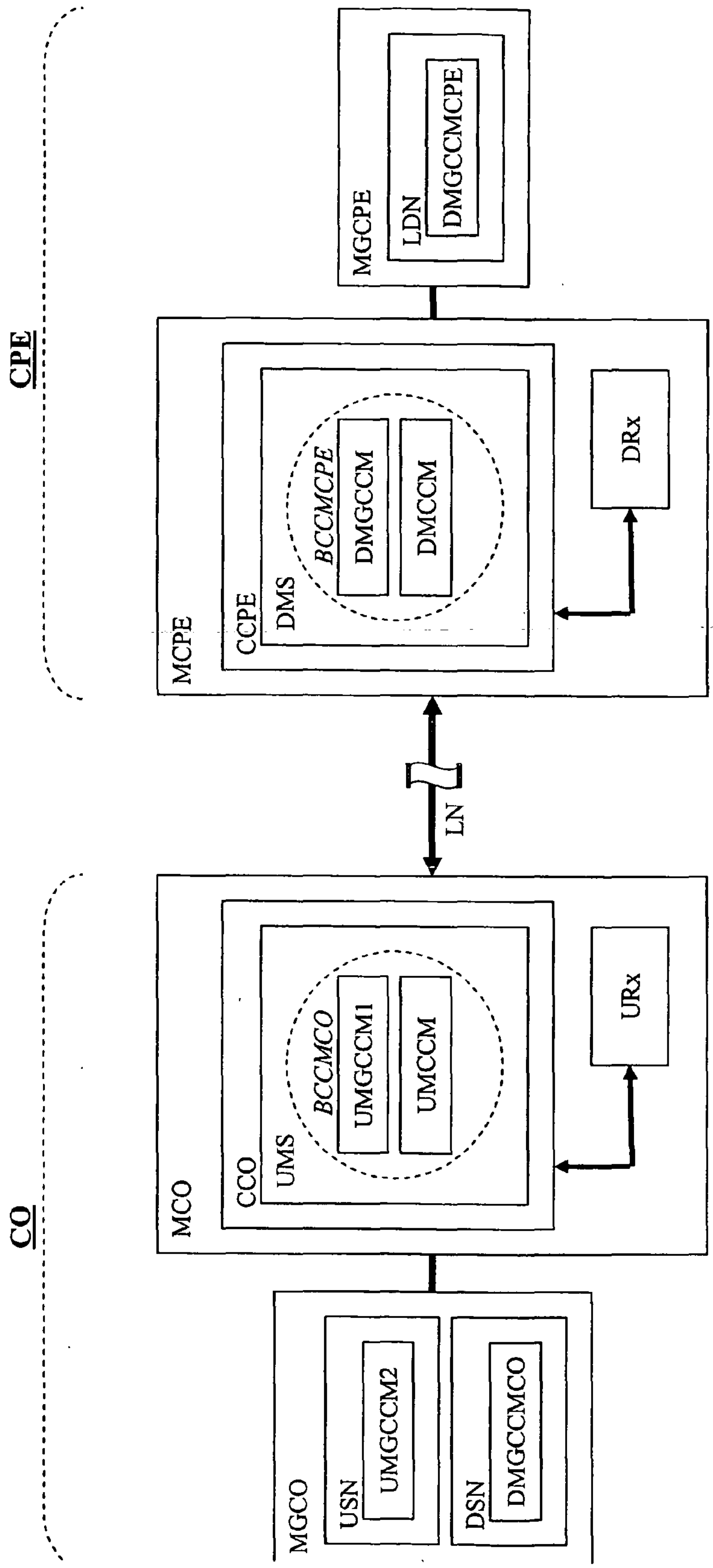

CPE
MGCPE
LDN
DMGCCMCPE
MCPE
CCPE
DMS
BCCMCPE
DMGCCM
DMCCM
DRx
LN
CO
MCO
CCO
UMS
BCCMCO
UMGCCM1
UMCCM
URx
MGCO
USN
UMGCCM2
DSN
DMGCCMCO

Fig 1

DIGITAL SUBSCRIBER LINE MODEM WITH BITLOADING USING CHANNEL CONDITION MODEL

[0001] The present invention relates to a telecommunication arrangement with a modem having a receiving module coupled to a controlling module, said receiving module is adapted to receive at least one channel via a communication line, said channel being adapted to transport data by means of signals with modulation having a bitload which is modifiable, said controlling module is adapted to modify the bitload used by said receiving module as a function of current measurements performed by the modem immediately prior to a current bitloading.

[0002] Such a telecommunication arrangement with a modem capable of operating at different bitloads/datarates is generally known in the art. Therein, the bitload/datarate used by the receiving module is based on current channel conditions measurements, being measurements at one particular point in time, generally immediately prior to the current bitloading.

[0003] The "bitload" is defined as following. If the modulation is BaseBand Modulation (BBM) or Single Carrier Modulation (SCM), the bitload corresponds to the number of information bits per modulation symbol, also called modulation or signaling time slot. If the modulation is Multi Carrier Modulation (MCM), the bitload corresponds to the set of numbers describing the number of information bits per modulation symbol for each carrier, e.g. corresponds to the array of bi as defined in ITU-T G.992.3 Section 8.5.

[0004] BaseBand Modulation (BBM) is a modulation type without first modulating the signal onto a carrier, e.g. Pulse Amplitude Modulation (PAM); Single Carrier Modulation (SCM) is a modulation type in which the signal is modulated onto a single carrier, e.g. Quadrature Amplitude Modulation (QAM), Carrierless AM-PM (CAP); and Multi Carrier Modulation (MCM) is a modulation type in which multiple carriers are used, e.g. Discrete MultiTone modulation (DMT). These modulation types are generally known in the art.

[0005] The process of determining a bitload is called "bitloading". This can be a determination of the complete bitload as in initialization, a determination of a part of the bitload as in "showtime" BitSwapping, e.g. as defined in ITU-T G.992.1, or a determination of a part of the bitload or of the complete bitload, as in "Showtime" On Line Reconfiguration (OLR), e.g. as defined in ITU-T G.992.3.

[0006] "Initialization" (a.k.a. Training) is the state or time period immediately preceding "Showtime", during which signals are exchanged between the modems in order to prepare showtime, but in which no user data are being communicated. Showtime (a.k.a. Data Transmission State or Steady State) is the state during which user data are being communicated by the modems.

[0007] A channel condition is any characteristics of the channel. The channel being defined as starting at the interface where the to be transmitted user data is given as input to the modem, and ending at the interface where the received user data is given as output by the modem connected to the other end of the communication line. Therefore, the channel includes parts of the communication line, following [illegible] face, analog front end, analog-to-digital convertors, digital-to-analog convertors, transmit and receive filters, gain scalers, modulation/demodulation, constellation encoding/decoding, channel coding/decoding, forward error correcting coding/decoding, scramblers, CRC generation and verification, . . . As such any parameter which can be measured in any of the functional blocks of the channel constitutes a channel condition. The channel condition measurement predominantly used in the prior art is the Signal-to-Noise Ratio (SNR) measured at the receiver, for MCM typically on each of the carriers.

[0008] In known telecommunication arrangements, a problem occurs in the modem on channels with fast changing noise conditions. If the noise environment changes drastically after startup, i.e. during the showtime, due for instance to crosstalk caused by a neighboring modem starting up, the bitload may need to be modified in order to adapt to the new conditions. In some cases, such processes (like BitSwapping or OLR) that adapt the bitload during showtime are not sufficient and a re-initialization may be needed. This interrupts the service and is disturbing to the customer.

[0009] In other words, the "traditional" bitloading cannot take into account sudden changes in noise environment. When changes are too high, on-line reconfiguration cannot cope and the only option is to shut down the connection en do a re-initialization. A re-initialization will always interrupt the service, even if it can be shorter than a full initialization.

[0010] To solve this problem, different solutions exist in the art.

[0011] It is first to be noted that, in a preferred embodiment of the present invention, the modem is an adaptive xDSL modem.

[0012] Such a modem is a modem which is part of a Digital Subscriber Line (DSL) capable of operating at different bitloads/datarates. An Asymmetric Digital Subscriber Line (ADSL) modem or a Very high speed Digital Subscriber Line (VDSL) modem for instance belong to the adaptive xDSL modem type.

[0013] Most, but not all, of known solutions to the above problem are applicable to an adaptive xDSL modem.

[0014] A first known solution to limit the vulnerability of modems to fast increasing noise levels that could be absent at the time of initialization, is the adapt the bit allocation and/or datarates during operation (i.e. in showtime). In current multi-carrier modems the initial datarate and the initial bitload is determined based on the Channel SNR-per-carrier measured during initialization, which is only a snapshot in time corresponding to the current noise conditions. However, over the course of time (during showtime) the noise conditions on the loop can vary, requiring a different shape of bitload for the same datarate (with decreased SNR margin) or could even require a decrease of the datarate. For slow variation in the noise conditions, methods have been defined in ADSL and VDSL standards to adapt the bitload in both ways: bit swap, i.e. change of bitload without change in datarate, as for instance mentioned in ADSL ITU G.992.1, ADSL2 ITU G.992.3 and ANSI T1.424 MCM VDSL, and respectively Seamless Rate Adaptation (SRA), i.e. change of bitload with change in datarate, as for instance mentioned in [illegible]

[0015] This first solution is good for slowly changing noise conditions. However, in some crosstalk scenarios, the noise condition varies fast, and the proposed solution is too slow to react in time to avoid bit errors and/or to avoid a re-initialization. The reason therefore is that crosstalk noise from a newly switched-on xDSL modem increases instantaneous.

[0016] A second known solution to limit the vulnerability of modems to fast increasing noise levels that could be absent at the time of initialization, is the use of an a-priori determined limitation to a certain maximum datarate. The level of limitation is determined by means outside the modem, but is communicated to the modem via a management interface before bitloading in initialization.

[0017] In modems using BaseBand Modulation (BBM) or Single Carrier Modulation (SCM) this second solution gives sufficient control. Indeed, in the case that the modems use a fixed bandwidth and an adaptive constellation size, the limitation to a maximum datarate will result in a limitation to a maximum number of bits per symbol (i.e. the PAM or QAM constellation size). Therefore, to an upper limit on the minimum required SNR (e.g. to sustain a desired Bit Error Rate (BER) of e.g. 1E-7 with a desired SNR margin of e.g. 6 dB). The limitation is chosen such that the minimum required SNR is lower than or equal to the expected “worst case” (i.e. lowest) SNR, occurring during “worst case” noise conditions. Modems implementing the ITU-T V.32-bis voiceband modem standard are examples of this case.

[0018] In the case that the modems use a fixed constellation size and an adaptive bandwidth (given a fixed transmit power), the limitation of the datarate will result in a limitation of the bandwidth, and therefore to an increase in transmit PSD level. The limitation is chosen such that the required transmit PSD level minus the fixed required SNR is higher than or equal to the expected “worst case” noise level, occurring during “worst case” noise conditions. Modems implementing the ITU SHDSL G.991.2 Recommendation are examples of this case.

[0019] It is further to be noted that modems implementing the ANSI T1.424 SCM VDSL standard are not rate-adaptive and are therefore having the concept of maximum datarate.

[0020] Moreover, in modems using Multi-Carrier Modulation (MCM), this second solution does not give sufficient control. Indeed, the a-priori limitation to a maximum datarate will result only in a limitation to a maximum the number of bits per MCM symbol, which is a limitation only on the SUM OF the number b_i of bits per carrier, summed over all carriers used (i.e.

$$\sum_i b_i \leq \text{limit}$$

[0021]). As it does not provide a limitation of the number of bits for each specific carrier (b_i), it is possible that during initialization with low noise conditions, the modem determines a bitload which allocates a b_i on some carriers which is too high, needing a required SNR higher than the “worst case” SNR on those carriers during fast increasing noise conditions. The more the change of the noise spectrum during noise during operation, the higher the vulnerability, and the higher the likelihood of excessive BER or re-initialization. Modems implementing any of the known (up-to-date) ITU Recommendations ADSL ITU G.992.1, G.992.2, G.992.3, G.992.4, G.992.5 or VDSL ANSI T1.424 MCM standard are examples of this case.

[0022] It is to be noted that this second known solutions is available in almost all types of modems: baseband, single carrier, multi-carrier, . . .

[0023] A third known solution to limit the vulnerability of modems to fast increasing noise levels that could be absent at the time of initialization, is the use of an a-priori determined (single number) limitation of the maximum constellation size to a certain maximum number of bits per constellation, i.e. PAM or QAM constellation size. The level of limitation is determined by means outside the modem, but is communicated to the modem via a management interface before bitloading in initialization.

[0024] This third solution is identical to the above second solution and gives sufficient control in modems using Base-Band Modulation (BBM) or Single Carrier Modulation (SCM).

[0025] However, in modems using Multi-carrier Modulation (MCM) this third solution does not give sufficient control. Indeed, the a-priori limitation to a single number maximum number of bits per constellation (i.e. max b_i limit), e.g. the G.992.1 limit that is called BIMAX, does not provide a sufficient limitation of the number of bits for each specific carrier (b_i). It only limits the b_i on the carriers with the largest constellations, and these carriers are not necessarily the carriers that are vulnerable to fast changing noise levels. Also carriers with smaller constellations could be affected by fast changing noise levels. In other words, a max b_i acts on carriers with large SNR values during initialization, which do not coincide with carriers with large SNR variation during showtime.

[0026] Modems implementing any of the known (up-to-date) ITU Recommendations ADSL ITU G.992.1, G.992.2, G.992.3, G.992.4, G.992.5 and VDSL ANSI T1.424 MCM standard are non-perfect examples of this case. The BIMAX is fixed during the design phase of the modem transmitter, and not controllable over a management interface.

[0027] It is to be noted that this third known solutions is available in almost all types of modems: baseband, single carrier, multi-carrier, . . .

[0028] A fourth known solution to limit the vulnerability of modems to fast increasing noise levels that could be absent at the time of initialization, is the use of an a-priori determined (single number) Target SNR margin. In this solution, the noise level assumed during initialization for determining the datarate, equals the noise level measured during the current conditions of initialization but increased with a certain factor called “Target SNR margin”. The level of the target SNR margin is determined by means outside the modem, but is communicated to the modem via a management interface before bitloading in initialization. Typically the target SNR margin is chosen such that it is higher or equal to “worst case” noise level minus the best case noise level. By doing so, the assumed noise level is always higher than the “worst case” noise level. As in this solution, it carrier, multi-carrier, . . . Examples of such modems are respectively, modems implementing ITU SHDSL G.991.2 Recommendation, respectively ANSI T1.424 SCM VDSL standard, and respectively ITU Recommendations ADSL G.992.x up-to-date or ANSI T1.424 MCM VDSL standard. This fourth known solution is the most used today for ADSL modems.

[0029] It is to be noted that the term "worst case" is used as a short hand. It does not necessary mean to the "worst case" ever, e.g. over infinite time, or over all lines of the complete network. It corresponds to that case of channel conditions having a predetermined acceptable likelihood of occurrence such that an operator is deeming this acceptable, e.g. acceptable stability of the link over a certain given time period, or for a subset of the network.

[0030] This fourth solution is the most used at the present time. However, it is not suited for some situations as mentioned below.

[0031] This fourth known solution is not suited for noise types with fast increasing noise levels, which remain stable at a high level afterwards (for a non-negligible time), e.g. crosstalk rising from the switching-on of an xDSL system on another pair in the same cable. For this type of noise, it is clear that the initialization/re-initialization could take place during the "worst case" noise conditions. Taking a high target SNR margin on top of these "worst case" noise levels, is unnecessary and leads to an excessive loss of datarate.

[0032] This is for instance the case of a twisted pair cable with ADSL links, but where the ADSL modems are not yet switched-on by their users. Then, the ADSL crosstalk level in the cable is absent. The noise level will be equal to the background noise level. The first ADSL modem that switches-on will see this background noise level during initialization. However, the crosstalk level will increase with each new ADSL modem that is switched on. When during operation of this first link, the number of users increases, e.g. from 1 to 50, the channel crosstalk will increase to its worst case maximum. Table 1 gives approximate numbers for the increase of noise level Δ when the noise evolves from a background noise of −140 dBm/Hz to a level corresponding with a Far-End CrossTalk (FEXT) of 50 ADSL disturbers:

TABLE 1

Looplength 0.4 mm	Noise level increase Δ [dB] (approx.)	G.992.5 Downstream rate [Mbps] with 6 dB SNR margin in SELF XT (approx.)
1000 m	40	17
2000 m	30	13
3000 m	18	6
4000 m	7	3

[0033] With the target SNR margin solution, the operator will have to assign a large target SNR margin at least equal to this noise level increase, in order for this first user to have a stable operation, and to withstand the noise increases. As can be seen, the SNR margin that has to be taken for stable operation increases for larger offered datarates.

[0034] For a user connecting when all other (e.g. 49) users are already on line, the noise is already at its maximum and

aware of the order in which the users are switching-on, he has to assign one target SNR margin for all users. Therefore this large target SNR margin is assigned as well to the last user(s). As a consequence, the last user(s) will experience an excessive datarate loss. As an example, for 3000 m, the SNR margin to be taken is 18 dB. This is 12 dB higher than the usual 6 dB as shown in the Table 1. A loss of 12 dB corresponds to 4 bit per carrier. Over a 1 MHz usable bandwidth, this corresponds to a datarate loss of 4 Mbps, resulting in a reduction of the datarate to 2 Mbps.

[0035] It is also not suited for impulsive noise types, i.e. fast increasing and decreasing noise of very short duration. Due to the very short duration, it has negligible influence on the noise measurement result during initialization. The measurement will only indicate the average noise power level over the full measurement period, corresponding with the stationary noise component and not the "worst case" peak power level during the impulse noise. As impulsive noise and stationary noise come from different independent sources, taking a SNR margin with respect to the stationary component is a problematic solution to cope with impulsive noise.

[0036] It is also not suited for noise types of short duration, i.e. with a duration that is shorter than the duration of the noise measurement during initialization, e.g. <1 sec. The measurement will only indicate the average noise power level over the full measurement period that somewhat influence the measurement result, and not the "worst case" peak power level during the noise with short duration. This case is a noise type that falls in between the two above noise types and, as a consequence, its disadvantages are a mixture of the disadvantages of the two above cases as well.

[0037] On the other hand, this fourth solution is suited for fast small changes in actual noise levels per carrier, in such a way that the loss in datarate is then still acceptable.

[0038] It is also suited for slow but somewhat larger changes in actual noise levels per carrier bit with still a small change in average noise level, e.g. due to temperature effects. In this case, the On Line Reconfigurations can adapt the bit loading with bitswap, before the SNR margin per carrier drops below zero. However, the average SNR margin will still decrease slowly. As long as the change in average noise level is small, the target SNR margin can be kept acceptable.

[0039] Modems implementing any of the known (up-to-date) ITU Recommendations ADSL ITU G.992.1, G.992.2, G.992.3, G.992.4, G.992.5 and the VDSL ANSI T1.424 MCM standard are examples of this case.

[0040] A fifth known solution to limit the vulnerability of modems to fast increasing noise levels that could be absent at the time of initialization, is the use of an a-priori determined model of the "worst case" noise level, occurring during "worst case" noise conditions, which is fixed in a standard or some other design document, and therefore is fixed in the equipment. This solution is known only in the domain of datarate-adaptive ITU SHDSL G.991.2 modems, where the model of the expected "worst case" noise level is fixed in this ITU standard (see for instance G.991.2 Table A-13 & Table B-14). This is possible because of the deploy-

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