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PowerLine Telecommunications (PLT); Spectral Management of neighbouring PLT networks based on Dynamic Spectral Management (DSM)

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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

Executive summary

Addressing the coexistence problems of PLT neighbourhood networks operating in customer environments, the present document describes spectral management for OFDM based transceivers for minimizing the impact like the drop of bitrate.

The solution is based on spectral management reducing the power level of interfering PLT carriers on PLT neighbourhood carriers and spreading data on remaining PLT carriers. The Dynamic Spectral Management (DSM) processing implemented in PLT modems is suitable for second generation PLT modems operating up to 80 MHz.

The present document propose a new approach for solving the interference caused by neighbouring networks, when at least two customers are using PLT modems on powerline.

It is proposed to adopt this approach, so that PLT home networking transceivers are equipped with Dynamic Spectral Management (DSM) in the domain master.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The majority of the population in the world live in multi-dwelling unit (MDU) buildings. The need for sharing high-speed networking within these often closely spaced units has resulted in an increase in the use of High Frequency (HF) generated by powerline telecommunications (PLT).

The PLT networks within a given MDU will be in close proximity to each other, and connect to the same wiring, so the signals will be detectable on adjacent networks. This may appear as a source of interference, which can limit the PLT throughputs.

This is a common problem of all networking technology whose signals are not physically constrained. Neighbouring Networks (NN) interference occurs when signals transmitted over one home network propagate to neighbouring networks.

For PLT, signals can transfer to other PLT networks through inductive propagation or due to low attenuation when the networks share common feeder lines as the number of PLT deployed systems increases.

The present document describes a technique based on DSM to address this problem.

Dynamic Spectrum management (DSM) has been recognized as a key technology for tackling multi-user crosstalk interference for DSL broadband access.

The present document proposes a method based on dynamic spectral management multi-user signals from several PLT modems operating in neighbouring networks. Inside this network the domain master modem have the capacity to handle complex DSM operations.

The solution, described in the present document, is based on minimization of the interference by coordination at Physical layer level using dynamic spectral management approach.

Solving this interference at signal level is important for the next generation of PLT modems and in large scale deployments of next generation home networks with peaceable relationship with users in a vicinity.

DSM methods can avoid unnecessary impoliteness between neighbours using PLT modems if their Domain Master modems integrate efficient carrier management using DSM.

PLT networks communicate using high frequency signals transmitted over a residence's mains power wiring. The signal power is generally sufficient to allow communication between all the in-home power sockets; however, this means the signals can also propagate beyond the intended residence.

Many PLT technologies transmit at the highest signal strength allowed, to overcome noise and ensure they can pass data at the maximum rate within their own network; however, this increases the problem for their neighbours. The number of neighbouring networks affected depends on the PLT signal strength, topology of the MDU wiring, and the impedance between networks. It is quite common for PLT networks more than one floor away to detect signals from another PLT network.

This interference occurs when a line in the electrical network is situated close to a line in this other network. This is because, as these high-rate technologies use at least partially the same reserved frequency band, and the same data coding method by distribution over carrier frequencies, in this case OFDM, when a line in the electrical network is situated in the vicinity of a line in this other network, the transmission performance of the transmission channel of each of the two networks degrades, causing in particular losses of transmission rate on these two networks.

This interference is amplified when the modems in the two local networks are supplied by the same electrical source since, in this case, coupling by conduction between the modems occurs.

The use of the electrical network and another network for distributing the services of a triple-play offer therefore poses the problem of interference between a powerline signal that is transmitted between modems on an electrical network and a signal that is transmitted on another network, which may be an electrical network possibly distinct from the first.

More precisely, this iterative method consists, at each iteration, of optimizing the transmission rate of the transmission channel on the line and the transmission power level of the signal transmitted on this channel, considering the interference on the other lines in this network as noise and subject to a given spectral density profile.

1 Scope

The present document defines requirements on coexistence between two PLT transceivers operating in the same frequency band and on same electrical cables on different neighbouring networks.

The present document includes a solution based on signal processing algorithms for minimizing of the interferences caused by one PLT on other PLT network based on spectral management

It is assumed the PLT network is based on a master and slaves modems.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] W. Yu et al: "An Adaptive Multiuser Power Control Algorithm for VDSL", GLOBECOM01, vol. 1, 2001.

[i.2] ETSI TR 102 269: "PowerLine Telecommunications (PLT); Hidden Node review and statistical analysis".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BF Frequency Band
DM1 Domain Master for user 1
DM2 Domain Master for user 2
DSL Digital Subscriber Line
DSM Dynamic Spectrum Management
HF High Frequency
MAC Medium Access Controller (Layer 2)
MCPL PLT Modem Courant porteur en Ligne
MDU Multi-Dwelling Unit
MIMO Multiple Input Multiple Output

NN	Neighbouring Networks (PLT)
OFDM	Orthogonal Frequency Division Multiplexing (Multi-carrier transmission)
PHY	Physical Layer /transmission (Layer 1)
PLT	PowerLine Telecommunication
PSD	Power spectral density
R_1	Electrical Network 1
R_2	Electrical Network 2
S_1	PLT signal for user 1
S_2	PLT signal for user 2
SNR(F)	Signal to Noise Ratio at frequency F
VDSL	Very high speed Digital Subscriber Line (15 MHz)
VDSL2	Second generation of VDSL (30 MHz)

4 Configuration of the PLT network in customer premises

It is assumed that the Service Provider has installed a network using the same PLT technology in each user unit. These networks will interfere with one another to an extent dependent on their relative physical location, potential for signal propagation between networks, and the electrical path the signals can take between networks.

The configuration of the PLT networks in close proximity to apartments, which may or may not be the case, depending on MDU wiring rules for each country.

The PLT signals can cross over between networks over the in-building wiring. Typically, there is 20 to 40 dB attenuation between networks due to the circuit breakers, meters, cable distances and topology; however, this value will vary between individual PLT nodes and between PLT networks.

According to ETSI TR 102 269 [i.2], the median attenuation @ 15 MHz between sockets in the same flat is 40 dB, while median attenuation @ 15 MHz between in different flats is 60 dB. Roughly, this would add 20 dB for median inter unit attenuation.

Each network in the MDU building experiences its own set of interference, distinct from that of other networks. Therefore, each network has its own NN PLT networks mitigation needs. The interference a PLT network experiences is known as the network's interference pattern. Further, each node in each network has its own node interference pattern. NN interference can be time varying with respect to amplitude or even presence.

These nodes not only experience NN interference when they are powered up, they also change the interference pattern for all networks and nodes that detect their signals.

This interference occurs when a line in the electrical network is situated close to a line in this other network. This is because, as these high-rate technologies use at least partially the same reserved frequency band, and the same data coding method by distribution over carrier frequencies.

However, as the number of PLT networks deployed in the building increases, neighbouring network interference increases and service deteriorates, with resultant service calls.

The local network's nodes detect the NN signals as noise, thus raising the noise floor and reducing the signal to noise ratio (SNR) of the local nodes, effecting their throughput and ability to overcome other noise they encounter.

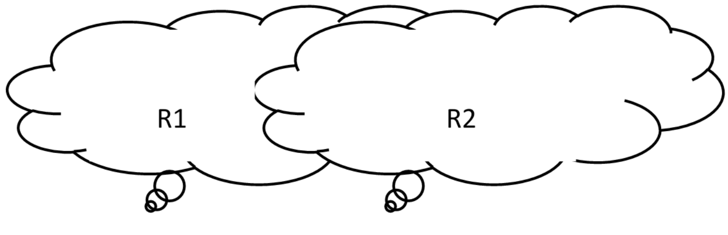

Figure 1: Illustration of two electrical networks R1 and R2 interfering in a MDU

As stated previously, PLT networks interference is deemed to be high when another PLT signal is strong enough to be detected by a local network node as a valid PLT signal and that this signal's power level is enough to overcome local PLT signals.

When signals are at this level, the interfered networks' ability to pass data deteriorates and they shall use some form of mutual mitigation, or they will operate with a significantly lower throughput or even lose connectivity.

The newly introduced Multiple Input, Multiple Output (MIMO) PLT modems is a means of having multiple transmit paths and receive paths when 3-wire cabling and sockets are used in residences. MIMO may actually exacerbate NN interference in that MIMO-PLT may enable PLT signals from one unit to reach another unit with a stronger overall signal.

The power leads have higher attenuation than other lead types due to transiting breakers and meters. While this interference MIMO-PLT pattern is similar to SISO-PLT as MIMO signal paths between living units.

With PLT signal transmission over the power grid network, there is signal attenuation due to the breakers and meters. This attenuation, in most cases, however, it is not enough to eliminate inter-unit network interference.

5 Solution based on iterative bit-loading

The present clause describes a method for reducing interference between a signals transmitted by power line modem networks within the neighbourhood vicinity. In general terms, the present document describe a method of reducing interference between a powerline signal S_1 transmitted between modems MCPL1 in an electrical network R_1 and a signal S_2 transmitted between modems MCPL2 in another network R_2. The signals S_1 and S_2 are coded by the distribution of data on allocated carrier frequencies that all belong to the same reserved frequency band BF.

The signals S_1 and S_2 are coded by the distribution of data on allocated carrier frequencies that all belong to the same reserved frequency band BF. The M is the number of carrier frequencies Fm allocated for coding the signal S_1 are denoted (m = 1 to M).

The method also comprises a step 1 of measurement, by each modem MCPL in the electrical network R_1, of the transmission characteristics of each carrier frequency F that may be used for coding the signal S_1, a step 2 of detection, by analysing the transmission characteristics measured, of at least one carrier frequency that is allocated or may be allocated for coding the signal S and is common with at least one carrier frequency that is allocated for coding the signal Se and the measured transmission characteristics of which are degraded with respect to those of a previous measurement, and step 3 of optimization of the distribution of the data of the signal S_1 on carrier frequencies so as to minimize the transmission power level of the carrier frequencies that are common with the carrier frequencies thus detected while optimizing the transmission rate of the signal S_1. According to one implementation of the method, step 1 is implemented by each slave modem in the electrical network and step 2 is implemented by a master modem.

According to this implementation, during step 1, each slave modem MCPL measures transmission characteristics on each carrier frequency F in the reserved frequency band BF.

The transmission characteristics measured on a carrier frequency F are the spectral density level of this carrier frequency, the gain and the variance of the complex transmission channel relating to this carrier frequency and the transmission rate of the signal S_1.

The measurements made by each slave modem are then transmitted to the master modem.

A step 2 of detection, by analysing the transmission characteristics measured, of at least one carrier frequency that is allocated or may be allocated for coding the signal S and is common with at least one carrier frequency that is allocated for coding the signal Se and the measured transmission characteristics of which are degraded with respect to those of a previous measurement.

For this purpose, the master modem analyses the transmission characteristics, and of each carrier frequency $F_{1,m}$ and the rate that it has received from each slave modem.

This analysis consists for example of calculating the signal to noise ratio SNR(F) of each carrier frequency by equation (1) for a given H transfert function of a PLT channel affected by a Gaussian noise defined by the standard deviation σ:

$$SNR(F_{1,m}) = \frac{P_{1,m}\left|H_{1,m}\right|^2}{\sigma_{1,m}^2} \tag{1}$$

and comparing this signal to noise ratio SNR(F) with a value of this ratio previously calculated from the previously measured transmission characteristics.

According to another example, the master modem compares the transmission rate with a previously measured transmission rate.

When the transmission characteristics measured by a slave modem are degraded with respect to a previous measurement, for example when the measured transmission rate is less than a previously measured rate and/or when the signal to noise ratio SNR($F_{1,m}$) is lower than a value of this ratio calculated from previously measured transmission characteristics, the master modem then considers each carrier frequency, the measured transmission characteristics of which are degraded with respect to those of a previous measurement and which is common with a carrier frequency, is replaced by a new carrier frequency (p = 1 to P), of the frequency band BF.

According to one implementation of the method, a carrier frequency Fm and a carrier frequency Fn are common when they are separated from each other by a distance less than a predetermined maximum distance, which may be either zero, that is to say the two carrier frequencies are equal to the same value, or strictly greater than zero, that is to say the two carrier frequencies have values that are different but close together.

The distance is defined by the difference between the cardinal sine of the carrier frequency of the signal S weighted by a filter that limits the secondary lobes of the cardinal sine, and the cardinal sine of the carrier frequency of the signal S_1 weighted by a filter that limits the secondary lobes of the cardinal sine.

For each carrier frequency, the measured transmission characteristics of which are degraded with respect to those of a previous measurement and which is common with a carrier frequency, is replaced by a new carrier frequency (p = 1 to P), of the frequency band BF.

The data of the signal S_1 that were up until then coded on the P carrier frequencies are then distributed over these new carrier frequencies so that the transmission rate of these new carrier frequencies is maximized subject to the maximum transmission power of each new carrier frequency complying with a specific spectral density profile.

According to an implementation of step 3, implemented by the master modem, each carrier frequency, the measured transmission characteristics of which are degraded with respect to those of a previous measurement and which is common with a carrier frequency, is replaced by a new carrier frequency (p = 1 to P), of the frequency band BF. It should be noted that P is less than or equal to M.

Each new carrier frequency ($F_{1,p}$) is chosen in a sub-band of the reserved frequency band in which no carrier frequency is allocated for coding the second signal (S_2).

When more than one carrier frequency is chosen in the complementary sub-band, these carrier frequencies are chosen so that a minimum distance separates them, in order to prevent any interference between them.

The data of the signal S_1 that were up until then coded on the P carrier frequencies are then distributed over these new carrier frequencies so that the transmission rate of these new carrier frequencies is maximized subject to the maximum transmission power of each new carrier frequency complying with a specific spectral density profile, that is to say the distribution of the data is effected by solving the following equation (2):

$$R^* = \max_{P_{1,p}} \sum_{p=1}^{P} \log_2\left(1 + \frac{P_{1,p}\left|H_{1,p}\right|^2}{\sigma_{1,p}^2 + \alpha + \beta\sqrt{F_{1,p}}}\right) \tag{2}$$

$$\text{subject to the constraint } \sum_{p=1}^{P} P_{1,p} \leq \bar{P}_1, \quad P_{1,p} \geq 0 \quad \forall p \tag{3}$$

in which are the measurements of the transmission characteristics of a carrier frequency carried out during step 1, and the expression represents a modelling of the coupling between the electrical network R_1 and the network R_2. It should be noted that this coupling model depends on the carrier frequency, which reflects reality.

The pair of parameters is estimated by the minimization by least squares of the measurements of the transmission characteristics of each carrier frequency F carried out during step 1.

In this case, the P carrier frequencies make it possible to code the data coded up until then on the P carrier frequencies, that is to say the transmission rate of the signal S_1 after replacement of the carrier frequencies is equal to the transmission rate of the signal S_1 previously measured by a slave modem, and step 3 is terminated.

In the contrary case, that is to say if the transmission rate of the signal S_1 obtained at the end of the optimization step is less than a previously measured transmission rate of this signal S_1, at least one other carrier frequency (c = 1 to C) is chosen in the sub-band complementary to the sub-band BF. When more than one carrier frequency is chosen in the complementary sub-band, these carrier frequencies are chosen so that a minimum distance separates them, in order to prevent any interference between them.

The data of the signal S_1 that have not been able to be coded on the carrier frequencies of the sub-band BF are then distributed over these carrier frequencies of the complementary sub-band so as to minimize the transmitted power level of each carrier frequency subject to the measured transmission rate being reached, that is to say the data of the signal S_1 that have not yet been able to be coded and decoded.

The data are distributed by solving the following equations (for details see paper on DSM in [i.1]):

$$P^* = \min_{P_{1,c}} \sum_{c=1}^{C} P_{1,c} \tag{4}$$

$$\text{under the constraint } \bar{R}_1 = \sum_{c=1}^{C} \log_2 \left(1 + \frac{P_{1,c} \left| H_{1,c} \right|^2}{\sigma_{1,c}^2 + \alpha + \beta \sqrt{F_{1,c}}} \right) \tag{5}$$

in which $P_{1,c}, \left| H_{1,c} \right|^2, \sigma_{1,c}^2$ are the measurements of the transmission characteristics such as:

P: the power injected on electrical networks by PLT modems;

H: the transfer function of PLT channels between two nodes and their variance in which are the measurements of the transmission characteristics of a carrier frequency made during step 1, and designates the total minimum power level transmitted; and

α and β are parameters related to electrical wiring.

It should be noted that the number of carrier frequencies chosen in the complementary sub-band is chosen empirically so that all the data carried by the carrier frequencies are distributed over the carrier frequencies band.

Let it be assumed that, at the end of step 2, the master modem has detected two carrier frequencies and allocated or that may be allocated for coding the signal S that are common to the carrier frequencies 6 and 9 allocated for coding the signal S_1. In addition let it be assumed that the measured transmission characteristics of these carrier frequencies 6 and 9 are degraded with respect to those of a previous measurement.

According to step 3, the network R is an electrical network and the signal S is a signal of the powerline modem that is transmitted over this network R between modems. Step 3 is implemented by equipment that is accessible to each of these master modems.

According to step 3, the distribution of the data of the signal S_1 on the carrier frequencies is optimized minimizing the transmission power level of the carrier frequencies that are common with the carrier frequencies thus detected while optimizing the transmission rate of the data of the signal S_1, the repetition of the said steps is synchronized on the frequency of the electric current of an electrical network.

However, this optimization is achieved by the PLT master modem, in competition with the optimization of the distribution of the data of the signal S_2 on the carrier frequencies allocated, subject to the constraint of a specific spectral density (PSD) profile. Following the optimization of equation (3), the transmission power levels $P_{2,n}$ are minimized subject to the measured transmission rate R_2 being maximized.

However, this optimization is achieved in competition with the optimization of the distribution of the data of the signal S_2 on the carrier frequencies allocated, subject to the constraint of a specific spectral density (PSD) profile.

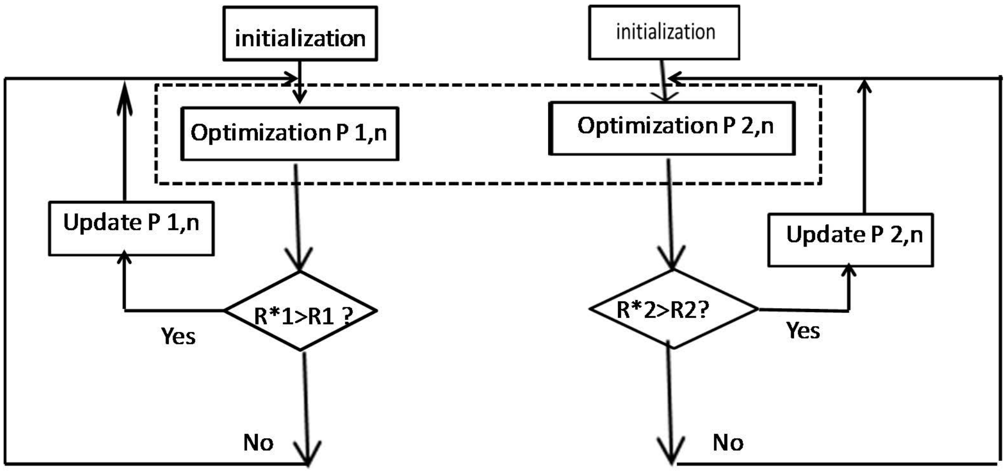

Figure 2: Illustration of Iterative algorithm for 2 users

Figure 2 shows a diagram of an iterative algorithm that allows such a competitive optimization of the distributions of the data of the signals S_1 and S_2 on their carrier frequencies for 2 users could been generalized to 8 users in a MDU.

Following the optimization of equation (3), the transmission power levels $P_{2,n}$ are minimized subject to the measured transmission rate R_2 being reached.

The coupling between the electrical network R_1, for example of the PLT modem , and the electrical network R, for example of the PLT mode type, is modelled by the expression . The pair of parameters is estimated by minimization by least squares of the measurements of the transmission characteristics of each carrier frequency $F_{1,m}$ made during step 1.

The principle of the algorithm consists of obtaining distributions of the data of the signals S_1 and S_2 so as to achieve the measured transmission rates under the P(Power) constraint defined as PSD (Power Spectral Density).

Initially, the transmission power levels are fixed at predetermined values depending on the PSD for PLT transmission and each PLT carrier transmit an amount of data depending on SNR($F_{1,m}$) estimated during a period. Next, during a first iterative step, commonly referred to as iterative data allocation, the transmission power levels are minimized subject to the measured transmission rate being reached, that is to say by solving equation (3) in which the exponents * indicate that they are values reached by the optimization:

This algorithm is based on the reference [i.1], pages 394-398.

Following the optimization of equation (3), the transmission power levels $P_{2,n}$ are minimized subject to the measured transmission rate R_2 being reached, that is to say by solving equation (4) in which the exponents * indicate that they are values reached by the optimization:

$$P_2^* = \min_{P_{2,n}} \left(\sum_{n=1}^{N} P_{2,n} \right) \qquad (6)$$

under the constraint $$R_2^* = \sum_{n=1}^{N} \log_2\left(1 + \frac{P_{2,n}\left|H_{2,n}\right|^2}{\sigma_{2,n}^2 + \alpha + \beta\sqrt{F_{2,n}}}\right) \quad (7)$$

in which the transmission characteristics are measured by each slave modem in the network R, namely the spectral density level $P_{2,n}$ of this carrier frequency, the gain $\left|H_{2,n}\right|^2$ and the variance $\sigma_{2,n}^2$ of the complex transmission channel relating to this carrier frequency and the transmission rate $\bar{R}_2$ of the signal S.

Once equation (4) has been optimized, the optimization of equation (3) is once again carried out, and then optimization of equation (4) and so on as long as the transmission rate R_1^* is estimated as being sufficiently close to (less than or greater than or equal to) the measured transmission rate R_1 and the transmission rate R_2^* is estimated as being sufficiently close to the measured transmission rate R_2.

When these two conditions are satisfied, the first step is followed by a second step during which the transmission power levels $P_{1,m}$ and $P_{2,n}$ are updated in accordance with the following relationships:

The same phenomenon can be seen, namely that the spectral density P2* obtained is concentrated on carrier frequencies that are not allocated for coding the signal S_1 or at the very least to carrier frequencies the transmission power levels $P_{1,m}$ of which are the lowest.

$$\left\{\begin{array}{llll} if & R_1^* > R_1 + \varepsilon & then & P_1^* = P_1^* - \delta \\ if & R_1^* < R_1 & then & P_1^* = P_1^* + \delta \\ if & P_1^* > \bar{P}_1 & then & P_1^* = \bar{P} \\ if & R_2^* > R_2 + \varepsilon & then & P_2^* = P_2^* - \delta \\ if & R_2^* < R_2 & then & P_2^* = P_2^* + \delta \\ if & P_2^* > \bar{P}_2 & then & P_2^* = \bar{P} \end{array}\right\} \quad (8)$$

The second step is followed by the first step as long as the transmission rate R_1^* is greater than the measured transmission rate R_1 or the transmission rate R_2^* is greater than the measured transmission rate R_2.

The parameters δ and ε are fixed empirically, for example at respective values of 3 dB and 10 %.

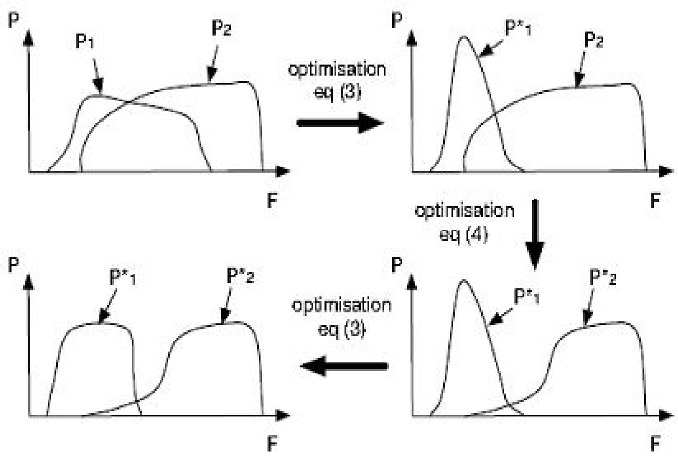

Figure 3: Illustration of overlapping frequency allocation and their re-allocation after DSM algorithm

Figure 3 shows an illustration of two iterations of this algorithm for distributing the data of the signals S_1 and S_2 competitively and could been generalized by applied 2 by 2 interfering

Each timing diagram shows the spectral transmission power densities of the signals S_1 and S_2 according to the carrier frequencies of the reserved frequency band BF. The timing diagram at top left shows these densities P_1 and P_2 following the initialization of the transmission power levels $P_{1,m}$ and $P_{2,n}$. The timing diagram at top right shows these densities once the transmission power levels $P_{1,m}$ have been optimized in accordance with equation (3). It can be seen that the spectral density P_1^* obtained is concentrated on carrier frequencies that are not allocated for coding the signal S or at the very least on carrier frequencies the transmission power levels $P_{2,n}$ of which are the lowest. The timing diagram at bottom right shows these densities once the transmission power levels $P_{2,n}$ have been optimized according to equation (4). The same phenomenon can be seen, namely that the spectral density P2* obtained is concentrated on carrier frequencies that are not allocated for coding the signal S_1 or at the very least to carrier frequencies the transmission power levels $P_{1,m}$ of which are the lowest.

Thus, at each iteration of the first step of the algorithm, the spectral transmission power densities are distinguished from one another, thus preventing interference between the signals S_1 and S.

The timing diagram at bottom right shows the spectral transmission power densities once the transmission power levels $P_{1,m}$ have once again been optimized according to equation (3) during a second iteration of the first step of the algorithm. It can be seen that the spectral transmission power density P_1^* is spread over a larger number of carrier frequencies because transmission power levels $P_{2,n}$ the carrier frequencies $F_{1,m}$ of which are close to the carrier frequencies $F_{2,n}$ are lower values than at the previous iteration.

Thus, after a few iterations of the algorithm, the spectral power densities are distinguished from one another and are spread over the entire reserved frequency band.

6 Recommendation based on DSM for NN PLT coexistence in a MDU

The next generation of PLT modem shall adopt an iterative bit-loading algorithm, described in the present document, allowing the reduction of interference between a power line signal corresponding to a slave modem from user 1 and controlled by DM1 and another slave modem from user 2 and controlled by DM2 and assuming that these slave modems are in the neighbourhood network for a MDU.

The benefits of Dynamic Spectrum Management (DSM) in terms of reducing the power consumption and improving the data rates in PLT networks operating in a MDU context as specified in the present document and could been implemented for next generation of PLT networks and Home Gateways.

History

Document history		
V1.1.1	March 2015	Publication