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ScienceDirect
C. R. Physique 10 (2009) 4–12
Comptes Rendus Physique

New approaches in Electromagnetic Compatibility / Nouvelles approches en Compatibilité Electromagnétique

Electromagnetic environment and telecommunications: towards a cognitive electromagnetic compatibility

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Available online 14 March 2009

Abstract

This article deals with the electromagnetic environment management problem within the context of high speed digital transmissions deployed in wired telecommunication networks.

Traditionally, Electromagnetic Compatibility (EMC) is assured by filtering for better electromagnetic immunity, and by cable shielding for emission limitation.

However, like cognitive radio, we can also, for high speed wired transmissions, treat the EMC as an intelligent and autonomous system capable of perceiving its environment, interpreting it, making suited decisions, and reacting according to the constraints related to the electromagnetic environment.

In this context, some application examples are here given in order to illustrate this evolution towards a cognitive EMC in wired networks. ***To cite this article: A. Zeddam et al., C. R. Physique 10 (2009).***

Résumé

Environnement électromagnétique et télécommunications : vers une CEM cognitive. Cet article aborde le problème de la gestion de l'environnement électromagnétique dans le cadre de transmissions numériques haut débit déployées dans les réseaux de télécommunications fixes.

En matière de CEM, on recourt traditionnellement à des techniques de filtrage ou de blindage pour résoudre respectivement les problèmes d'immunité et d'émission électromagnétique.

Cependant, à l'instar de la radio cognitive, on peut également, pour ces transmissions haut débit, traiter la CEM à l'aide d'un système capable de percevoir son environnement, de l'interpréter, de prendre des décisions appropriées pour réagir en fonction des contraintes liées à l'environnement électromagnétique.

Dans ce contexte, quelques exemples d'applications viennent illustrer cette évolution vers une CEM cognitive. ***Pour citer cet article : A. Zeddam et al., C. R. Physique 10 (2009).***

Keywords: Electromagnetic Compatibility; Digital transmission

Mots-clés : Compatibilité électromagnétique ; Transmission numérique

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doi:10.1016/j.crhy.2009.02.001

1. Introduction

The advent of "information superhighways" became a reality with the maturity of transmission technologies, particularly xDSL (Digital Subscriber Line) on wired access networks and PLC (Power Line Communications) in domestic networks.

The massive deployment of these systems, associated with the use of higher and higher frequency bands (HF bands) created new reliable transmission challenges, but also many electromagnetic compatibility (EMC) problems.

The EMC studies and standards aim at guaranteeing a correct functioning of systems and equipments in the presence of electromagnetic disturbances (immunity issue). They also aim at assuring that the deployment of high bit-rate transmission systems do not produce jamming of neighbouring systems, such as radio receivers and more particularly amateur radio (emission issue).

New real time and multimedia services increasingly necessitating data rates, press transmission system designers to raise their transmitted powers. In term of EMC, this results in more electromagnetic radiation emitted from the physical transmission support.

Regarding the electromagnetic immunity of the xDSL and PLC systems, electromagnetic noise has the more significant impact on the quality of service (QOS) delivered by these technologies.

Impulsive noise is a particularly disturbing source of data loss. It especially degrades the quality of the video services, and more generally that of the real-time ones (VoIP…). This noise is often generated by electric devices and equipment located in the domestic environment. It is then conveyed by electric cables and coupled on telephone copper pairs. Impulsive noise has a short duration and high-amplitude.

At present, the robustness increase of the high bit rate transmission systems against impulsive noise is a discussion subject on several standardization bodies (such as [1–3] for xDSL and [4] for PLC), from which many solutions are issued.

The electromagnetic emission issue is, also, the object of intense debate. Parameters discussed are usually the maximum transmitted power and the Power Spectral Density (PSD) mask.

In the wired cognitive EMC, the classic protection and emission-limiting techniques can be sensibly completed by new methods extracted from cognitive radio technology [5]. Rather than utilizing static error correction and emission-limiting techniques, modems would be then be allowed to perceive their electromagnetic environment, analyze it and take the adequate corrective measures and transmission profiles.

In wireless communications, the cognitive radio concept uses adaptive solutions for managing the spectrum of each user. In wired communications, the latter concept can also be introduced [6]: some techniques such as Dynamic Spectrum Management (DSM) [7–10], as well as adaptive noise detection and processing, can, indeed, be part of it.

After a brief description of the cognitive radio concept, the electromagnetic emission issue is examined, and an example of a cognitive approach for the PLC systems is given: an adaptive "notching" technique allowing one to avoiding radio broadcast stations frequencies. Then, the electromagnetic immunity issue is highlighted, and some concrete examples of cognitive techniques against impulsive noise are presented for both xDSL and PLC systems.

2. Cognitive radio concept

Cognitive radio is an intelligent radio system capable of perceiving its environment, of interpreting it, and of making suitable decisions according to factors such as the electromagnetic environment, internet provider strategy, needs of each user…

In term of perception, cognitive radio:

– Analyzes the spectrum use in its environment;
– Detects the types of neighbouring networks and technologies, the terminal position and speed….

As regards decision, cognitive radio:

– Establishes appropriate communications, for example by avoiding disturbing surrounding uses;
– Widens the communications possibilities of a terminal, for example by defining radio parameters in software way, by adapting the modulation scheme, and by downloading new firmware for new technology's compatibility.

To make the speediest and best decisions, cognitive radio integrates learning techniques making it capable of:

- Reacting rapidly to the short-term environment fluctuations, such as traffic demand and interference variations;
- Taking advantage of its previous experience to improve its long-term decisions.

The cognitive radio thus presents several interests for the telecommunications operators:

- More effective use of the available spectrum, thanks to an increased flexibility with regard to the current model;
- Jamming avoidance by new frequency sharing, for example by spectrum listening before emission and dynamic spectrum management;
- Terminals with vaster possibilities, and capable of auto-adapting to the behaviour and customs of the user;
- Cognitive networks capable of re-configuration according to the environment and the needs.

The introduction of cognitive radio is subordinated to the implementation of mature technologies insuring a sharing between systems exempt from mutual jamming and guaranteeing the activity of the various users of the radio spectrum.

Therefore, the standardization and the normalization surrounding the cognitive radio must be elaborated with a scrupulous care to guarantee users and operators against uncontrolled drift.

“Cognitive EMC”, as a projection of the cognitive radio concept on the wired telecommunications, leads to the treatment of electromagnetic disturbances in an intelligent, adaptive, and software way as a supplement to the classic EMC approach.

Cognitive EMC, based on signal processing methods, can find the reasons of its success in the following elements:

- Digitalization of the signals;
- Increasing DSP (Digital Signal Processors) treatment speeds;
- Appearance of real-time services more and more sensitive to the impulsive noise;
- Electromagnetic disturbances in differential mode overlapping with useful signals.

In next sections, we illustrate by examples the application possibility of the cognitive EMC concept in xDSL and PLC technologies. The electromagnetic emission and immunity issues are presented separately.

3. Electromagnetic emission issue

Here, a cognitive EMC application is described for indoor PLC technology where electromagnetic emission is a crucial task. Indeed, the respect of the emission limits is often made to the detriment of a transmitted power reduction, resulting in data rate and reach limitations.

In order to protect neighbouring radio stations and amateur radio from PLC radiations at shared frequencies, the Orthogonal Frequency Division Multiplexing (OFDM) gives the possibility of reducing the transmitted PSD only in these shared frequencies, called “notches”. Actually “notches” are static; we hence speak about “static notching”.

In Fig. 1 is reported the PSD mask for the HomePlug AV standard [4]. This figure shows that the PSD is decreased from -50 to -80 dBm/Hz in notched frequencies.

In this context, an “adaptive notching” could be introduced as a cognitive EMC technique for indoor PLC systems. Rather than applying a static notches configuration, the newly connected PLC modem adapts its notches repartition according to the radio waves actually present in its environment. As a consequence, short wave radio broadcasters and amateurs are protected in the domestic networks, while inutile static notches are avoided.

This “adaptive notching” technique is aimed at being autonomous. PLC modems sound the radio spectrum and detect, with a pre-fixed sensitivity and in real time, neighbouring radio waves. Notches are then introduced only on detected radio bands. As only a part of the whole radio stations is usually received at a customer’s home, the data rate reduction due to the “adaptive notching” would be weaker than that due to “static notching”.

This technique is actually under discussion within the ETSI and industry manufacturers [11].

Test campaigns performed by some manufacturers in laboratory and in real sites in association with the European Broadcasting Union (EBU) demonstrated the efficiency of this technique for the PLC systems. More details about these tests are given in [12].

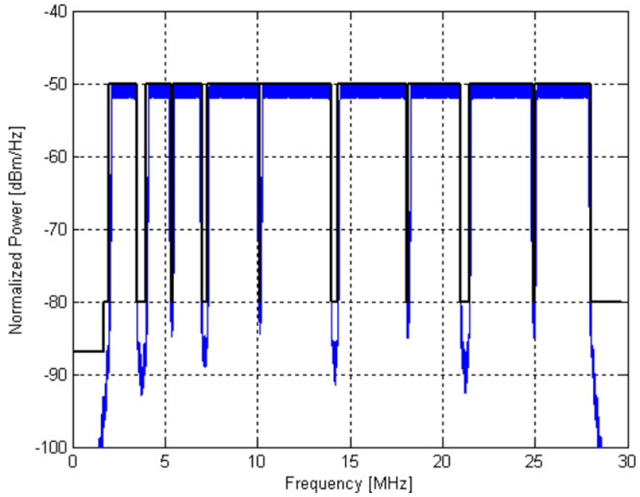


Fig. 1. Homeplug AV transmitted PSD mask.

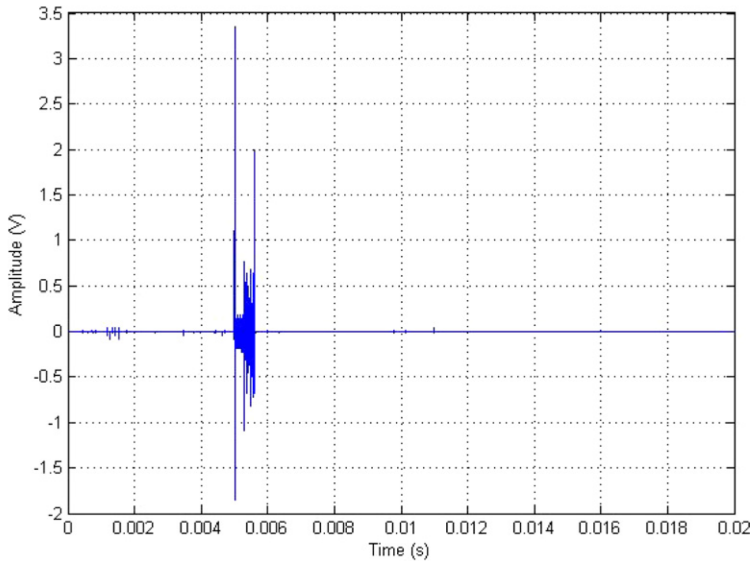


Fig. 2. Example of impulsive noise.

Furthermore, this technique willing today to protect HF radio broadcasts between 2 and 30 MHz can easily be extended to higher frequency bands.

4. Electromagnetic immunity issue

In this section, cognitive EMC application examples are presented for the electromagnetic immunity against impulsive noise in both xDSL and PLC systems.

Undeniably, impulsive noise impacts the quality of the real-time services. It is usually generated by electrical devices (engines, halogen lamps...). As its duration is very short (from some μs to some ms), as shown in Fig. 2, it does not reduce transmission bandwidth and data rate, but causes the appearance of a short series of erroneous bits. For video services this appears as pixels and picture freezing on TV screens as shown in Fig. 3.

Immunity actions against impulsive noise can be divided into common mode actions and differential mode ones.

Actions related to the common mode are hardware implemented, and can be summarized:

Fig. 3. Impulsive noise impact on ADSL2 TV.

1. Band-pass filtering at the entrance of the Analog Front End (AFE) of the receiving modems. This filter avoids the out-band frequency components of the impulsive noise, and minimizes consequently the Automatic Gain Control (AGC) saturation risk.
2. Protection components against lightning over-voltages [13].
3. Common mode choke [14]. Self inductances are used to reduce the common mode noise.

Actions related to the differential transmission mode consider the impulsive noise as a differential signal added to the useful one. Here modem developers appeal to advanced signal processing techniques for noise detection, learning and cancellation.

Other techniques of impulsive noise effect mitigation are implemented by exploiting the binary state of the information to transmit. These techniques are generally a combination of Interleavers and Forward Error Correction (FEC) codes. In xDSL systems, this concept is called Impulse Noise Protection (INP) [15].

In what follows, impulsive noise mitigation techniques and cognitive EMC concept application examples are given separately for xDSL and PLC systems.

4.1. xDSL technologies

Besides the common mode hardware techniques implemented in xDSL modems, the latter use three main protection techniques against impulsive noise: Impulse Noise Protection (INP) [15], FEC, and Automatic Repeat request (ARQ).

4.1.1. INP

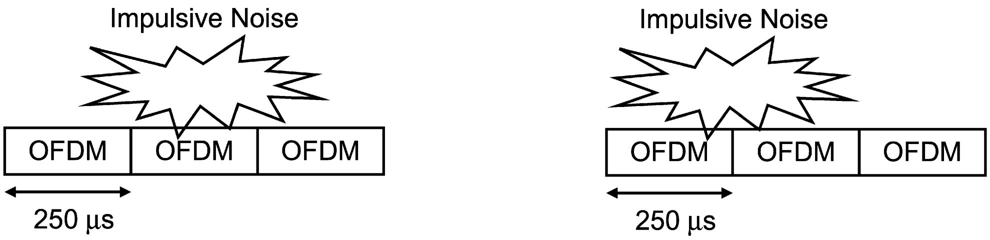
This technique is already part of ADSL2 [1], ADSL2+ [2], and VDSL2 [3] standards.

INP takes integer values referring to the number of correctible OFDM symbols when mistaken by impulsive noise. INP equal to n can correct n damaged OFDM symbols in a fixed time interval (equal to the interleaving depth). Each INP value corresponds to a couple of a Reed-Solomon FEC code-rate and an interleaving depth.

In practice, a minimum INP value of 2 is programmed for TV users. Fig. 4 shows the impact of an impulsive noise whose duration is greater than 250 µs (which is equal to the OFDM symbol length in ADSL2 and ADSL2+) and lower than 500 µs. This noise can damage 3 (a) or 2 (b) OFDM symbols. In the first case an INP = 2 can be non-sufficient and transmission errors could not be corrected. In the second case, with INP = 2 no impact of impulsive noise can be felt by the system.

In this way, the greater the INP value is, the more protected xDSL systems are with respect to impulsive noise. Nevertheless, a great INP value supposes that the following are important:

1. FEC redundancy, and thus less effective data rate;
2. Interleaving depth, and consequently more critical latency.



a) Three damaged OFDM symbols - potential impact of the impulsive noise with INP=2

b) Two damaged OFDM symbols - no impact of the impulsive noise with INP=2

Fig. 4. Example of impulsive noise impact – INP = 2.

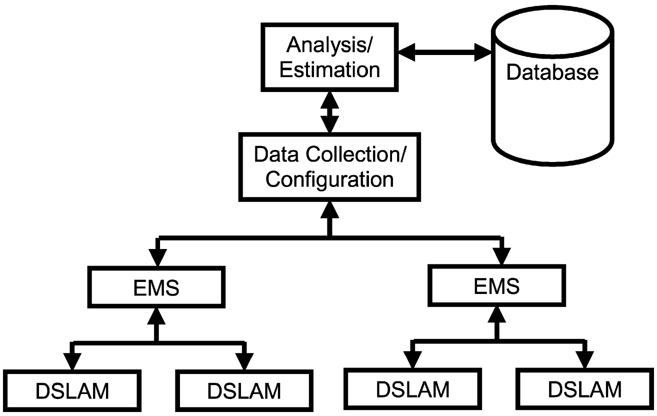


Fig. 5. Advanced DSL management architecture.

To overcome these drawbacks, the cognitive EMC concept could be introduced. An advanced DSL management can allow adaptive detection of the lines more subjected to impulsive noise and avoids applying constraining INP values to stable xDSL lines.

A cognitive DSL monitoring can also be in place to provide fast detection of line problems, to enable automatic remedial actions, and to avoid the costly steps of customer calls and manual interventions.

Key parameters for line problems solving are, in addition to INP, noise margin and transmitted PSD level. Noise margin augmentation leads to an increased robustness against impulsive noises, and PSD level reduction implies less radiations on the close users, leading to less stationary noise on their lines.

Once more, a cognitive EMC technique can be utilized here to adaptively reduce the PSD levels and increase the noise margins of the transceivers depending on their data rate needs. Thus, allowing highest speeds for all DSL lines and maintaining the highest levels of service quality. These actions can be part of the Dynamic Spectrum Management (DSM) communications field [7–10]. Contrarily to static spectrum management, DSM allows adaptive allocation of spectrum to various users in a multiuser environment as a function of the physical channel demographics, to meet certain performance metrics [7].

To set up these adaptive solutions, architectures are proposed by manufacturers. A simplified architecture example is proposed in [16] and reported in Fig. 5.

In this architecture, the core of the management system is the two modules: Data Collection/Configuration and Analysis/Estimation. The Data Collection/Configuration module interacts with existing Element Management Systems (EMS) used for DSLAM (DSL Access Multiplexer) management.

The Data Collection/Configuration module sends data to the Analysis/Estimation module, which in turn executes algorithms to derive useful information about the DSL lines. Based on this information, the Analysis/Estimation module can send configuration commands back to the Data Collection/Configuration module. The Analysis/Estimation module makes use of a database storing current and historical information about the line's behaviour and performance.

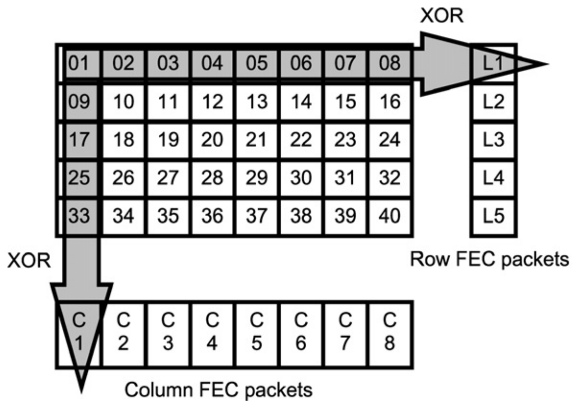


Fig. 6. FEC matrix construction.

4.1.2. FEC

The Forward Error Correction (FEC) [15,17] is issued from the normalization group Pro MPEG Forum [18] and only concerns xDSL video streams. This technique has the merit of simplicity, since the error correcting codes are produced there by means of a simple "exclusive OR" (XOR) operation. Indeed, after arranging data packages in matrices (e.g. in lines and columns), the coder located at the network head applies the XOR operation to each line and column, forming hence an error-protected "FEC matrix" (see Fig. 6).

The lower the FEC matrix size, the more protected MPEG frames are with respect to impulsive noise, as the redundancy is larger, to the detriment of less effective data rate and more latency.

As for the INP, cognitive EMC can similarly be applied to the FEC technique. For each transmission line, the size of the FEC matrix can be adaptively adapted to the impulsive noise activity.

4.1.3. ARQ

ARQ is a protocol for error control in data transmission. When the receiver detects an error in a packet, it automatically requests the transmitter to resend the packet. This process is repeated until the packet is error free or the error continues beyond a predetermined number of transmissions.

The ARQ process has the complexity of requiring a reserved acknowledgment channel to ask for retransmission [19]. This needs either a server, as for the Video on Demand (VOD), or retransmission features in the network equipments (routers, DSLAM…). At present, some network manufacturers allowed this retransmitting function in xDSL chips, but often as a property solution [20].

We can already put forward that the ARQ process is a cognitive EMC technique, as the retransmission is only done when errors are detected. To improve this process, new techniques for precise detection of impulsive noise simultaneously at transceiver and receiver can led to intelligent retransmission of data without receiver request. It was, indeed, demonstrated in [24] that 70% of temporally detected impulsive noises at receiver side are simultaneously detected at transceiver side.

Having said this, in addition to its ability to increase the data rate and the reach performances for xDSL users, the cognitive EMC can participate to make greener the xDSL operations by reducing the power consumption by telecommunications equipments, which nowadays has become a global imperative. In fact, for xDSL operators, a strong desire for ecologically sound operations combined with rising energy costs at central offices resulted in a requirement for increased power efficiency while preserving the continuing DSL evolution towards higher data rates.

4.2. PLC technology

In spite of the ARQ and advanced error correction technique (Turbo Encoding/Decoding for Homeplug modems for instance) used against the electromagnetic disturbances, certain users encounter, nevertheless, some transmission problems as soon as the number of conveyed services increases, or when the required data rate rises (for example when passage to High Definition television).

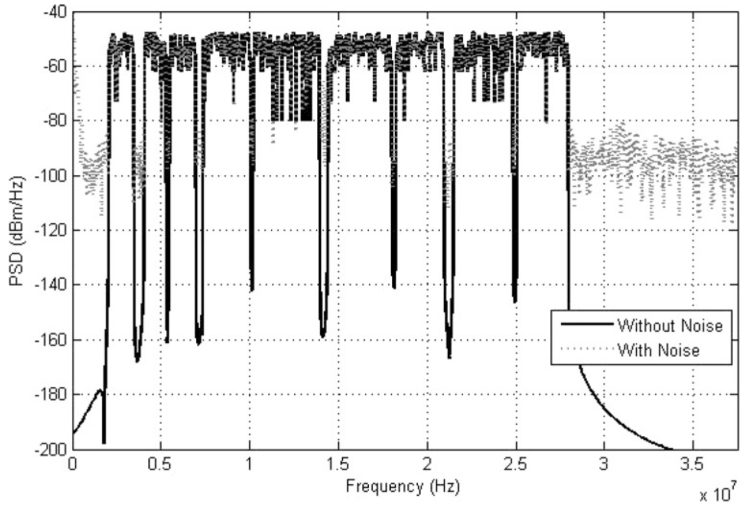


Fig. 7. HomePlug AV signal with and without impulsive noise.

To improve retransmission and error correction systems, a cognitive EMC application consists in detecting and precisely locating impulsive noises. Indeed, the majority of the error correcting codes (LDPC, Viterbi coding, Turbo-Codes…) are more efficient when locating the data effectively damaged by noise. In fact, our studies showed that transmission performances can be significantly enhanced if we erase the temporal samples where impulsive noise is detected (Blanking) [24]. An example of detection method is that of Matsuo, described in [21] and [22].

A precise detection of the electromagnetic disturbances can thus be a key issue for increasing the telecommunications systems performances. This is also apart of the cognitive EMC concept, as belonging to the perception stage. Below, a novel detection method is introduced for PLC systems. This method takes advantage from the unused carriers in the PLC frequency mask (see Fig. 1) to locate impulsive noises. Indeed, impulsive noise being generally broadband, it affects used carriers as well as unused ones. In the receiver side, data transmitted on unused carries is known; it is thus easy for the receiver to detect disturbances.

Fig. 7 represents the spectrums of two HomePlug AV signals at receiver side, respectively during a normal transmission (Black curve) and when an impulsive noise happens (gray curve). We note that the impulsive noise increases considerably the signal level on unmasked carriers.

More details about this detection technique are given in [23] and [24].

5. Conclusion

In this article, the cognitive EMC concept commonly used in radio telecommunications was extended to wired systems. Application examples were proposed separately for electromagnetic emission and immunity issues.

The emission issue goal is to protect neighbouring radio stations and radio amateurs from wire radiations at shared frequencies. A “static notching” technique is at present imposed for PLC system manufactures. To improve data rate and reach performances, a “dynamic notching” concept was introduced.

The immunity issue concerns protection against impulsive noise. Application examples were given for both xDSL and PLC systems. For xDSL, dynamic profile (INP, noise margin, transmitted PSD) as well as FEC matrix size can be dynamically set to transmission lines depending on impulsive noise activity. For PLC, a precise detection of the electromagnetic disturbances was cited as a key issue for increasing error correcting performances.

The continuous evolution towards higher data rates will allow a successful development of the cognitive EMC in wired networks. Furthermore, in the context of sustainable development the application of the cognitive EMC principles may also limit equipment’s energy consumption.

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