A Hybrid Meta-Heuristic Algorithm for Dynamic Spectrum Management in Multiuser Systems: Combining Simulated Annealing and Non-Linear Simplex Nelder-Mead

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ABSTRACT

One of the major sources of performance degradation of current Digital Subscriber Line systems is the electromagnetic coupling among different twisted pairs within the same cable bundle (crosstalk). Several algorithms for Dynamic Spectrum management have been proposed to counteract the crosstalk effect but their complexity remains a challenge in practice. Optimal Spectrum Balancing (OSB) is a centralized algorithm that optimally allocates the available transmit power over the tones making use of a Dual decomposition approach where Lagrange multipliers are used to enforce the constraints and decouple the problem over the tones. However, the overall complexity of this algorithm remains a challenge for practical DSL environments. The authors propose a low-complex algorithm based on a combination of simulated annealing and non-linear simplex to find local (almost global) optimum spectra for multiuser DSL systems, whilst significantly reducing the prohibitive complexity of traditional OSB. The algorithm assumes a Spectrum Management Center (at the cabinet side) but it neither relies on own end-user modem calculations nor on messaging-passing for achieving its performance objective. The approach allows furthering reducing the number of function evaluations achieving further reduction on the convergence time (up to ~27% gain) at reasonable payoff (weighted data rate sum).

Keywords: DSM, Multi-User Digital Subscriber Line (DSL), Nelder-Mead, Non-Linear Simplex, Simulated Annealing

INTRODUCTION

Ideally, Optical Fiber should be the technology to be deployed to reaching the end-users (Fiber to the Home-FTTH-). However, the investment and maintenance costs are still prohibitive for some countries as indicated by Cioffi (2007). Digital subscriber line (DSL) technology is currently the most widely deployed broadband access technology and will continue to play
an important role during the coming years. In a previous report from Point-Topic by Vanier (2009), it is mentioned that the number of DSL subscribers adds up to ~65% of all worldwide broadband access technologies (being followed by ~21% of cable modem subscribers).

However, to cope with the bandwidth-intensive and a mixed set of quality-of-service (QoS) and quality-of-experience (QoE) requirements of the many emerging broadband applications and services (i.e., VoIP, triple-play services including HDTV, IPTV, video-conferences, etc.), it is essential to further improve DSL technology.

One of the major sources of performance degradation of current DSL systems is the electromagnetic coupling among different twisted pairs within the same cable bundle (also referred to as crosstalk). The presence of crosstalk transforms DSL systems into a very challenging multi-user multicarrier interference environment, where different users, i.e., modems, can significantly impact each other’s datarate transmission and the quality of the line; thus, having a direct impact on the final end-user experience.

Spectrum coordination management consists of coordinating the transmit spectrum of each modem so as to prevent (or substantially mitigate) the impact of crosstalk; nowadays, relatively new techniques like the different levels of DSM (single-user coordination, multi-user, vectoring, etc.) as proposed in the literature (Cioffi, 2007; Cioffi & Mohseni, 2004; Song et al., 2002; Ginis & Cioffi, 2002; Cioffi et al., 2006; Yu, Ginis, & Cioffi, 2002; Cendrillon et al., 2006; Yu et al., 2004; Cendrillon et al., 2006; Yu et al., 2004; Tsiaflakis et al., 2005; Papandriopoulos & Evans, 2009; Cendrillon & Moonen, 2005; Tsiaflakis et al., 2008) allow increasing dramatically the bitrates over copper lines, up to (or even higher than) fiber capacities.

One of the first proposed DSM algorithms (Yu, Ginis, & Cioffi, 2002) was iterative waterfilling (IWF) where it was demonstrated a significant performance improvement over traditional (let say, static spectrum management) multiuser DSL lines. This algorithm iteratively measures the aggregate interference received from all other users, greedily water-pouring their own power allocation. However, this approach disregards the impact on other users.

Cendrillon et al. (2004, 2006), proposed an Optimum Spectrum Balancing (centralized) algorithm, therefore assuming centralized control in a Spectrum Management Center (SMC). OSB applies dual decomposition (Yu, Lui, & Cendrillon, 2004) making use of Lagrange multipliers to enforce constraints that are coupled over the tones to find the optimal power allocation to a predetermined quantum and to lower the complexity from exponential to linear in the number of tones. As this algorithm considers the damage done to other modems, OSB avoids a selfish optimum, thereby significantly improving its performance over IWF. However, OSB remains difficult to implement over practical DSL lines though many attempts to reduce this complexity appear in Cendrillon et al. (2004, 2006).

Tsiaflakis et al. (2005) proposed to exploit Lagrange multipliers properties, making the number of Lagrange multiplier evaluations independent of the number of users and smaller compared to other existing search algorithms. However, the convergence time still remains a challenge.

Papandriopoulos and Evans (2009) proposed a new (semi-centralized/distributed) algorithm whose performance outperforms IWF at similar complexity, whereby applying a series of convex relaxations. Cendrillon and Moonen (2005) proposed an iterative spectrum balancing algorithm to reduce the complexity and the convergence time, leading to suboptimal performance, yet.

We initially explored a different approach by using a simplex bounded search algorithm (Cordova & van Biesen, 2010), to reduce overall OSB complexity obtaining near-optimal results but the convergence time was still about 900s for a two-user case. Extra efforts have been performed since then to drastically reduce the convergence time by using Globalized Bounded Nelder-Mead (GBNM) leading to tractable computational complexity and reducing the
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