



## **Enhanced Multicarrier Techniques for Professional Ad-Hoc and Cell-Based Communications**

**(EMPhAtiC)**

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### **Abstract:**

One of the strategic dissemination objectives is the organization of a workshop in order to increase public awareness of the project results and provide a forum for discussions involving partners and external participants. In this deliverable details are given about the workshop Advanced Multicarrier Waveforms and Mechanisms for Future Ad-Hoc and Cell-Based Systems during the Tenth International Symposium on Wireless Communication Systems - ISWCS'13. It consisted of 11 accepted contributions from the open call for papers and 3 invited talks by renowned multicarrier systems experts. The audience fluctuated between 40 and 50 participants.

**Keywords:** Professional Mobile Radio systems, Public Protection and Disaster Relief, Filter bank based, Multicarrier Scheme, Spectrum Sharing, System cohabitation, Advanced waveforms, 3GPP LTE evolution

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0.1	28.10.2013	Leonardo G. Baltar (TUM)	Initial version
0.2	29.10.2013	Leonardo G. Baltar (TUM)	Small modification
1.0	31.10.2013	Leonardo G. Baltar (TUM)	Typo corrections and final version

## Executive Summary

The realization of a workshop has the objective to raise interest of research community into the core technologies developed within EMPhAtiC project, together with sharing/disseminating this know-how in Europe. To fulfill this objective, the EMPhAtiC project successfully organized a workshop on 27 August 2013 during the Tenth International Symposium on Wireless Communication Systems - ISWCS'13 at Ilmenau, Germany.

ISWCS'13 is a yearly successful symposium on wireless communications that has been always hosted in Europe with exception of its first edition. With an average of 300 attendees it provide an appropriate framework for the project workshop.

For the EMPhAtiC workshop, a call for papers was officially published in January 2013 and the deadline for submissions was 31st March, 2013. This opened the possibility for authors external to the project to publish their results and allowed public visibility of the workshop. The project partners were strongly recommended to submit their contributions. The result was the acceptance of 10 papers from internal project contributions and one external contribution. To motivate inputs and discussions during the workshop, and also attract more public attention, 3 renowned experts were invited to give talks showing their view of future advanced multicarrier schemes. The workshop had the duration of one day starting at 9:00 and finishing at 17:00. The attendance was considered very good with the audience varying between 40 and 50 persons, especially if considering that 2 other workshops and 2 tutorial sessions were running in parallel.

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## 1. Introduction

Public Safety organisations are using radio communications systems for the day to day operational needs (called PP1: Public Protection in day to day mode), for exceptional events (called PP2: Public Protection in exceptional planned events: sports events, cultural events, demonstrations, etc.), and for disaster recovery conditions (called DR: Disaster Relief: exceptional unplanned events). These usages are called collectively as PPDR, which corresponds to Professional Mobile Radio (PMR) services for Public Safety organisations.

Today they use dedicated radio communications systems TETRA, TETRAPOL in Europe and in a large part of the world, APCO25 in North America) primarily for voice communications and also for low rate data transmissions. This is due to the technological limitations of currently deployed PMR /PPDR systems, which only use a small frequency bandwidth and have thus limited throughput.

In recent years Public Safety organisations in the UK, France, Netherlands and some other countries have been conducting trials on high-speed data communications, in line with the PMR evolution trend. There is clearly a need amongst these organisations to have in 5 to 10 years nationwide networks to support mission critical applications like those listed above.

Services like Imaging, Digital mapping / Geographical information services, Video (real time and slow scan), and data base access remote require much higher data rates than what the currently deployed PMR/PPDR systems can support. Broadband techniques using bandwidths in the range of 1.4, 3, or 5 MHz, such as the 3GPP LTE system, enable high data rate transmissions and demanding PPDR data applications. The above mentioned services and applications are becoming more and more important for the missions of Public Safety organisations.

### 1.1 *EMPhAtiC project motivation*

The EMPhAtiC project addresses the described trends and needs to upgrade the PMR/PPDR networks (TETRA, TETRAPOL, TETRA TEDS, APCO 25, ETSI dPMR, iDEN, and others) towards supporting broadband data communications services. The new required capacity can be achieved in two complementary ways: by obtaining new frequency bands for PPDR data services and by fitting a novel broadband data service within the scarcely available spectrum devoted to PMR systems. To satisfy the growing demands, both directions actually have to be followed. In EMPhAtiC project we focus on the latter approach, which can be seen as a very challenging evolution path, but also the most realistic opportunity to benefit from the advantages of latest developments in multicarrier waveforms and related signal processing techniques. One of the major issues is being able to introduce new broadband data services within the current frequency allocation, in coexistence and cohabitation with current PMR/PPDR systems.

### 1.2 *Vision & Objectives*

The considered coexistence scenario, deployment of broadband data service in a band already occupied by narrowband PMR channels. In such a scenario high flexibility and spectral agility in combination with efficient fragmented spectrum use are necessary requirements for the broadband system. To reach good spectral efficiency and minimize interferences between the different services, well-contained spectrum, providing improved adjacent channel protection, is critical. The general objectives of EMPhAtiC are:

- to propose an innovative technological solution allowing increased data throughputs for

Public Safety radio-communication systems in cohabitation with existing networks in the same frequency bands, to facilitate a smooth migration towards broadband systems.

- to develop an efficient and highly flexible/variable filter-bank processing structure for use in heterogeneous environments with irregularly fragmented spectrum.
- enable a flexible spectrum use for mobile broadband applications, while taking into account commercial and regulatory opportunities and constraints.
- development and use in PMR/PPDR context of advanced multicarriers waveforms and signal processing techniques and find applications in various other scenarios of flexible spectrum usage and cognitive radio.
- Radio scene analysis for flexible spectrum usage is also an important technological objective.
- demonstration of the superiority of the EMPhAtiC architecture when compared to prior known solutions.

### ***1.3 Concentration and Audience***

The results obtained in the EMPhAtiC project will benefit all parties in the wireless arena:

- **Academia and research centers** first contributing with their solid backgrounds in this field, will benefit from EMPhAtiC to improve their research profiles. The work will stipulate dissemination of this knowledge to undergraduate and PhD students. This will generate skilled engineers, which will be well prepared to start their professional career in the wireless sector.
- **Industrial partners** The benefits of the Project for Industrial Partners will be felt in the areas of improved products and solutions available through the Project. This will allow the parties to take advantage of improved system performance due to new ideas before their competition. Therefore, the target (from industrial point of view) is to improve the positioning of European industry in the PMR domain in terms of research, technology mastery and evolution for the future. Two major worldwide companies, CASSIDIAN and TCS, are major actors in the EMPhAtiC projects and they are strong and prime players in the domain of PMR. Dynamic SMEs working in the domain of broadband mobile radio communications are also involved in the development of the European industrial potential in the PMR/PPDR domain and to support European industry positioning on mobile wireless broadband systems.
- **Users** who will eventually be offered optimised services because of the higher flexibility and efficiency resulting from advanced wireless systems providing high quality of services.
- **Society** The European Industry has been in the forefront of wireless technologies for example with the early introduction and standardization in the nineties of the Digital Mobile Solution of GSM. The early adoption of new technologies has proven an enormous success for the involved industries first and lastly for the society they are serving. The society can take advantage in advance of other competing countries of an improved service and a technological prestige that finally rubs on other aspects of the economical toil.

The focus of EMPhAtiC is to improve efficiency of mobile broadband networks especially in term of radio coverage and capacity. This target is the keystone for reducing the cost of deployment of radio networks for PMR applications, and also more generally for Broadband Mobile Radio networks. This enables major cost savings in radio network deployment, especially in suburban and rural areas, by minimizing the number of radio sites required. This lowers also the cost of communications onto mobile radio networks by using more efficiently the scarce resource of radio frequencies.

## 2. ISWCS 2013

The International Symposium on Wireless Communication Systems is yearly event and in 2013 was on its tenth edition. The symposium started in 2004 and, with exception of its first edition, it always took place in European countries. As a consequence, a great number of contributions and participants come from European universities, research centers and industries. The average number of participants is around 300 per year.

### 2.1 *The tenth edition: Wireless Communications for the 2020s*

The symposium was organized by the Ilmenau University of Technology between 27th-30th August 2013 and the venue was a conference center inside the university campus at Ilmenau, Germany.

Besides EMPhAtiC workshop, three other workshops and four tutorials took place on the first day. On the following three days there were 5 plenary talks by keynote speakers, one panel session, 30 oral sessions, 3 poster sessions and 2 demonstration sessions. The open call counted 264 submissions and from them 166 papers were accepted, resulting in a 51% acceptance rate.

According to the call for papers, ISWCS'13 had the following overview:

*"The aim of this symposium is to provide a forum for researchers and technologists to present new ideas and contributions in the form of technical papers, panel discussions as well as real-world evaluation of many ideas in wireless communications, networking and signal processing employed to support the needs of the Information Society. This tenth symposium will bring together various wireless communication systems developers to discuss the current status, technical challenges, standards, fundamental issues, and future services and applications. ISWCS'13 seeks to address and capture highly-innovative and state-of-the-art research from academia, the wireless industry as well as standardization advances. The scope of the conference includes a wide range of technical challenges encompassing wireless communications, information theory, quality of service support, networking, signal processing, cross-layer design for improved performance, wireless broadband access, and cooperative networking."*

The symposium was divided into three tracks:

- Track 1: Communication theory, signal processing, information theory, antennas and propagation
- Track 2: Networking, protocols, cognitive radio, wireless sensor networks, services and applications
- Track 3: Special sessions

There were 3 best paper awards for each of the tracks.

The symposium technical sponsors were the Institute of Electrical and Electronics Engineers (IEEE), IEEE Vehicular Technology Society (VTS), German Association for Electrical, Electronic & Information Technologies (VDE), VDE Information Technology Society (ITG) and Ilmenau University of Technology's International Graduate School on Mobile Communications (Mobicom), Integrated Communication Systems Group, and Communications Research Laboratory.

In addition, ISWCS'13 had two sponsors: Innovationszentrum für Telekommunikationstechnik GmbH IZT, a spin-off of the Fraunhofer-Gesellschaft, Germany's leading institution for applied research, and Rohde & Schwarz, a German company and one of the world's leading



manufactures of test and measurement, communications and broadcasting equipment. Moreover, ISWCS'13 was supported by the DFG (German Research Foundation), the self-governing organisation for science and research in Germany.

### **3. Advanced Multicarrier Waveforms and Mechanisms for Future Ad-Hoc and Cell-Based Systems**

For the EMPhAtiC workshop, a call for papers was officially published in January 2013 and the deadline for submissions was 31st March, 2013. This opened the possibility for authors external to the project to publish their results and allowed public visibility of the workshop. The project partners were strongly recommended to submit their contributions. The result was the acceptance of 10 papers from internal project contributions and one external contribution. To motivate inputs and discussions during the workshop, and also attract more public attention, 3 renowned experts were invited to give talks showing their view of future advanced multicarrier schemes. The workshop had the duration of one day starting at 9:00 and finishing at 17:00. The attendance was considered very good with the audience varying between 40 and 50 participants, especially if considering that 2 other workshops and 2 tutorial sessions were running in parallel.

In the following sections more details about the EMPhAtiC workshop are presented. Starting with the topics contained in the call for papers, details about the invited talks and their speakers, the final workshop program and a few pictures of the event give some impressions of its success.

#### **3.1 Call for papers - Topics**

In the workshop call for papers, contributions presenting advances on the following topics but not limited to them were invited:

- Multicarrier waveforms and signal processing solutions for narrowband co-existence
- Advanced multicarrier waveforms for TVWS and future PMR systems
- Advances on prototype filter design for filter bank based multicarrier systems
- Advanced techniques for out-of-band radiation reduction
- Advanced on synchronization and equalization for multicarrier waveforms
- Advanced schemes for optimizing diversity processing and spectrum efficiency.
- Frequency sharing solutions in broadband and narrowband systems.
- Multimodal, multi-access methods for next generation communication
- MIMO schemes and co-channel interference mitigation in narrow bands
- Advanced filter-bank multicarrier scheme for intrinsic interferences mitigation
- Highly adjustable multirate digital filters for multicarrier systems
- Cross-layer aspects and radio resource management in cell-based and ad-hoc PMR/PPDR networks
- Relaying and range extension techniques
- Cognitive radio as an enabler approach for flexible and adaptive next generation PMR communications.
- Novel applications of enhanced multicarrier schemes for spectrum sharing
- Implementation aspects, architectures and building blocks for multicarrier systems, including TVWS and PMR
- Regulatory and standardization aspects

## 3.2 *Invited Talks*

The EMPhAtiC workshop hosted 3 invited talks with the following titles, abstracts and speakers biography.

### 3.2.1 **Bellanger, CNAM (Conservatoire National des Arts et Métiers), Paris-France, Filter Banks in Communications: Challenges and Perspectives**

Abstract: After the successful deployment of digital transmultiplexers at the interface of analogue and digital networks in the early eighties, one would have expected more applications of filter bank techniques in the communication systems to come. Instead, the multicarrier transmission concept has been implemented with OFDM in all the emerging applications: digital broadcasting, ADSL, PLC, local area wireless networks and cellular networks. Why communication equipment developers and network operators are so reluctant to use filter bank based techniques? In the talk, three obstacles to the use of filter banks in communications are discussed, namely delay, equalization and complexity in both concept and computations. Two approaches, FBMC/OQAM and FMT/QAM, are compared and contrasted in that respect. To conclude, suggestions are offered to help get the support of standardization groups and gain acceptance by decision makers in industry and network operation.

Biography: Maurice Bellanger graduated from ENST (Ecole Nationale Supérieure des Télécommunications), Paris, in 1965 and received the doctorate degree from the university of Paris in 1981. He joined the company Philips Communications in France in 1967 and, since then, he has worked on digital signal processing and applications in telecommunications. In 1991, he joined CNAM (Conservatoire National des Arts et Métiers), a public education and research institute, as a professor of electronics. He is now emeritus professor. From 2008 to 2010, he was the coordinator of the European Research FP7-project “Physical Layer for Dynamic Spectrum Access and Cognitive Radio”-PHYDYAS (<http://www.ict-phydyas.org/>). Elected a Fellow member of the IEEE in 1984, for contributions to the theory of digital filtering and the applications to communication systems, he was the technical program chairman of the conference ICASSP’82 in Paris. He was the president of EURASIP, the European Association for Signal Processing, from 1987 to 1994 and the chairman of the France section of URSI (Union Radio Scientifique Internationale) from 2006 to 2008. He is a member of the French Academy of Technology.

### 3.2.2 **Pierre Siohan, Orange Lab, Rennes-France, FBMC: An Idea Whose Time Has Come**

Abstract: In the famous paper: “Multicarrier modulation for data transmission: An idea whose time has come”, the author refers to conventional OFDM and also to multicarrier modulation based on offset (or staggered) QAM. Actually, in 1990 OFDM was already there with wireless (DAB) and wired (DSL) transmission systems and, since then, has known a tremendous success. At the contrary, all OFDM variants, today known as Filter Bank Multi-Carrier (FBMC) systems, are still marginal from a standardization and industrial point of view. However, with the OFDM/OQAM/IOTA proposal, the paper by Le Floch et al. in 1995 has renewed the interest for enhanced multicarrier systems. The talk will propose an overview of the impressive progresses that are being made since that time to get very competitive FBMC systems. Then, we will focus on some features of FBMC that still deserve a particular attention. Among those, are FBMC flexibility, packet transmission and efficient equalization.

Biography: Pierre Siohan (IEEE SM 1999) received the PhD degree from the École Nationale Supérieure des Télécommunications (ENST), Paris, France, in 1989. In 1977 he joined the Centre Commun d'Études de Télédiffusion et Télécommunications (CCETT), Rennes, where his activities were first concerned with the communication theory and its application to the design of broadcasting systems. Afterwards, he was in charge of the CCETT Mathematical and Signal Processing Group. From September 2001 to September 2003, he took a two-year sabbatical leave, being directeur de recherche with the Institut National de Recherche en Informatique et Automatique (INRIA), Rennes. Now, he is Expert in Networks and Telecom at Orange. His current research interests are in signal processing for communication, especially for radio and power line communication systems. Dr. Siohan has authored 31 papers in refereed international journals, 30 patents and 90 papers in international conferences. Recently, he was a guest editor of the special issue on "Filter Banks for Cognitive Next Generation Multicarrier Wireless Communications," which appeared in EURASIP ASP journal.

### **3.2.3 Andrea M. Tonello, University of Udine, Udine-Italy, What's Next and Why on Filter Bank Modulation? From Concatenated FMT to Cyclic Block FMT**

**Abstract:** Multicarrier modulation is enjoying great success in state-of-the-art physical layer wireless and wireline (e.g., power line communications) technologies. The most popular architecture is orthogonal frequency division multiplexing (OFDM). Aiming at increasing spectral efficiency, more general architectures based on filter bank modulation (FBM) have been proposed. This talk offers an overview of some recent advances and results about FBM trying to motivate the reasons why there is still space to devise interesting FBM digital architectures for application in multiple access asynchronous channels (both wireless and power line) affected by doubly dispersive fading and various non-idealities. In particular, focus will be given to Filtered Multitone Modulation (FMT) and novel schemes, namely, concatenated OFDM-FMT, MIMO Precoded FMT, Hybrid FMT, and Cyclic Block FMT. The application of such solutions is motivated by multiple ambitious objectives: the robustness not only to channel impairments but also to hardware limitations (FMT), the orthogonalization of the uplink channel (Concatenated FMT), the high capacity in MIMO frequency selective channels (Precoded FMT), the agile use of spectrum and the flexible adaptation of available resources (Hybrid FMT), the overall reduced latency/complexity and increased performance with simple orthogonal filter bank design (Cyclic Block FMT). The main features of such schemes will be described and illustrative examples of performance will be given.

Biography: Andrea M. Tonello is an Aggregate Professor at the University of Udine, Italy (since 2003) where he leads the Wireless and Power Line Communication Lab. He is also the founder and president of WiTiKee, a university spin-off company. From 1997 to 2002 he has been with Bell Labs Lucent Technologies firstly as a Member of Technical Staff and then as a Technical Manager at the Advanced Wireless Technology Laboratory, Whippany, NJ and the Managing Director of the Bell Labs Italy division. He obtained the Laurea degree (1996) and the Doctor of Research degree in electronics and telecommunications (2003) from the University of Padova, Italy. Dr. Tonello received several recognitions among which the Lucent Bell Labs Recognition of Excellence award (1999), the Distinguished Visiting Fellowship from the Royal Academy of Engineering, UK (2010) and the Distinguished Lecturer Award by the IEEE Vehicular Technology Society (2011-13 and 2013-15). He also received (as co-author) five best paper awards. He is the Vice-chair of the IEEE Communications Society Technical Committee on Power Line Communications. He serves/ed as an Associate Editor for the IEEE Transactions on Vehicular Technology (2007-2013), for the IEEE Transactions on

Communications (2012-TD) and IEEE Access (2013-TD).

### 3.3 Final Program

- 09:00 - 09:30 (Invited talk): "Filter Banks in Communications: Challenges and Perspectives", Maurice Bellanger (CNAM - Conservatoire National des Arts et Métiers, Paris-France)
- 09:30 - 09:50: "Timing Offset Compensation in Fast-Convolution Filter Bank Based Waveform Processing", Markku K. Renfors (Tampere University of Technology, Finland); Juha Yli-Kaakinen (Tampere University of Technology, Finland)
- 09:50 - 10:10: "Analysis of the nonlinear spectral re-growth in FBMC systems for cognitive radio context", Saidou Sall (Paris-Est Marne-la Vallée University, France); Hmaied Shaiek (CNAM, France); Daniel Roviras (CNAM, France); Yahia Medjahdi (CNAM, France).
- 10:50 - 11:20 (Invited talk): "FBMC: An Idea Whose Time Has Come", P. Siohan, Orange Lab, Rennes-France
- 11:20 - 11:40: "Preamble Design for Channel Estimation in OFDM/OQAM Cooperative Systems", Christos Mavrokefalidis (CTI, Greece); Eleftherios Kofidis (CTI, Greece); Athanasios A. Rontogiannis (CTI, Greece); Sergios Theodoridis (CTI, Greece).
- 11:40 - 12:00: "Low feedback downlink MIMO channel estimation for distributed FBMC systems using SNR measurements", Jerome Louveaux (Université Catholique de Louvain, Belgium); François Horlin (Université Libre de Bruxelles, Belgium); Andre Bourdoux (IMEC, Belgium).
- 13:40 - 14:10 (Invited Talk): "What's Next and Why on Filter Bank Modulation? From Concatenated FMT to Cyclic Block FMT", A. M. Tonello, University of Udine, Italy
- 14:10 - 14:30: "Comparison of linear and widely linear processing in MIMO-FBMC systems", Màrius Caus (Universitat Politècnica de Catalunya (UPC), Spain); Ana Perez-Neira (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) and Universitat Politècnica de Catalunya (UPC), Spain).
- 14:30 - 14:50: "On interference cancellation in Alamouti coding scheme for filter bank based multicarrier systems", Rostom Zakaria (CNAM, France); Didier Le Ruyet (CNAM, France).
- 14:50 - 15:10: "EM based Per-Subcarrier ML Channel Estimation for Filter Bank Multicarrier Systems", Leonardo Gomes Baltar (Technische Universität München, Germany); Amine Mezghani (Technische Universität München, Germany); Josef A. Nossek (Technische Universität München, Germany)
- 15:40 -16:00: "Non-uniform FBMC - A pragmatic approach", Sladjana Josilo (Faculty of Technical Sciences, UNS, Serbia); Milos Pejovic (Faculty of Technical Sciences, UNS, Serbia); Slobodan Nedic (Faculty of Technical Sciences, University of Novi Sad, Serbia).
- 16:00 - 16:20: "Link Performance Model for System Level Simulations of Filter Bank Multicarrier-Based Systems in PMR Networks", Alexandra Oborina (CTTC, Spain); Christian Ibars (Centre Tecnològic de Telecomunicacions de Catalunya - CTTC, Spain); Lorenza Giupponi (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain); Faouzi Bader (SUPELEC, France)

- 16:20 - 16:40: "Time and frequency synchronization for downlink CoMP with FBMC", Nicolas Cassiau (CEA-Leti Minatec, France); Dimitri Kténas (CEA, France); Jean-Baptiste Doré (CEA, France).
- 16:40 - 17:00: "Link to System Mapping for FBMC Based Systems in SISO case", Dmitry Petrov (Magister Solutions Ltd. and University of Juväskylä, Finland); Tobias Hidalgo Stitz (Magister Solutions Ltd., Finland); Pavel Gonchukov (University of Juväskylä, Finland).

### 3.4 Impressions

Figs. 3-1 and 3-2 show some impressions of the EMPhAtiC workshop.



Figure 3-1: Workshop ready to start with the first invited talk



Figure 3-2: Audience of the third invited talk



## Glossary and Definitions

Acronym	Meaning
3GPP	Third Generation Partnership Project
APCO25	Association of Public Safety Communications Officials Project 25
ETSI	European Telecommunications Standards Institute
ETSI pDMR	ETSI private Digital Mobile Radio
FB-MC	Filter Bank-based Multi-Carrier
iDEN	integrated Digital Enhanced Network
IEEE	Institute of Electrical and Electronics Engineers
ITU-R	International Telecommunication Union Radiocommunication sector
IMT	International Mobile Telecommunications-Advanced
LTE	Long term Evolution
LTE-A	Long Term Evolution - Advanced
PMR	Personal Mobile Radio
PPDR	Public Protection and Disaster Relief
pDMR	private Digital Mobile Radio
TETRA	TErrestrial Trunked RAdio
TETRA TEDS	Tetra Enhanced Data Service
TETRAPOL	A digital FDMA PMR system developed by Matra/EADS
QoS	Quality of Service
WiMAX	Worldwide Interoperability for Microwave Access
WWRF	Wireless World Research Forum