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## Editorial of Special Issue

# Future Evolution of Public Safety Communications in the 5G Era

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**P**ublic Safety (PS) or Professional Mobile Radio (PMR) communications technologies are undergoing significant transformation towards broadband. The Terrestrial Trunked Radio (TETRA) as one of the earliest critical communication systems has evolved from narrowband data in its first release to the current wideband data Tetra Enhanced Data Service (TEDS). TEDS gives higher data rates with up to several hundred kbit/s and very well fits into the existing PMR frequency landscape. The APCO25 suite of standards in North America had a similar evolution.

While still providing essential PMR services like voice, group calls and messaging, the evolution of Public Safety communication must include data-rich broadband services to support a wide range of applications to enhance the operational capability of PMR users. Examples of services and applications include remote healthcare, video-streaming, health monitoring of the first responders and so on. In comparison to mobile applications in the consumer market, PMR applications have severe requirements in terms of signal quality, security, reliability, and coverage. In addition, the usage patterns can be significantly different from the consumer market, as public safety officers must often face unexpected situations (e.g., emergency crisis) and still be able to rely on full traffic capacity and high Quality of Service (QoS) from the networks. The design of future PMR communications must take into consideration these requirements and needs.

Significant advances have been achieved in the last years and are still under development focusing on the use of advanced signal processing techniques using flexible multicarrier waveforms in PMR bands to satisfy emerging new data service needs in cohabitation with existing networks in the same frequency bands, to facilitate a smooth migration towards broadband

systems and to increase spectrum efficiency. One example is Spectrum sharing, which is expected to bring substantial benefits for a better use of the radio spectrum, helping to mitigate the severe spectrum scarcity problem (mainly in the EU PS band). However, there are several issues that put a question mark on the deployment of PMR systems and their integration with fifth generation (5G) communication technologies and vision.

First of all, the integration of PS system in LTE-Advanced (LTE-A) is still not optimized for voice calls (and especially not for the group calls), meaning that it will have to coexist for some time with the PMR conventional networks (e.g., TETRA) for basic voice services. Moreover, LTE-A is still not designed as a mission critical system. High availability and security features are not inherent in all the aspects - so some additions to the LTE-A standard or implementation scenarios have to be made, especially in the case of future interoperability and usage of commercial 5G networks for PS scenarios. In addition, standards for direct communications, like LTE Device to Device (D2D) or ad-hoc networks must be still validated on the basis of the requirements of security and reliability.

With proper implementation of these concepts, PMR users may rely on future 5G systems in the same manner they rely on current narrowband PMR systems. Meanwhile, the design and integration of parallel or complementary usage of traditional PMR systems for voice communication and next generation PMR users in 5G systems for mission critical broadband data transfer still remain as open challenges. In particular, the research and standardization for internetworking of heterogeneous networks for PMR is still not completed. This special issue aims to investigate all aspects relevant to the development of the PMR communications systems and networks, and their future evolvement in the fifth generation (5G) communication environment. We

received over this special issue ten submissions altogether, out of which eight were accepted through a rigorous peer review process. Note that in the following sections, the terms PMR and PS are used with the same meaning.

In this context, the work presented in the paper “*Analysis of strategies for progressive 5G emergency network deployment*” by Vilhar, Andrej et al., provides an analysis on network deployment strategies. It is evident that the temporary communication systems for emergency situations have traditionally been provided by a single communication technology. They are typically based on the 2G technologies for mobile radio that cannot meet the data rate requirements of contemporary applications. Emergency systems based on the 3GPP LTE technology are presently under investigation, and there is increasing interest in including new 5G concepts. 5G may enable the employment of multiple heterogeneous communication systems such as fast deployable areal platforms, ad-hoc portable terrestrial stations and satellite communications, all of which integrated with the preserved part of the existing wireless infrastructure. Such an integrated approach is studied and evaluated in this work, based on the simultaneous use of the remaining terrestrial systems and additional LAPs (Low Amplitude Platforms). Simulations of the system were performed using the GRASS-RaPlaT tool, augmented with the AMS-DEMO tool for optimizing a radio network configuration and based on a set of four criteria functions.

Different scenarios are investigated in the presented work for setting up the initial emergency network configuration that is primarily focused on providing the high coverage needed for emergency forces. This is followed by recovering the complete system with larger capacity and better quality of service. Application of 5G principles, such as carrier aggregation, has proved to be beneficial. The performance of the emergency network is evaluated in a geographic location of the city of Ljubljana in Slovenia, and compared with the existing mobile network in this area. Based on the results, recommendations are given for the procedures needed to rebuild a mobile network after a disaster.

In “*Enhanced Multicarrier Techniques for Narrowband and Broadband PMR Coexistence*”, it has been shown by S. S. Krishna Chaitanya Bulusu, et al., that the conventional orthogonal frequency division multiplexing (OFDM)-based long-term evolution (LTE) system needs sufficient guard-band or additional filtering in order to coexist in a PMR band, even without considering the RF impairments of the transmitter. In practice, it is imperative to take into account the RF

impairments in radio communication systems, such as the non-linear (NL) nature of a high power amplifier (PA). The authors investigate in this work some enhanced multicarrier techniques allowing the coexistence of narrowband and broadband PMR systems that can support asynchronous access, have low latency and be able to be operated with NL devices. Obtained simulation results show that a LTE-like post-OFDM broadband system working with NL PA devices can still co-exist with legacy PMR systems with high energy efficiency, when proper PA linearization techniques are applied in combination with effective peak-to-average power ratio reduction methods.

The simulation results obtained by the authors suggest that a LTE-like FBMC-OQAM or FBSC (Filter Bank Single Carrier) broadband system can coexist with PMR systems, when accompanied by proper PA linearization and PAPR reduction techniques. Linearization of NL PA can be achieved by digital pre-distortion techniques and this topic shall be duly considered in their future work.

The work on “*Blind Channel Estimation for FBMC-based PMR transmission*” presented by M. Terré et al., propose a blind channel estimation technique using filter bank multi-carriers (FBMC) waveforms in a fast varying channel context for PMR transmissions. In several PMR contexts the channel changes rapidly, it is the case in the 400 MHz band for propagation corresponding to hilly terrain propagation channels. In such cases the waveform needs more pilots and they should be sent more frequently. Alternative solutions are based on data aided channel tracking or data aided blind or semi-blind channel estimation. In this work, the authors focus on the blind channel estimation problem. To analyse how pilots can be cancelled, authors introduce a blind algorithm able to estimate and to track the frequency response of the propagation channel. The authors propose to blindly estimate the propagation channel without any signal to noise ratio increase and with only a small number of transmitted symbols, typically less than 150 FBMC symbols. The proposed blind approach was firstly based on a fourth power elevation of FBMC receiver outputs. Then a regularization step was proposed, through an inverse Fourier Transform and an auto-deconvolution step, to directly estimate the channel impulse response. The only drawback of this proposal comes from a previous mandatory estimation of the channel impulse response length that has not been fully addressed in this paper. Nevertheless this estimation can be replaced by an upper bound of the channel delay spread.

A “*Novel D2D Resource Partitioning and Allocation Schemes for SC-FDMA-based Public Safety Systems*”, is proposed by Seung-Hoon Park et al. In this work the authors emphasize the importance of Device-to-device

(D2D) communication for the provision of the broadcasting service for PS terminals in out-of-network coverage. A sensing-based resource-allocation scheme is desirable, rather than a random approach, for next-generation PS systems so that higher data rates and a massive connectivity can be supported. Furthermore, the potential of D2D-enabled devices will be burgeoning in the forthcoming era of the Internet of Things (IoT) and 5G, making the pursuance of the performance enhancement of D2D-based PS communications a matter of the utmost importance for the industry.

The half-duplex and resource collisions are the main design constraints, especially for the single carrier frequency division multiplexing (SC-FDMA) based D2D broadcast system. A novel resource-allocation scheme is proposed in this work, whereby the resource partitions are managed adaptively based on sensing results. The system-level evaluation and analysis results show that proposed scheme significantly improves upon the overall network performance of the conventional scheme, especially with respect to the resource-collision rate and the throughput.

To overcome a combination of the collision issue and the half-duplex problem in an SC-FDMA system, a gradual scheme for the partitioning and selection of resources for which random and sensing-based approaches are effectively combined is proposed in this work.

In addition, a mathematical model for the evaluation of the performance at the transmitter side and system level simulations for the verification of the performance improvement at the receiver side are also provided. According to provided results by the authors, the proposed scheme will contribute to the efforts regarding standardization and development implementation for PS communication systems in the near future.

“*Power efficiency, phase noise, and DC offset in constant envelope OFDM transceiver*“, is a work presented by Kiviranta, Markku et, al. The aim here is to consider constant envelope orthogonal frequency-division multiplexing (CE-OFDM) which is an attractive candidate for the future long term evolution (LTE) over satellite and device-to-device (D2D) communications in merging public safety and commercial networks. The constant envelope modulation allows power amplifier (PA) to operate near saturation levels thus maximizing power efficiency, and since the phase noise transforms just into an additive noise term after the phase detector, the CE-OFDM has significant advantage compared to phase noise sensitive OFDM. The transceiver power efficiency is evaluated by measuring the bit error rate (BER) as a function of average PA input signal-to-noise ratio (SNR) so that the effects of the PA nonlinearities are taken into account in the performance evaluation. Our simulation results show that with a typical nonlinear

satellite amplifier, the CE-OFDM approach has up to 6.0 dB gain compared to the OFDM approach. This is beneficial especially in a channel having high attenuation. The consistent gains for the ideally linearized amplifier and common terrestrial 3-way Doherty amplifiers are 2.2 and 2.5 dB respectively. The enhanced PA efficiency enables battery to be smaller or last longer in mobiles devices, which is an important requirement in PS operational contexts. For CE-OFDM implementation, a simple transmitter and receiver structure with novel dc offset removal is presented in this work. The authors note that the key factor for the rapid uptake of the future fifth generation (5G) systems is the maximization of technology commonalities with existing systems.

In the following work on “*A Novel Geometric Handover Model for Aerial 4G Networks with WiFi-based X2 Interface*“, R. Fedrizzi et, al., explain that given the temporary nature of radio communications for mission critical scenarios, the existing dedicated PS network lacks the flexibility of cutting edge technologies (e.g., in the consumer market) to leverage on packet data services. In this context, new challenges arise such as high capacity demand and low-latency flexible backhaul connection for PS users. In this paper, the authors consider a scenario in which 4G LTE radio coverage is provisioned by aerial eNodeBs (AeNBs) installed on low-altitude platforms (LAPs) raised in the sky and interconnected through WiFi links. The authors focus their attention on the critical aspect of the 3GPP handover mechanism studying the handover performance using an X2 interfaces over WiFi links. The authors develop a novel geometric model of the handover in the context of PS communications but extensible also to other contexts.

Relying on such a model, the handover failure probability is computed taking into account the different handover phases. The coverage area of an AeNB is studied using a suitable Air-to-Ground (ATG) propagation model while the average handover duration is computed taking into account the delay introduced by the WiFi communication dynamics. Very promising results are provided in this paper.

In the work “*Dynamic PSS and Commercial networks spectrum sharing in the time domain*“, G. Bartoli et al., acknowledge that the possibility for PS and Security operators of using a wide range of data-centric services improves their coordination and responses to emergency crisis. Therefore, there is great consensus in the evolution of existing Public Safety and Security (PSS) mobile communication systems (i.e., PS or PMR systems) towards broadband, with the exploitation of LTE technology, commonly used in commercial

networks. Having a single technology allows synergies between commercial and PSS worlds; in particular, the authors are interested in an efficient spectrum sharing between the two networks. Indeed, a portion of spectrum dedicated to PSS, large enough to satisfy emergency situations, may result unused most of the time, with a consequent waste of precious resources. This is reason why the authors propose a spectrum sharing policy based on dynamic allocation of time sub-frames. Differently from previous approaches, the authors considered some resource portions exclusively dedicated to one of the two networks, and other portions simultaneously accessed. Therefore, the goal of the proposed scheme is to find suitable resource partitioning and users allocation. Users are allocated depending on the level of received interference, with the aim of a fair behaviour in different portions of the frame. Moreover, proposed algorithm takes into account different priorities that can be given to the two networks depending on the operative scenario. Effectiveness and accuracy of the proposed scheme are proven by a comparison with other benchmark methods and with the optimal solution of the resource partitioning problem, in terms of unsatisfied data rate requests.

Last but not least, the work on “*A Software-Defined 5G Cellular Network with Links Virtually Pooled for Public Safety Operators*” is presented by Maurizio Casoni et al. For the authors, during disaster relief operations, PS personnel performs data communication almost exclusively through terrestrial commercial networks. However, common cellular infrastructures are often unable to provide acceptable throughput and even basic availability, due to congestion or potential disruptions of the communication infrastructure. In order to overcome these issues, the authors of this work propose the implementation of a network abstraction that is defined as Virtual Resource Pooling. This allows to virtually pool the resources provided by the cellular channels on which field operators are connected. The proposal aims to harmoniously blend together the multi-homing capabilities of modern devices and their collaborative potential, by leveraging the SDN facilities that are expected to be present in the core infrastructures of 5G networks. Coupled with the envisioned performance and packet core plasticity of the latter, such a system may have the potential to provide future PS operators with broadband capabilities and high quality of experience (QoE) in day to day tasks and major planned events, while providing improved communication guarantees in unplanned disasters. To perform an experimental assessment, the authors describe the test bed that has been built and used to perform network emulation runs and to extract their results. These results indicate that a system with Virtual Resource Pooling may greatly enhance not only the throughput and QoS properties, but

also the resilience guarantees that network tenants may offer to field operators. In this work, the authors were able to provide and analyse and provide various emulation results, verifying that such a system may be able to efficiently administrate the pooled resources even in heterogeneous environments. Moreover, it is shown how Virtual Resource Pooling (VPR) may realistically result in significant performance gains and improved resilience guarantees, with as little as two concurrently forwarding nodes.

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