Report of Short Term Scientific Mission (STSM) of
COST CA15127-RECODIS

STSM Topic: Flexible Waveforms for Wireless Communication at Disaster Relief

STSM Applicant: Dmitry Petrov, Magister Solutions Ltd., University of Jyväskylä, Finland
Host: Alexey Vinel, Halmstad University, Sweden
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1. Background and targets of the STSM

Public safety organizations are using wireless communications for their everyday operations, including public protection, massive events, and in exceptional disaster recovery conditions. Nowadays, most of Professional Mobile Radio (PMR) systems in Europe are TErrestrial Trunked Radio (TETRA) [1] and TETRAPOL [2] based. These networks were primarily designed for voice and low data rate services. Thus, many of the essential broadband services (e.g. video streaming, remote control, transfer of medical information, etc.) that require higher data rates cannot be not supported. Development of these services in Europe is additionally complicated as there is no unified European-wide spectrum allocated for critical communications. The Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) has recently added 2 x 5 MHz and 2 x 3MHz blocks either side of the Public Protection and Disaster Relief (PPDR) spectrum options in Band 28 (around 700 MHz) [1]. For example, Jeppe Jepsen, a TCCA board member, says that “the conditions that were forced upon the 2 x 5 MHz below Band 28 mean there will be difficulties in getting chip manufacturers to make these chips” [3]. However, the ECC decision does not cover the 410 to 430 MHz range, despite co-existence studies having been performed and that the 400 MHz range can offer national-level flexibility [4].

Thus, the principle objective of the STSM was to analyze the enablers of broadband PMR networks. In particular, the applicability of advanced waveforms for flexible and efficient multi-access spectrum usage in PPDR was discussed. Additionally, the attention was devoted to the consideration of modern approaches to the computer simulations of wireless networks and their applicability in PPDR case. Finally, one of the most complicated scenarios under discussion was the situation when network infrastructure is not available anymore (e.g. after a disaster) or overloaded. However, it is urgent to provide local connectivity for the rescue services. Therefore, the STSM was primarily related to the RECODIS working group 1 (WG1). Additionally, the same considerations can benefit also WG3 since it suggests an alternative communication technology to be used when public communication network performance is degraded.

2. Main results of the STSM

One of the direct ways to provide broadband connectivity for the rescue services is to use existing Long Term Evolution (LTE) technology on dedicated frequencies. For example, such solution is already in use in South Kora. The deployment is leveraging the same dedicated 700 MHz spectrum as the national public safety network in the country, showing how LTE helps different critical communications agencies [5]. However, this approach cannot be applicable in European countries (at lease yet) for the reasons mentioned in the previous section.

Next, another alternative is to use PPDR services directly over public cellular networks. There are already existing mechanisms such as Mission Critical Push to Task (MCPtP) and Device 2 Device (D2D) communication standardized in 3GPP Release 13. Moreover, most of routine (i.e. non-mission-critical) traffic can be already transmitted over public networks. However, good performance in normal conditions is getting unpredictable in the case of accidents or disasters when public cellular networks are likely to suffer from congestion and may eventually fail more easily than the PMR networks [7].

It would be greatly beneficial to deploy broadband data communication services within the spectrum currently devoted to the PMR network (i.e. in 400 or 700 MHz bands). In order to utilize the spectrum efficiently, a cognitive radio approach can be used. The multicarrier (MC) transmission scheme should be capable of identifying and exploiting unused frequency gaps, coexisting with other users or services occupying the spectrum around these gaps. Transmission of signals using such MC modulation scheme should produce only negligible interference to already operating wireless communication systems. Orthogonal Frequency-Division Multiplexing (OFDM) is the principal modulation techniques used in LTE, WiFi, and coming New Radio (NR) 5G standards. However, it has a poor spectral localization due to the rectangular impulse used for modulation. It results in a potentially high intercarrier interference (ICI) in non-synchronized transmission and strong out-of-band emission. Hence, OFDM is not capable of fulfilling the strict interference requirements for coexistence with the PMR network, unless a lot of sub-carriers are used as a guard band, which significantly reduces the OFDM spectral efficiency advantage. Thus, an alternative MC techniques should be selected.

The following sub-sections will describe the main topics discussed during the STSM: flexible waveforms and Filter Bank based MultiCarrier (FBMC) for PMR, connectivity at disaster scenarios and network simulations.

2.1. Flexible waveforms and FBMC for broadband PMR

A promising MC modulation alternative to OFDM is the Filter Bank based MultiCarrier (FBMC) technique, which usually modulates a prototype filter with tight frequency localization to obtain frequency localized sub-carriers. As it was shown in the EMPhAtiC (http://www.ict-emphatic.eu/) project, with FBMC it is possible to create spectrum holes inside wideband allocations that correspond well to the narrowband PMR technologies. Therefore, this approach opens the way for the coexistence of new broadband FBMC-based and legacy TETRA/TETRAPOL networks in the same band (Figure 1).

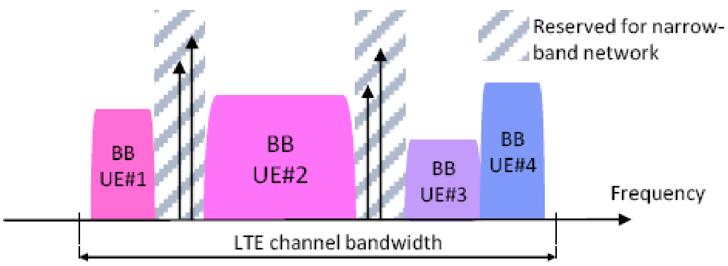

Figure 1. Coexistence of narrowband and broadband radios in the same band [8].

The Fast Convolution Filter Bank (FC-FB) technique described in [9] extends the system flexibility of FBMC in the case of non-continuous spectrum. In particular, with this approach it is possible to transmit and receive narrow- and broadband signals by selecting an appropriate waveform and signal parameters.

NarrowBand Internet of Things (NB-IoT) cellular technology recently standardized in 3GPP Release 13 shows the way how to deploy narrowband sensors in PMR context also. However, when the data is divided into shorter pieces, significant overhead can be observed due to longer filters of FBMC. Therefore, several authors recently proposed to perform Fast Fourier Transform (FFT)/Inverse FFT based convolution without overlapped processing in such a way that circular distortion can be discarded [10]. This scheme is called Circular Fast Convolution FBMC (CFC-FBMC).

Generalized frequency division multiplexing (GFDM) also has potential for PMR applications due to its flexible time-frequency characteristics [11]. GFDM uses interference overlapping non-orthogonal subcarriers, therefore cancellation schemes need to be used for detection in the receiver.

2.2. Disaster relief scenarios

Dedicated MPR network plays very important role in after-disaster situations, firstly, because the performance of public networks can get unpredictable. Outages may happen even when the network infrastructure is still functioning but suffers from increased load or occasional equipment faults. Therefore, the lower frequency bands (around 700 MHz and especially 400 MHz) becomes a big advantage of PPDR over regular LTE network deployed at 2000 MHz carrier. For example, Figure 1 demonstrates that the radius of the coverage area can be doubled.

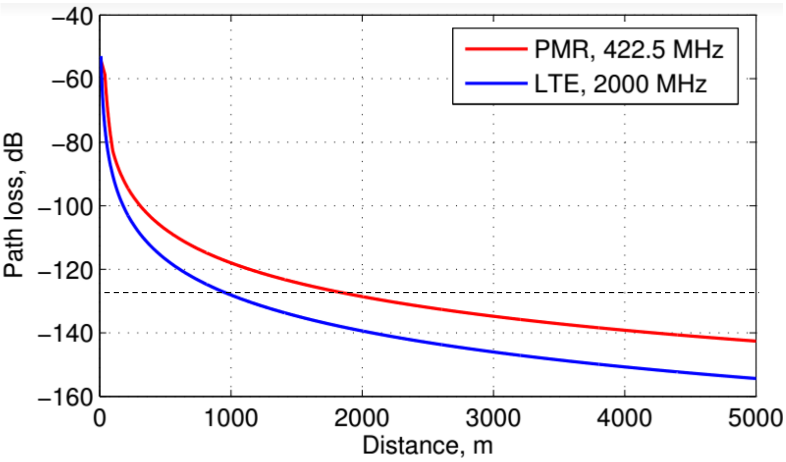

Figure 2. Path loss dependence on distance for PMR (422.5 MHz carrier) and for LTE (2GHz carrier).

When network coverage in the disaster area is completely unavailable, then it is crucial to provide connectivity as fast as possible for the rescue groups. It is also of utmost importance to be able to have a coverage area as wide as possible with the ability to extend critical parameters like capacity and coverage in hotspots for temporary deployed equipment or local networks in the field. Quick hotspot deployment can be enabled by the utilization of self-backhauling links, like it is shown in Figure 3. Higher frequency bands (over 6GHz considered for 5G) can be used because there is much more free spectrum available there. However, this may require implementation of advanced beamforming schemes to achieve reasonable radio link distances. Additional capacity gains can be also expected thanks to the use of advanced waveforms and spectral efficiency improvements for IoT-like traffic.

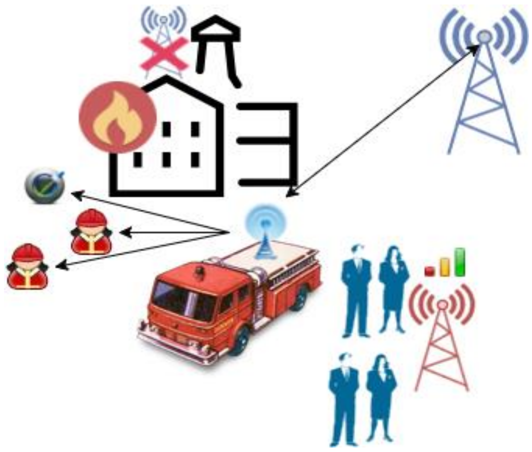

Figure 3. Mobile self-backhauling PMR hotspot in a disaster relief scenario.

2.3. Simulations of FBMC PMR networks

In many circumstances simulation is the only method of evaluation and optimization of real networks and also in prototyping. Moreover, computer modeling gives much more flexibility in the selection of equipment configuration, scenario typologies, user mobility, and other parameters.

System-level simulations of wideband PMR network require abstraction of the physical layers due to the computation performance reasons. Effective Signal to Interference and Noise Ratio (ESINR) mapping usually used in MC OFDM-based systems should be updated because FBMC technology possesses additional intrinsic interference introduced by the real orthogonality of the filters. In the channels with high frequency selectivity FBMC distortion power (P_e) cannot be neglected and depends on the shape of the waveform (G) and on the derivatives of the channel impulse response H in frequency domain [13]. The first order approximation of the distortion power is

$$P_e^{(1)}[m] = \frac{2P_s}{M^3}\left\|\frac{H'[m]}{2\pi H[m]}\right\|^2 G.$$

Additionally, if the channel is also time-variant (e.g. when the transmitter or receiver are installed of the fast-moving car or train) then the derivatives of the channel impulse response in time domain should be considered. Thus, the actual values of the SINR in addition to interference (P_i) and noise (N_0) components also include FBMC distortion (P_e):

$$SINDR = \frac{P_s\|H[m]\|^2}{P_e + P_i + N_0}.$$

This FBMC distortion can be mitigated by using special equalizers.

Finally, for the complete analysis of the PMR scenario interference coming from the narrowband technology should be taken into account. Ns-3 simulator is a popular open-souse platform that can be used as a basis for such studies.

3. Conclusions

In the STMS we studied the challenging problem of wideband PPDR network development. There are no unified spectrum bands for these applications in Europe yet, and coexistence with other technology in the same band is one possibility to get more bandwidth. This is an attractive niche for new flexible waveforms with good frequency localization properties. The approach based on FC-FB was found to be the most promising solution. Additionally, the application of flexible waveforms can bring gains in the disaster relief scenarios with self-backhauling, when hotspots are placed on special vehicles (e.g. ambulance, pumpers).

The STMS provided a good possibility to discuss our current research topics and to find common points of interest. We are going to implement a joint simulation scenario of PPDR network. The findings of this study shall be published in an appropriate IEEE conference proceedings.

4. References

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