Air transport has been identified as a dominant factor for sustainable economic growth worldwide, and A/G communications are extremely critical for achieving an ATM system that is capable of matching all future air traffic demands. The VHF COM spectrum (118 - 137 MHz) has been globally allocated for aeronautical safety communications over continental areas. This spectrum is currently organised in voice channels of 25 kHz or 8.33 kHz and a unique voice VHF channel is assigned to each air traffic control (ATC) sector or function.

The B-VHF research project, which has been co-funded by the European Commission under the Sixth Framework Programme (FP6), has investigated a new approach to overcome the VHF spectrum bottleneck. The main focus of the B-VHF project was initially put on the feasibility analysis of a broadband VHF aeronautical communications system based on multi-carrier code-division multiple-access (MC-CDMA) technology.

A modern, fully-digital broadband B-VHF system has been designed at a high level, to match the future aeronautical communications requirements gathered from strategic ATM documents. The B-VHF system design covers both voice and data link services in a safety-related ATS and AOC environment.

Based on the high-level system design, an operational concept has been developed, accompanied by the deployment concept focused on the initial system deployment, i.e. operating the B-VHF system together with other systems in the crowded VHF COM range and on subsequent transition towards the fully deployed B-VHF system. Both the operational concept and deployment concept allow the system to be deployed and used in the VHF COM range and in other spectrum ranges anticipated for aeronautical communications.

Starting from the high-level system design, simulation scenarios and a simulation framework have been developed, allowing for the verification of project goals via detailed simulations at different layers of the communications protocol stack. The simulation
campaign started with separate simulations of the B-VHF physical layer and ended with system-wide simulations. The results have demonstrated that the B-VHF system is capable of operating under different scenarios with that number of users corresponding to expected future air traffic densities and under changing communications demands while providing higher aggregate channel throughput, broader scope of services and a higher performance level than today's legacy VHF systems.

The main objectives of the B-VHF project were to prove:
- suitability of multi-carrier technology for aeronautical communications;
- increased communications performance and flexibility;
- increased security;
- operational feasibility of deployment concept;
- feasibility of overlay concept in the VHF band.

The requirements for the B-VHF system have been derived from the Eurocontrol Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM beyond 2015 (MACONDO) and other public documents. Both functional and performance requirements of an integrated voice and data link B-VHF system have been taken into account.

The B-VHF functional scope, system design and the operational concept take specific requirements of air traffic services (ATS) and airline operational communications (AOC) voice and data link services into account.

The detailed B-VHF system design was based on the previously established system requirements and comprises B-VHF system-specific, user-transparent methods that are required for the system itself to work, including the system initialisation, automated net entry, automated seamless handover for wide-area coverage voice and data services, as well as internal procedures for service selection and resource allocation. The B-VHF system design comprises a broad scope of aeronautical communications services, with different priorities and quality of service as required for a specific application.

The design of the B-VHF physical (PHY) layer has been validated by means of simulations of the proposed algorithms. Overall system performance in presence of interference from legacy VHF systems towards the B-VHF system has been simulated as well.

Simulation scenarios consider different flight phases with appropriate broadband channel models, e.g. take-off and landing, parking, and en-route flights, taking typical and worst-case interference situations into account. The corresponding interference scenarios have been retrieved from the measurement flights as well as from the NAVSIM simulation tool.

The NAVSIM tool calculates the worst-case VHF channel occupancy at a certain location, for a certain cell size, and for a certain time. For this purpose, all GS were considered to be active and for each ATC sector one representative interfering A/C was placed as close as possible to the simulated victim A/C. Moreover, a duty cycle of 100 % for GS and A/C transmissions was used. With that setting, the worst-case in terms of interference (maximum interference) and in terms of the number of available VHF channels (lowest number) was obtained.

A specific synchronisation approach in a high-interference environment has been investigated, taking selected representative broadband VHF channel models into account. For reasons of simplicity, perfect synchronisation and channel estimation has been assumed when conducting the simulations. Multiple options for interference suppression by the B-VHF receiver and spectral shaping in the transmitter have been investigated.

In to further reduce the impact of narrowband interference (NBI), first leakage compensation has been applied only to strong interferers (red line), but only slight improvement has been achieved. This is due to the remaining undesirable impact of the two weak interferers. In particular, the target BER for voice services (10-3) could not be achieved within simulated Ps range.

When leakage compensation was applied to both strong and weak interferers (yellow line), a significant improvement was achieved. The best result was obtained by applying both windowing and leakage compensation to strong and weak interferers (lower green line). The required RX power required for achieving target BER = 10-3 for voice services could be significantly reduced compared to the case without NBI mitigation.

It can be concluded that with leakage compensation of strong and weak interferers combined with windowing the impact of NBI can be reduced such that the number of interferers and the total interference power has only a low effect on the system performance. The
overall system performance can be improved by further reducing NBI, e.g. by means of a more accurate NBI estimation or with an improved windowing function. The required TX power can be derived from the simulation results by simple link budget calculations taking into account e.g. antenna gain and propagation losses.

Different scenarios have been developed for the deployment of the B-VHF system in both the VHF COM range, as well as in other spectrum ranges (NAV-band, L-band, C-band) anticipated to be used by new aeronautical communications systems. During the work on B-VHF deployment scenarios, some issues were identified that should be considered in future activities. In particular, as no mature radio hardware was available, some assumptions had to be made about the B-VHF RF front-end performance. Scenarios consider aircraft that is equipped with B-VHF radios ('B-VHF aircraft') and aircraft carrying narrowband equipment ('NB aircraft'). In addition to the current situation where the entire airspace is 'narrowband-one' (NB airspace), two other options have been identified: B-VHF airspace, where B-VHF equipage is mandatory for all aircraft and B-VHF-supported airspace, with voluntary B-VHF equipage. All VHF scenarios are based on a strict overlay concept, which characterised that not any change of the legacy systems is mandated, and assume an integrated voice / data system.

As a first step towards a prototype a simplified B-VHF test bed has been implemented to demonstrate the technical feasibility of a B-VHF radio. The B-VHF test bed consists of a B-VHF transmitter and a receiver implemented in digital signal processing (DSP) technology and of a simple low-power TX and RX front-end. On the transmitting side, the baseband signal processing is conducted in the DSP and the analogue signal at the intermediate frequency is fed to the TX front-end input. The TX front-end converts the signal into the VHF COM band (118 - 137 MHz). The B-VHF receiver RX front-end converts the incoming RF signal to the intermediate frequency and forwards it to the receiving DSP board where the A/D conversion, the baseband signal processing and the evaluation take place. In B-VHF laboratory measurements, only the FL (from GS to A/C) has been investigated. Three airborne radios and one ground DSB-AM radio have been used as DUT (device under test) equipment. For measurement purposes, the DSB-AM channel under test has been adjusted such that it coincides with the centre frequency of the broadband B-VHF FL transmitter signal.

The interference measurements with B-VHF system transmitting over the reception bandwidth of the DSB-AM receiver comprised the following scenarios:
- All OFDM carriers are active - 12 carriers may appear within the IF bandwidth of the DSB-AM receiver.
- A variable number of OFDM subcarriers is cancelled (left-out) around the carrier of the DSB-AM signal in order to suppress interference with the AM signal.

The impact of a VHF DSB-AM voice communications system on the B-VHF system and vice versa has been determined via laboratory measurements using several test procedures, comprising the following tests:
- B-VHF power spectrum measurements;
- B-VHF receiver sensitivity evaluation;
- evaluation of B-VHF interference imposed on analogue voice DSB-AM receiver;
- evaluation of DSB-AM interference on B-VHF victim receiver.

During the B-VHF project following valuable scientific results have been obtained:
- system requirements were defined;
- B-VHF functional scope, architecture and high-level system design were defined;
- B-VHF system operational concept was developed;
- ground- and airborne measurements of the VHF spectrum occupancy were conducted;
- VHF spectrum occupancy for Europe was modelled and simulated;
- detailed B-VHF system design has been elaborated and verified via separate simulations;
- based on the ground measurements a narrowband interference simulator for DSB-AM and VDL mode 2 was developed;
- a broadband VHF channel model was developed;
- B-VHF simulation framework has been developed (lowest two layers of the ISO-OSI model);
- performance simulations of the B-VHF system were carried out;
- B-VHF deployment scenarios were elaborated;
- test bed, comprising B-VHF forward and reverse links, has been implemented and evaluated in laboratory.

The simulations conducted within the B-VHF project have shown that a B-VHF overlay system in the VHF band is feasible. At the same time it was shown that interference conditions in the VHF band are severe. Therefore, further improvement / optimisation of proposed interference mitigation techniques and their validation with an improved B-VHF system demonstrator are required.
According to Eurocontrol and FAA roadmaps, aeronautical data communications should be preferably realised in the L-band, while voice communications should remain in the VHF band. The results of B-VHF system simulations allow for a conclusion that it may be possible to operate the B-VHF system in the L-band while maintaining the main characteristics.

The detailed assessment of the feasibility of the data-only B-VHF system for an application in the L-band and an assessment of necessary modifications of the system design should be investigated in detail in future work.

The results of the B-VHF activities have been presented at the ATC Maastricht exhibitions and at several international conferences in Europe and the USA.

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