DECT NR+: A new radio standard to benefit professional audio applications

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Abstract

DECT-2020 New Radio (marketed as NR+ by the DECT Forum) is an ETSI-developed Radio Interface Technology (RIT) that meets the IMT-2020 requirements for Ultra-Reliable Low Latency (URLLC) and massive Machine Type Communication (mMTC). Therefore, in late 2021, it was approved by the ITU-R to be included in the 5G family of standards. Constituting the world's first non-cellular 5G technology, DECT NR+ targets nomadic wireless applications that can be deployed anywhere by anyone at any time. Along with the option to operate in the license-exempt 1.9 GHz DECT band, the mesh-networking capability of NR+ makes the technology a compelling choice for Small and Medium-sized Enterprises (SMEs) and the Program Making and Special Events (PMSE) industry.

In this paper, we first give an introduction to PMSE and its core application of wireless microphone systems. We then provide an overview of DECT NR+ and show how it can benefit wireless professional audio applications. Finally, we report on our activities within the Franco-German joint research project MERCI which incorporates companies from the media and event sector to work towards a shared vision of delivering fully immersive audio-visual experiences through DECT NR+ cooperative networks. As part of the project, we are developing a Software-Defined Radio (SDR) platform to evaluate and demonstrate the technology for the conceived use cases.

Introduction

A piece of equipment that is employed in virtually any application scenario from the Program Making and Special Events (PMSE) sector is the wireless microphone. Television and radio broadcasters utilize it for electronic news gathering (ENG), companies in the entertainment industry use it in film productions and stage performances, and equipment rental and installation companies supply it to event venues such as convention centers [1]. Depending on the particular use case, a wireless microphone system faces a variety of challenges and requirements. Generally speaking, parameters such as the cost per wireless audio link, the battery runtime, and the capability to encrypt the audio data need to be considered. In most PMSE settings, latency is another critical factor. For example, professional musicians who use in-ear monitoring usually require the total round-trip time (i.e., measured from analog input to analog output) to not exceed 4 ms [4]. Since audio dropouts would ruin any live performance and are not acceptable in a professional audio context, a wireless microphone system is further expected to guarantee a reliability comparable to that of a cable-based transmission. Moreover, the system should not compromise on audio quality and offer a flat frequency response and full dynamic range. On the RF side, a wireless microphone system is challenged by multipath propagation, frequency-selective fading, and multiple sources of interference. In case of belt-worn transmitters, the RF performance is also adversely impacted by the human body which causes a loss in signal power. In spite of all this, a typical PMSE scenario requires a wireless microphone system to cover an area of operation of 100 m^2 [4]. Finally, given the scarcity of frequency resources, it is crucial that the spectrum is utilized efficiently and in compliance with local regulations.

Wireless microphone systems comprise a transmission chain that is either fully analog or digital, or makes use of both analog and digital technology. Such hybrid systems employ digital audio signal processing but rely on analog modulation. In analog systems, which commonly employ frequency modulation (FM), the amplitude of the audio signal is used to vary the instantaneous frequency of the carrier wave. Carson's rule states that the bandwidth requirement B_T of an FM signal is approximately equal to twice the sum of the peak frequency deviation Δf and the highest modulating frequency f_m [1]:

$$B_T = 2(\Delta f + f_m). \tag{1}$$

The frequency deviation in turn is calculated as the product of the sensitivity of the frequency modulator and the amplitude of the modulating signal. Consequently, increasing the bandwidth allows a higher deviation from the carrier center frequency and therefore leads to an improvement in dynamic range. For this reason, analog wireless microphone systems usually employ wideband FM, where $\Delta f \gg f_m$. However, in practice the bandwidth available to an FM system is constrained. As a solution, a technique known as companding is used. To accommodate the limited dynamic range of the channel, the modulating signal is compressed at the transmitter and then again expanded at the receiver (see Figure 1). Clearly, the use of companding alters the original audio signal and might result in audible artifacts at the receiver's output. Another aspect that requires consideration is the innate characteristic of the FM demodulator

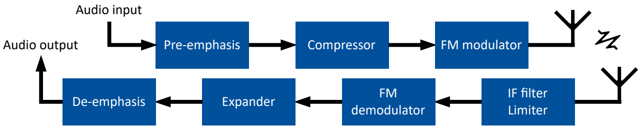

Figure 1: Analog wireless microphone system [1].

to amplify high-frequency noise. To combat this behavior, the high-frequency signal components are attenuated at the receiving end in a process called de-emphasis. Unfortunately, this also suppresses the desired signal in the affected frequency range, making it further necessary to boost the high-frequency components of the modulating signal prior to transmission in a process known as pre-emphasis.

Fully digital wireless microphone systems utilize digital technology in both audio signal processing and modulation. Usually, bandwidth-efficient modulation schemes such as Gaussian Minimum Shift Keying (GMSK) are employed to occupy less frequency resources. Some digital systems, especially those operating in ISM bands, also make use of spread spectrum techniques such as direct sequence and frequency hopping to prevent eavesdropping and avoid interference. By stepping away from the analog frequency modulation, digital systems no longer require emphasis and companding and therefore potentially offer a higher audio quality. Moreover, digital systems typically employ both audio and channel coding (see Figure 2) which improve the reliability of the transmission and increase the resistance to channel impairments. This is achieved by making use of Forward Error Correction (FEC) codes in the channel coding and Packet Loss Concealment (PLC) techniques in the audio coding. Unlike analog systems that have virtually zero latency, digital systems are challenged by processing and coding delays. However, the absence of digital signal processing in analog systems renders error correction and concealment mechanisms impossible. Additionally, only digital systems have the capability to utilize encryption for the secure transmission of sensitive data. Apart from offering negligible latency, analog systems also have the benefit of being comparatively low in cost. Furthermore, in weak RF environments, the audio signal degrades gracefully as opposed to the "cliff effect" experienced in digital systems [1].

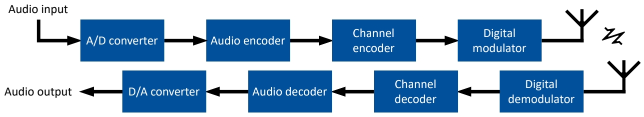

Figure 2: Digital wireless microphone system [1].

After the terrestrial television broadcasters switched from analog to digital, the released radio spectrum was reallocated as part of the so-called digital dividend [2]. Unfortunately, this was mostly to the benefit of mobile network providers that offer wireless broadband services to the public. Due to regulatory decisions, the spectrum available to wireless microphones is becoming increasingly scarce [6]. PMSE equipment has to share the spectrum with other radio communication services and commonly operates as a secondary user in locally vacant television broadcasting channels, so-called TV White Spaces (TVWS), in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands [2]. As secondary users, wireless microphones have to follow a no-interference, no-protection policy. Devices operating under such condition must not interfere with the primary users (incumbents) and cannot claim any protective measures against the interference caused by the primary users. Some wireless microphone systems rely on operation in the unlicensed ISM frequency bands (e.g., at 2.4 GHz) which have the advantage of not being subject to geographical restrictions. On the downside, these bands need to be shared with other radio technologies such as the omnipresent Wi-Fi and Bluetooth. Consequently, the ISM bands are usually heavily congested. Another frequency band which allows license-exempt operation and has quasi-global availability is the 1.9 GHz DECT band. What sets it apart from the ISM bands is that it is exclusively available to radio devices utilizing DECT technology and therefore offers a low-interference environment (see Figure 3).

Figure 3: The 1.9 GHz DECT band is not as congested as the 2.4 GHz ISM band (image created using DALL·E 3).

From DECT to NR+

The classic DECT may be considered fairly old technology, as the first round of Digital Enhanced Cordless Telecommunications (DECT) standards was published in 1992 by ETSI. The ETSI is a not-for-profit European Standards Organization (ESO) that creates ICT standards and, within the technical committee DECT (TC DECT), develops, ratifies and maintains DECT technologies. In 1999, the ITU-R approved DECT as IMT-2000 (3G) technology. Then, about 21 years later, the technical specification of the new radio standard DECT-2020 New Radio (NR) was first published. Merely one year later, in the fall of 2021, the ITU-R included DECT-2020 NR in the IMT-2020 family of standards and therefore approved it as 5G technology. DECT-2020 NR is often referred to as just NR+, which is the marketing name that is being used by the DECT Forum, an organization that campaigns for DECT technologies and spectrum access.

DECT and NR+ are not only related by name but also adhere to similar design principles. Both technologies employ Frequency-Division Multiple Access (FDMA) and Time-Division Multiple Access (TDMA) which means that the radio resources are divided into frequency channels and time slots. Since the communication follows a Time-Division Duplex (TDD) manner, uplink and downlink share the same frequency channel but access it at different time slots. The radio frames have a duration of 10 ms and are split into 24 time slots which, in NR+, are further subdivided into up to 16 subslots. Furthermore, a basic channel width of 1.728 MHz is used in both technologies.

With NR+, the physical layer has seen significant improvements by incorporation of the latest state-of-the-art technology. Classic DECT employs single-carrier modulation which is significantly affected by multipath distortion and frequency-selective fading. This holds particularly true in scenarios where the delay spread exceeds 100 ns and antenna diversity is not being used [3]. Therefore, NR+ utilizes Cyclic Prefix Orthogonal Frequency-Division Multiplexing (CP-OFDM) which is a multi-carrier modulation scheme that is less prone to these effects. In CP-OFDM, the data is transmitted in parallel on multiple orthogonal narrowband subcarriers. This bears the advantage that, in case of frequency-selective fading, only some subcarriers are affected by the channel impairments. The use of channel coding techniques then allows the corrupted data still to be recovered. NR+ utilizes advanced Forward Error Correction (FEC) by means of turbo coding. Figure 4 illustrates the results of link-level simulations that were conducted for both classic DECT and NR+ under different SNR conditions in a Rayleigh fading scenario with a delay spread of 100 ns and no receiver diversity. It can be seen that NR+ (solid color curves) outperforms classic DECT (dashed color curves) in terms of Packet Error Rate (PER). In addition to CP-OFDM and turbo coding, Hybrid Automatic Repeat reQuest (HARQ) is another factor contributing to the reliability of NR+. With HARQ, erroneous data is not discarded at the receiver but rather buffered for later combination with the data received in subsequent retransmissions. By applying a different puncturing pattern to the turbo encoder output at each transmission, the receiver incrementally gains extra information. Therefore, this is referred to as Hybrid ARQ with incremental redundancy. In order to be able to adapt to varying channel conditions and throughput demands, NR+ offers various transmission configurations. Accordingly, a total of twelve Modulation and Coding Schemes (MCS) are available, providing the possibility to use 1024-QAM at different coding rates. Depending on the number of subcarriers and their spacing, the bandwidth is scalable to a maximum of 221.184 MHz. On top of that, NR+ also supports antenna diversity and up to 8 x 8 MIMO operation.

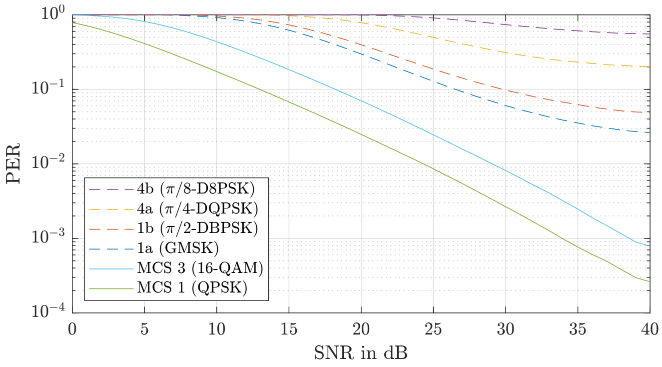

Figure 4: Simulated Packet Error Rates in a Rayleigh fading channel with one receiving antenna [5].

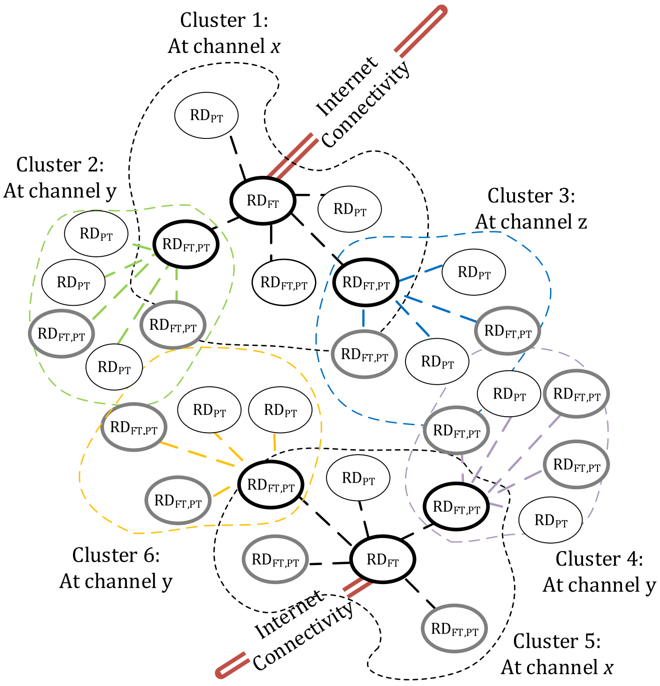

Figure 5: DECT-2020 NR network in mesh topology as shown in ETSI TS 103 636-1.

Being the first non-cellar private 5G technology, NR+ fulfills the IMT-2020 requirements for Ultra-Reliable Low Latency Communication (URLLC) and massive Machine Type Communication (mMTC). This basically means that NR+ qualifies as cable-replacement technology and allows large-scale network deployments with high device density. Other than operation in the dedicated DECT band, NR+ principally also supports TDD IMT frequency bands below 6 GHz. Since there are no base stations, SIM cards, or subscriptions required to operate a NR+ network, the technology becomes accessible to anyone and can be nomadically deployed anywhere and at any time. In contrast to 3GPP 5G NR, DECT-2020 NR does not know fixed device roles. The radio devices dynamically adapt their operation mode and can choose to operate as Fixed Termination point (FT), Portable Termination point (PT), or take both roles at the same time. In FT mode, the radio devices autonomously coordinate the local radio resources and provide the PT mode devices with the parameters that are necessary to perform an association. The PT mode devices can then act on this information and initiate communication to the devices in FT mode. Generally, decisions on device associations and data routing are made autonomously and do not require external control. Therefore, DECT-2020 NR sets the stage for decentralized, autonomous, and self-healing networks in a mesh topology (see Figure 5).

The MERCI project

Media and Event production via Resilient Communication on IoT Infrastructure (MERCI) is a government-funded Franco-German joint research project that started in November 2022 and runs until April 2025. By the incorporation of companies from the Industrial IoT (IIoT) and PMSE sector, the project constitutes a collaborative

R&D ecosystem for private 5G networks based on or complemented by DECT-2020 NR. MERCI follows the shared vision of creating fully immersive audio-visual experiences through NR+ cooperative networks that advantageously integrate nomadic PMSE devices into on-premises IoT infrastructure. Aiming at a practical, application-driven evaluation and demonstration of the technology, we are currently developing a Software-Defined Radio (SDR) platform as part of the project. This enables us to test and showcase NR+, and explore the feasibility of employing the technology in professional audio applications. In the course of the implementation, we identify issues and gaps in the technical specification and work collaboratively with TC DECT to improve and extend the standard. Another objective is to examine different use cases and investigate the extent to which they benefit from, for example, the mesh-networking capability of NR+. One such application scenario is illustrated in Figure 6; in this case a TV production of a large-scale sporting event (e.g., the Ultra-Trail du Mont-Blanc). In the scenario, wireless microphones are distributed along the race track of the sporting competition. The devices are organized in a mesh network topology and either connect to one another or to repeaters which can be nomadic or fixed-installation IoT devices. On the premises of the event, different broadcasting companies operate multiple of these networks. Therefore, the use case not only requires the URLLC capability of NR+ but also its mMTC functionality. Clearly, the scenario benefits from the mesh topology which increases the range of the network and extends its coverage area. In case of node failures, the network heals itself by relying on autonomous routing decisions which are based on a cost value. Consequently, there is no need to maintain routing tables in each device. The automatic interference management of NR+ further reduces the maintenance effort by making an extensive frequency planning redundant.

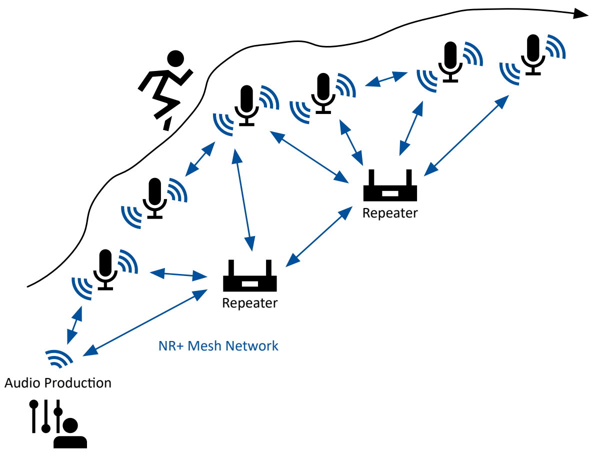

Figure 6: NR+ in a wide-ranging broadcast production (adapted from the MERCI WP 1.1 deliverable on use cases, requirements and demonstration scenarios).

Summary and perspectives

This work gave an overview of the new radio standard DECT-2020 NR and how it benefits professional audio applications such as wireless microphones. The improved physical layer with CP-OFDM, advanced FEC, and HARQ brings the advantages of DECT to the 5G world, and granted NR+ an ITU-R approval for the URLLC and mMTC scenarios. It supports various network configurations, is capable of communicating in a mesh topology, and provides appealing features such as an automatic frequency and interference management. Other than that, NR+ has access to the protected DECT spectrum but can also operate in TDD IMT frequency bands below 6 GHz. In response to a mandate issued by the European Commission, the CEPT (European Conference of Postal and Telecommunications Administrations) is currently evaluating the technical conditions that are necessary to allow the shared use of the 3.8 GHz to 4.2 GHz frequency band. Consequently, another 400 MHz of spectrum might become available. With this in mind, it is fair to say that NR+ has a bright future ahead.

Acknowledgement

The authors would like to thank the BMWK for the grants received as part of the MERCI project (FKZ: 01MJ22016D).

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