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Link-Level Performance Evaluation of IMT-2020 Candidate Technology: DECT-2020 New Radio

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Abstract—The ETSI has recently introduced the DECT-2020 New Radio (NR) as an IMT-2020 candidate technology for the mMTC and URLLC use cases. To consider DECT-2020 NR as an IMT-2020 technology, the ITU-R has determined different independent evaluation groups to assess its performance against the IMT-2020 requirements. These independent evaluation groups are now in process of investigating the DECT-2020 NR. In order to successfully assess a technology, one important aspect is to fully understand the underlying physical layer and its performance in different environments. Therefore, in this paper, we focus on the physical layer of DECT-2020 NR and investigate its link-level performance with standard channel models provided by the ITU-R for evaluation. We perform extensive simulations to analyze the performance of DECT-2020 NR for both URLLC and mMTC use cases. The results presented in this work are beneficial for the independent evaluation groups and researchers as these results can help calibrating their physical layer performance curves. These results can also be used directly for future system-level evaluations of DECT-2020 NR.

I. INTRODUCTION

Due to growing number of new applications day by day and their advanced requirements, the mobile communication industry witnesses a generation transition almost after every decade. To process this transition smoothly, different organizations regularly work together to create new standards, technical specifications, and regulations [1]. In the last years, the International Telecommunication Union, Radiocommunication Sector (ITU-R) Working Party 5D (WP5D) has set requirements for International Mobile Telecommunications 2020 (IMT-2020) to support the Fifth Generation (5G) use cases involving Ultra Reliable Low Latency Communications (URLLC), massive Machine Type Communications (mMTC), and enhanced Mobile Broadband (eMBB) [2]. By targeting one or more of these 5G use cases, Third Generation Partnership Project (3GPP) has developed technologies such as New Radio (NR), Narrowband Internet of Things (NB-IoT), and Long Term Evolution for Machines (LTE-M) that meet the requirements set by ITU-R [3], [4].

One of the candidate technologies currently being evaluated, submitted by European Telecommunications Standards Institute (ETSI) Technical Committee (TC) Digital Enhanced Cordless Telecommunications (DECT) and DECT Forum to ITU-R, is DECT-2020 NR [5]. The DECT-2020 NR is a Radio Interface Technology (RIT) that mainly focuses on applications that fall between the URLLC and mMTC extremes, e.g., presence monitoring. The DECT-2020 NR offers local deployment options without the need of a separate network

infrastructure or network planning, and supports autonomous and automatic operation once deployed. Hence, minimal deployment or maintenance effort is required making it an attractive technology. The legacy DECT standard was originally designed to support cordless telephone systems in early 1990s, but is continually updated in response to the developments in the technology. Its latest development, DECT-2020 NR, targets local area wireless applications, and offers star and mesh network topology to support URLLC and mMTC use cases, respectively. The DECT-2020 NR is operated in frequency bands below 6 GHz, and despite its advanced physical layer numerology and medium access control algorithms, it can coexist with the legacy DECT in current frequency bands allocated to legacy DECT.

The ETSI TC DECT has already provided detailed technical specifications of DECT-2020 NR [6]. However, to include DECT-2020 NR as an IMT-2020 technology, ITU-R has determined different independent evaluation groups to assess its performance against the IMT-2020 requirements. These independent evaluation groups are now in process of investigating the DECT-2020 NR.

In order to successfully assess a technology, one important aspect is to fully understand the underlying physical layer and its performance in different environments. Therefore, in this paper, we first explain the DECT-2020 NR in detail and then analyze the link-level performance under standard channel models. We have been already collaborating with the proponents for the self-evaluation of DECT-2020 NR, and we believe that the results presented in this paper will be beneficial to independent evaluation groups as well as other researchers. These results will help them in understanding the physical layer of DECT-2020 NR better, in calibrating their performance curves, and in analyzing system-level performance of DECT-2020 NR by directly considering these results in their evaluation for different considered channel conditions.

Our main contributions can be summarized as follows:

- We present a comprehensive overview of the newly introduced DECT-2020 NR standard (Section III).
- We implement its complete physical layer and perform extensive simulations to evaluate the performance with standard channel models provided by ITU-R (Section IV).
- Finally, we show the link-level performance of DECT-2020 NR for both URLLC and mMTC use cases, which serve as comparative values and can be used directly for future system-level evaluations (Section V).

II. BACKGROUND AND RELATED WORK

DECT-2020 NR is a relatively new technology and, hence, does not have a vast literature. Details of the DECT-2020 NR are provided by ETSI TC DECT in [5], whereas an overview is presented in [7]. The main focus of [7] is on the system-level evaluation of DECT-2020 NR and that also for the mMTC use case only. Recently, an independent evaluation group has also assessed this technology and provided the insights briefly in [8]. Due to lack of some details, authors were unable to conclude whether DECT-2020 NR meets the requirement specified to become an IMT-2020 technology.

To be considered as an IMT-2020 technology, DECT-2020 NR has to fulfil the requirement of 99.999 % reliability, user plane latency of less than 1 ms, and capability of supporting more than one million devices per km² [2]. These requirements are set by ITU-R WP5D to support different 5G use cases. The ITU-R is a regulatory body and its responsibility is to ensure efficient and interference free operations of different radio communication systems, whereas WP5D works within the ITU-R and oversees IMT systems (i.e., 3G onwards) in particular [1]. Both 3GPP and ETSI are standards developing organizations and are part of ITU-R WP5D. The 3GPP has been actively involved in developing technical specifications for mobile communication for more than two decades and it has developed technologies such as NR, NB-IoT, and LTE-M to be the part of IMT-2020 [3], [4]. Each of these technologies usually targets applications that are bounded to a particular use case. However, there are some applications that fall between the URLLC and mMTC extremes, e.g., remote light control and presence monitoring. The reliability and delay requirements in these applications are much stricter than the ones described by mMTC but are more relaxed in comparison to URLLC. Addressing such applications, ETSI TC DECT has recently introduced the DECT-2020 NR as a candidate technology for the IMT-2020.

The DECT-2020 NR offers a completely new physical layer numerology, advanced medium access control algorithms, and supports star as well as mesh network topology [5], [6]. However, in order to be considered as an IMT-2020 technology, its performance needs to be evaluated against the requirements defined in IMT-2020. In the literature, link-level performance of new technologies is usually evaluated by using standard channel models [9]. IMT-2020 has already provided different channel models to evaluate the candidate technologies in [10]. Therefore, in this work, we develop the physical layer of DECT-2020 NR and analyze its link-level performance. The next section provides an overview of the DECT-2020 NR technology.

III. DECT-2020 NEW RADIO

According to DECT-2020 NR technical specifications [5], any Radio Device (RD) in the network that has the capability of transmission and reception can be operated in either Fixed Termination (FT) mode or Portable Termination (PT) mode or both simultaneously. The RDs are free to choose any operation mode depending upon the local requirement. A RD operating

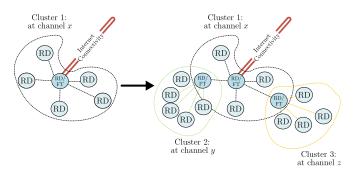


Figure 1: Formation of the mesh network topology.

in FT mode coordinates local resources, and provides information to other RDs on how to initiate a connection and communicate with it. The RD in FT mode is also responsible for routing the data either directly from the connected RDs to an external internet connection or through another RD in FT mode that has the access to the external internet connection. The RD in PT mode simply connects to the RD in FT mode for an indirect association to the external internet connection.

A star topology network supports URLLC use case and is formed by one RD in FT mode while other RDs directly connect to it in PT mode. Whereas, a mesh network topology is realized by adding more RDs that connect themselves to any of the network nodes, hence, offering a scalable solution for mMTC use case as shown in Figure 1. In the mesh network topology, all RDs are capable of routing data though they autonomously choose or change their role between routing and non-routing depending upon the local decisions. Also, no central coordinator is needed and routing is based on a cost value rather than maintaining a routing table in each RD resulting in autonomous routing. Moreover, there can be unrestricted number of RDs connected to any type or number of external internet connections in a single network offering more than one route for other RDs to choose, hence, minimizing the probability of outage.

In general, the DECT-2020 NR technology is targeted for frequency bands below 6 GHz. On physical layer, the system exploits Cyclic Prefix (CP) Orthogonal Frequency-Division Multiplexing (OFDM) in combination with Time Division Multiple Access (TDMA) as well as Frequency Division Multiple Access (FDMA) in a Time Division Duplex (TDD) mode for communication [6]. The OFDM subcarrier spacing is chosen between 27 kHz, 54 kHz, 108 kHz, or 216 kHz with a scaling factor $\mu=1,2,4,$ or 8, respectively. These different subcarrier spacings with a Fast Fourier Transform (FFT) size $\beta=64,128,256,512,768,$ or 1024 lead to a nominal Radio Frequency (RF) bandwidth between 1.728 MHz and 221.184 MHz.

A single radio frame in DECT-2020 NR has a total duration of 10 ms and consists of 24 slots resulting in a slot duration of 416.67 μ s. Each of these slots can accommodate 10, 20, 40, or 80 OFDM symbols depending upon the value of μ . A single slot is further divided into multiple subslots as discussed in [6]. Furthermore, on physical layer, the packet structure

TABLE I: DECT-2020 NR Packet Formats for URLLC and mMTC.

Packet Property	Format 0	Format 1	Format 2
(μ, β)	(1,1)	(4,1)	(4,2)
OFDM symbols	10	10	10
Transport Block Size	296	368	288
Modulation	QPSK	QPSK	BPSK
Code rate	1/2	3/4	1/2
Bandwidth (MHz)	1.728	6.912	13.824
Subcarriers	64	64	128
HARQ retrans.	0	1	1
Transmit antennas	1 or	r 2 (TX divers	sity)

involves Synchronization Training Field (STF) and Data Field (DF), and is transmitted followed by a Guard Interval (GI) to avoid overlapping of transmissions in consecutive time slots. The STF is composed of training data for time and frequency synchronization at the receiving side, whereas the DF incorporates Physical Control Channel (PCC), Physical Data Channel (PDC), and Demodulation Reference Signal (DRS).

The physical layer in DECT-2020 NR is mainly responsible for modulation and demodulation, error detection and correction, Hybrid Automatic Repeat Request (HARQ) soft combining, signal synchronization, and for providing data to upper layers. Moreover, the physical layer also performs Multiple Input Multiple Output (MIMO) antenna processing and offers a possibility of realizing transmit diversity and beamforming. Error detection is performed by using a 16 or 24 bit Cyclic Redundancy Check (CRC), whereas for error correction, Turbo Coding is employed. Finally, the supported modulations include Binary Phase-Shift Keying (BPSK), Quadrature Phase-Shift Keying (QPSK), as well as different Quadrature Amplitude Modulation (QAM), i.e., 16-QAM, 64-QAM, 256-QAM, and 1024-QAM.

IV. SYSTEM MODEL

In [2], the ITU-R defines minimum requirements that radio interfaces must meet in each usage scenario of IMT-2020 as mentioned earlier. For URLLC, for instance, the minimum requirement for user plane latency is 1 ms, and the minimum requirement for reliability is a probability of success of 99.999 % for layer 2 Protocol Data Unit (PDU) transmissions with a Transport Block Size (TBS) of at least 32 bytes. Based on these constraints, suitable packet configurations of the DECT-2020 NR in [6] satisfying these latency and packet size requirements can be determined. A selection of these configurations, which can be used for URLLC and mMTC, are listed in Table I. For the sake of simplicity, we call these packet configurations Format 0, Format 1, and Format 2. All of these formats can be used for both mMTC and URLLC use cases, however, in this particular work, we use Format 0 for mMTC, and Format 1 and Format 2 for URLLC use case. The indicated number of HARO retransmissions is the maximum number with respect to the latency condition for the URLLC use case.

TABLE II: Channel Parameters of Doubly Selective Channel.

Channel Property	Non Line-of-Sight	Line-of-Sight	
Power Delay Profile	TDL-iii	TDL-v	
RMS Delay Spread	363 ns	93 ns	
K factor	-	9 dB	
Carrier Frequency	700 MHz and 4 GHz		
UE Velocity	3 km/h and 30 km/h		
Doppler Spread	1.9 Hz to 111.2 Hz		
Simulation Bandwidth	27.648 MHz		
Simulation Tool	MATLAB MIMOchannel		

TABLE III: Receiver Configuration.

Receiver Property	Receiver configuration		
No. of Antennas	1, 2, or 4		
Diversity Combining	Maximum Ratio Combining		
Time Synchronization	on first channel tap		
Frequency Synchronization	ideal		
Channel Estimation	Wiener filter		
Channel Encoder/Decoder	MATLAB LTE Toolbox		

Furthermore, the ITU-R also specifies how the suitability of candidate technologies for IMT-2020 can be tested on the physical layer [10]. For link-level evaluation, different channel models are provided, each consisting of path delays and corresponding average path gains for both Non Line-of-Sight (NLOS) and Line-of-Sight (LOS) scenarios. The maximum Doppler frequency can be inferred from given carrier frequencies and the maximum velocity of User Equipments (UEs). The Doppler shifts are then distributed according to the Jake's spectrum. Thus, the combination of a Power Delay Profile (PDP) and a Doppler Spread (DS) results in a doubly selective channel. The channel parameters used in our simulations are summarized in Table II. Because the time distances between individual taps of the provided PDPs in [10] are partly shorter than one sample, all OFDM signals are oversampled to 27.648 MHz regardless of the net bandwidth.

The number of receive antennas that a base station or a UE may utilize varies according to the use case. In the case of mMTC, base stations can have up to 64 antenna elements, whereas a single UE can have a maximum of only 2 as described in [10]. For the URLLC use case, a base station is allowed to have up to 256 antenna elements and a UE up to 8. These antennas can be used for beamforming, transmit or receive diversity, etc. For our link-level evaluation, we consider only selected modes, i.e., a maximum of four receiver antennas and up to two transmitter antennas for diversity gain through space frequency block coding. The complete configuration of the receiver is listed in Table III.

For packet synchronization, we assume that packets are received at the first channel tap. This is a reasonable assumption as DECT-2020 NR exploits a slot-based system, therefore, time synchronization has a minor impact on the performance. To test the design of the pilot pattern of DECT-2020 NR, we use a two-dimensional Wiener filter for channel estimation. The channel coefficients are initially calculated by using an

exponential PDP with the largest conceivable delay spread and Jake's spectrum with the largest conceivable Doppler spread. It is important to note that during an operation, the Wiener filter coefficients are fixed, even if the instantaneous channel statistics deviate from the aforementioned assumptions [11].

The physical layer supports advanced channel coding (i.e., Turbo Coding) for both control and physical channels, and HARQ with incremental redundancy. The channel coding is based on Long Term Evolution (LTE) with only minor differences, e.g., DECT-2020 NR can incorporate two maximum code block sizes instead of one as is the case with the LTE [6]. The high similarity makes it possible to use existing encoders and decoders. Therefore, we use the channel coding from the LTE toolbox in MATLAB and incorporate it into our model in compliance with the DECT-2020 NR standard.

V. RESULTS AND DISCUSSION

To evaluate the performance of our system with the configurations presented in Section IV, we conducted Monte Carlo experiments and measured the Bit Error Rate (BER) and Packet Error Rate (PER) at the receiver. Each experiment ran until a convergence at a PER of 10e-5 or less was obtained, as this is the threshold that according to [2] has to be reached for the URLLC use case.

We first evaluate the performance of the first ten Modulation and Coding Schemes (MCSs) from [6] over an Additive White Gaussian Noise (AWGN) channel, and plot the results in Figure 2. The MCS 0 corresponds to BPSK with code rate 1/2, whereas MCS 1 and MCS 2 represent QPSK with code rate 1/2 and 2/3, respectively. Similarly, MCS 7 corresponds to 64-QAM with code rate 5/6 and so on. The size of the packet is fixed to $(\mu, \beta) = (1, 1)$ and a single slot is considered, which implies that the increasing modulation order also increases the TBS. As expected, for higher modulation order, high Signal-to-Noise Ratio (SNR) value is required to achieve the same PER performance. These results are inline with the theory and the trend is similar to what we observe for LTE. However, these results cannot be directly compared with LTE due to marginally different TBSs here. The performance curves shown in Figure 2 can be taken as a reference in the future to verify different implementations of the channel coding within the scope of DECT-2020 NR.

As a next step, we analyze the performance of our Wiener filter used for channel estimation. Figure 3 shows the actual measured BER after using the Wiener filter as well as the BER under the assumption of perfect channel knowledge. For the latter, we assume a flat fading Rayleigh channel. The results are shown for a Single Input Single Output (SISO), a 2×2 MIMO, and a 1×4 Single Input Multiple Output (SIMO) system. For SISO, the channel estimation of the Wiener filter makes the performance about 1 dB worse in comparison to a system with perfect channel knowledge. In the case of both MIMO and SIMO, this loss is around 2 dB. It is also interesting to note that there is a 3 dB gap between MIMO and SIMO results. This is because of the fact that the transmitter power must be split between the two transmit antennas in the case

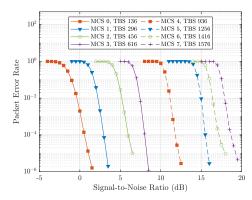


Figure 2: Packet error rate over different signal-to-noise ratio values in the AWGN channel under the assumption of perfect channel knowledge.

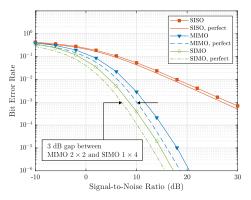
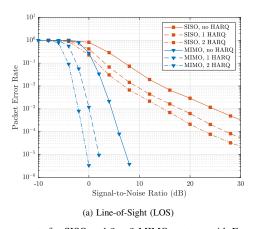


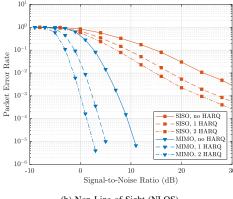
Figure 3: Bit error rate performance for QPSK modulation in the Non Line-of-Sight with and without perfect channel knowledge.

of MIMO. The comparison with closed-form solutions for the BER in Rayleigh fading channels was used for all experiments, since this confirms the accuracy of the results as well as the suitability of the pilot pattern in DECT-2020 NR.

We then investigate the performance of packet Format 0, i.e., the simplest among the considered formats, with both SISO and 2×2 MIMO antenna configurations, and plot the results in Figure 4. The results for LOS and NLOS scenarios are shown in Figure 4a and Figure 4b, respectively. Within the context of DECT-2020 NR, a SISO system could be deployed for Device-to-Device (D2D) communication within the mesh topology, where the devices must be as simple as possible in design. As expected, the PER in a SISO case for both LOS and NLOS decreases only slowly since there is no diversity. In the case of MIMO, since diversity is employed at both ends of the transmission link, the PER is highly improved. For the NLOS, we achieve a PER of 10e-5 without HARQ at a SNR of about 11 dB and with two HARQ retransmissions at a SNR of about 2.5 dB.

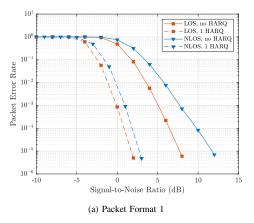
Finally, we focus on URLLC use case by considering SIMO with one transmit and four receive antennas for maximum reliability, and present the results in Figure 5. Figure 5a and Figure 5b show the performance for packet Format 1 and Format 2, respectively, in LOS and NLOS scenarios. It can be seen that in Figure 5b, we achieve a PER of 10e-5 at a SNR of $3.5 \, \mathrm{dB}$ for NLOS and at $2 \, \mathrm{dB}$ for LOS when using no HARQ. With one HARQ retransmission we reach the same threshold at





(b) Non Line-of-Sight (NLOS)

Figure 4: Packet error rate for SISO and 2×2 MIMO systems with Format 0. In the case of MIMO, the system utilizes both transmit and receive diversity.



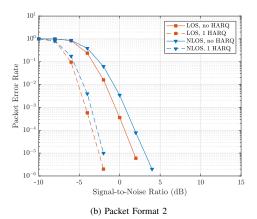


Figure 5: Packet error rate for 1×4 SIMO system with different packet formats and under different channel conditions.

a SNR of -2 dB and -2.5 dB for NLOS and LOS, respectively. For Format 1 in Figure 5a, the values are comparatively higher. This is because we use QPSK instead of BPSK with half the signal bandwidth.

VI. CONCLUSION

This work evaluated the link-level performance of the novel IMT-2020 candidate technology, DECT-2020 NR. We first provided an overview of the DECT-2020 NR and presented possible packet configurations that meet latency and packet size requirements for URLLC and mMTC use cases. We then considered doubly selective channel models as provided by the ITU-R to evaluate the performance with different configurations of antenna, HARQ retransmissions, and modulation and coding schemes. Our experiments show that in all cases, receivers can be built that operate close to perfect channel knowledge. This confirms that for the models tested, DECT-2020 NR is a well designed OFDM system. The results presented in this work can be used directly for future system-level evaluations by considering these PER values over different SNRs as an input.

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