Poster:
Empirical Packet Error Curves for DECT NR+

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***Abstract*—In this paper, we present empirical packet error curves for DECT NR+ across different Signal to Interference plus Noise Ratio (SINR) levels. The curves were fitted to measurements obtained from a physical testbed consisting of two nRF9151 DK and an Ettus USRP B210 acting as an Additive Gaussian White Noise (AGWN) source. Our results provide a foundation for Packet Error Rate (PER) models in system-level DECT NR+ simulations, though our conclusions are limited by their reliance on a single hardware platform. Our findings deviate from both theoretical predictions and what other measurements would suggest. Our findings highlight the importance of the selection of hardware for real-world experiments for the evaluation of DECT NR+.**

I. Introduction

DECT NR+ is a promising non-cellular 5G technology for Ultra-Reliable Low-Latency Communication (URLLC) and vehicular communication [1] but system-level simulations are still missing. These typically abstract from the complex mechanisms of the physical layer; thus, a well-calibrated packet loss model is a key component to capture modern features like channel coding and modulation. This also increases the comparability of different wireless technologies via simulations, which requires models of comparable fidelity. However, to the best of our knowledge, no such model exists for DECT NR+.

To enhance simulation models of DECT NR+, we conducted a first set of real-world experiments with nRF9151 DK devices to measure the Packet Error Rate (PER) under various levels of Additive Gaussian White Noise (AGWN) and with different Modulation and Coding Schemes (MCSs). Based on these measurements, we propose a PER model that can be integrated into simulators, but note that its parameters will likely need to be adjusted to compensate for the limited capabilities of the used development boards.

II. Related Work

Penner et al. [2] presented first simulative investigations of the link-layer performance – mainly PER – of DECT NR+ with ITU standard channel models. The first real-world experiments were conducted by Waßmann et al. [3] who investigated how different frequencies and numerologies influence the Bit Error Rate (BER) and PER of DECT NR+ while using an Ettus USRP B210 as sender and receiver. Graf et al. [4] used the nRF9131 EK to investigate the impact of transmission power and environment on the Packet Delivery Ratio (PDR).

For WLAN, the well-known NIST packet error model (created by Pei and Henderson [5] and based on the work of Miller [6]) exists, which is used by well-established simulators like ns-3 and Veins.

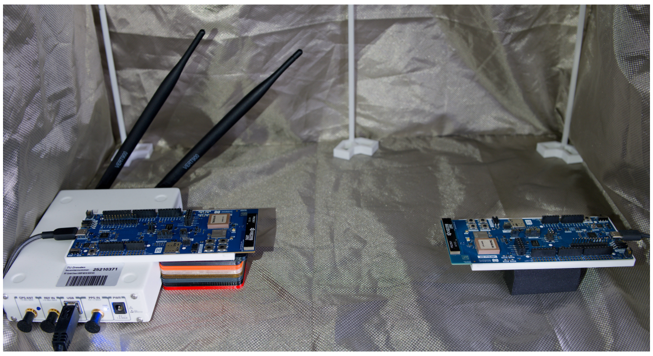

Figure 1. Experimental setup of two nRF9151 DK (sender right – receiver left) and the Ettus USRP B210 acting as the AGWN source in a Faraday cage.

To the best of our knowledge, no such model for the PER of DECT NR+ (which can then be integrated in such simulators) exists.

III. Methodology

We used two nRF9151 DK boards from Nordic Semiconductor (one as sender and one as receiver) – as well as a B210 which we used to generate AGWN – all connected over a wireless channel in a Faraday cage and placed 0.25 m apart from each other as shown in Figure 1.

We used GNU Radio to generate AGWN by connecting a *Fast Noise Source* block directly to a *USRP-Source* block. We used the Gaussian noise type, an amplitude of 300, and a sample rate of 5 MS/s at a center frequency of 1.885 GHz. We transmitted the signal through channel 0 of the B210's board 1, and used board 0 to record the signal for a plausibility check. We configured the transmit power of the B210 in the *USRP-Source* block as a parameter and refer to this input parameter as the *noise power level* – which is the independent variable.

The nRF9151 DK only supports numerologies with $\mu = 1$ and $\beta = 1$ and MCSs from 0–4 for band 1. Nordic Semiconductor provides an example program – called DECT shell – that can be used for physical layer compliant DECT NR+ communication. With its *perf mode* we can set the transmit power, the MCS, the duration of the transmission, and the inter-packet gap. After each transmission, it reports the Signal to Interference plus Noise Ratio (SINR) and the PER in absolut values – our dependent variables.

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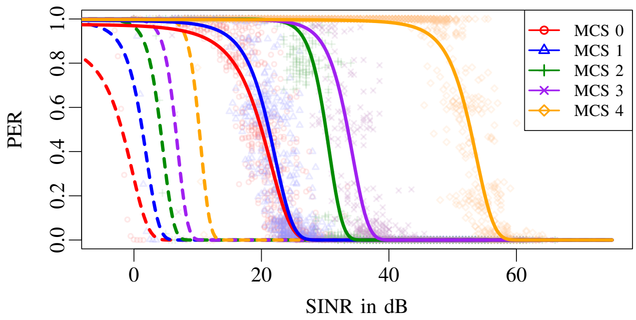

Figure 2. Raw sample points and curves of reported Packet Error Rate (PER) vs. reported Signal to Interference plus Noise Ratio (SINR) for all five Modulation and Coding Schemes (MCSs), fitted using Equation (1) (solid lines) along with theoretical values from Penner et al. [2, Figure 2] (dashed lines). Note the limited capabilities of the used development boards, especially in comparison to the theoretical values.

For each combination of noise power level (0.5–0.8 in steps of 0.1 and 0.8–1 in steps of 0.01), transmit power level (7 dBm), and MCS (0–4 following Table I for index mapping), we sent 210 packets over 1 s at channel 1663 (1.876 GHz), where each individual packet has a length of 4 slots and is followed by 8 gap slots. We repeated each measurement run 100 times with a random order of parameter values to avoid any temporal bias.

For each run, the DECT shell measures the throughput of the wireless channel and returns the number of successfully received packets, the number of Physical Control Channel (PCC) and Physical Data Channel (PDC) Cyclic Redundancy Check (CRC) errors, as well as the SINR and the Received Signal Strength Indicator (RSSI). We thus obtain a tuple consisting of measured PER and measured SINR as dependent variables under given noise power as the independent variable.

IV. Evaluation

For the creation of the PER curves, we used Non-linear Least Squares (NLS) regression with

$$\mathrm{g}(x) = 0.5 \times \mathrm{erfc}\Big(a\sqrt{(x+c)} + b\Big) \tag{1}$$

as the base model, where x is the SINR in linear scale with a constant offset $c = 20$ to shift all SINR values into a positive range. It uses the complementary error function (erfc) for normally distributed values, that is,

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2}\,\mathrm{d}t. \tag{2}$$

This follows the principle of tail probability calculation of Miller [6] as well as Pei and Henderson [5], while still allowing straightforward adaptations of the tuning parameters to model hardware with different capabilities.

V. Discussion

As expected, the order of the MCSs is preserved in that of the curves and the curves align well with the raw sample points. With a Residual Standard Error (RSE) of 0.14 for MCS 1 and 0.11 for all other MCSs, our curves represent the measured values quite well. This is especially true given the noisy nature of wireless channels. In the range with no sample spread – the stable PER ranges (zero or one) – the curves match perfectly.

Table I
Modulation and Coding Schemes (MCSs) together with fitted values from our measurements (exp) and for the simulated values from Penner et al. [2, Figure 2] for Equation (1). Note the limited capabilities of the used development boards.

MCS	modulation coding rate	data rate (in kbit/s)	a exp	b exp	a theo	b theo
0	BPSK 1/2	192.43	0.048	-1.54	1	-4.06
1	QPSK 1/2	389.88	0.053	-1.94	1	-4.85
2	QPSK 3/4	574.52	0.029	-2.9	0.83	-5
3	16-QAM 1/2	774.74	0.015	-2.32	0.67	-5
4	16-QAM 3/4	1171.31	0.001	-1.98	0.46	-5

Comparing our final values from Table I with the simulated values from Penner et al. [2, Figure 2] (also plotted as dashed lines in our Figure 2), we can identify a clear shift on the x-axis. Even more noticeable is that in the simulated values all curves are equidistant, while in our measured and fitted values a clear gap is present between MCS 3 and MCS 4.

This shown discrepancy between our measured values and the presented curves by Penner et al. [2] – which are based on simulations – and Graf et al. [4] – who used the nRF9131 – highlights the focus of the used hardware for evaluating the technology. The nRF9151 DK offers a promising entry point for DECT NR+ research, but comes with limited capabilities, which one needs to consider while evaluating the results.

VI. Conclusion and Future Work

We presented an empirical Packet Error Rate (PER) model for DECT NR+ based on measurements from a physical testbed. Our model provides a foundation for PER models of DECT NR+ in system-level simulators like Veins or ns-3, though its parameters will likely need to be adjusted to compensate for the limited capabilities of the used hardware.

Future work includes expanding the model to multi-antenna configurations, higher Modulation and Coding Schemes (MCSs), different numerologies, and more capable devices.

References

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