DECT-2020 NR for Professional Live Audio: Design Space Exploration and Practical Evaluation

Jan Dürre
Research Department
Sennheiser electronic SE & Co. KG
Wedemark, Germany
jan.duerre@sennheiser.com

Norbert Werner
Research Department
Sennheiser electronic SE & Co. KG
Wedemark, Germany
norbert.werner@sennheiser.com

***Abstract*—This paper presents an in-depth evaluation of the DECT-2020 New Radio (NR) standard for professional live audio applications, focusing on latency as a critical performance indicator. The evaluation uses the nRF91 modem series by Nordic Semiconductor, currently the first and only available devices with DECT-2020 support. We evaluate the potential of DECT-2020 by exploring the design space of the standard, explaining the complexity of trade-offs between latency, RF resource utilization, and transmission robustness. We then present our measurement setup, to analyze the performance. Based on a series of practical latency measurements with different configurations, we identify potential operation points for transmitting wireless audio over DECT-2020 and conclude that the minimum achievable latency with the current DECT-2020 modem implementation is 2.312 ms, at a cost of about one-third of the RF channel resources. Our results represent a minimum latency estimation as only the physical layer is currently available as an implementation, and other key performance indicators were not considered in this work. These findings provide valuable insights into the current state of DECT-2020 for professional live audio applications and highlight areas for future exploration.**

***Keywords*—DECT-2020 New Radio, NR+, professional live audio, wireless microphone, URLLC, 5G**

I. Introduction

Local wireless transmission (TX) of audio plays an important role in many professional live audio applications. The combination of wireless microphones and in-ear-monitoring (IEM) devices allow musicians to freely move on a live stage without having to manage cables. While the reliability requirement for the transmission seems obvious in a live stage scenario, there are also latency limitations tolerable by professionals. This is related to the feedback loop from microphone to mixing console and back to the in-ear-monitoring. The overall latency should not exceed about 4 ms for the full loop. While this includes a typical processing delay of about 2 ms in a mixing console, only 1 ms remains for each one-way wireless transmission [1] [2]. Figure 1 illustrates this typical stage setup. The data rate of a wireless audio stream can be approximated to about 200 kbit/s, assuming 48000 samples / s and a state-of-the-art professional live audio codec. Packet error rates should be smaller than 10^{-6} to ensure sufficient quality-of-experience for audience and artists [3].

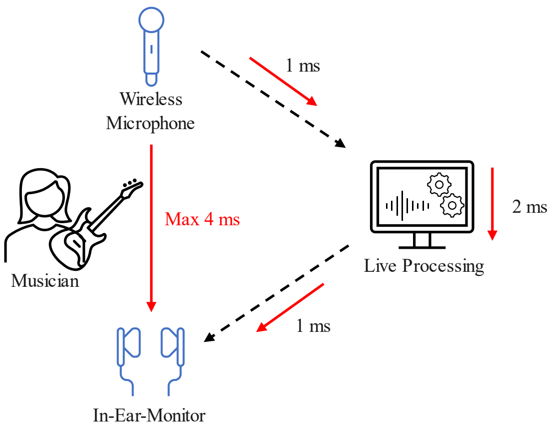

Fig. 1. Latency critical self-feedback loop in professional live audio applications

II. Wireless Technologies for Professional Live Audio

The selection and implementation of wireless technologies in the context of professional audio applications is a complex and heterogeneous field to navigate.

A. Custom and non-standard

As of today, the combination of all requirements from battery runtime, built size, deterministic transmission reliability and latency, cost, and spectrum access can be achieved with non-standard, hand-optimized, and highly interlinked audio and radio frontends, based on narrow- or wide-band analog or digital modulations. Although this approach results in commercially successful products, the customized nature of the overall stack leads to significant development costs with relatively slow innovation cycles.

B. Application agnostic

In contrast many successful standardized wireless technologies, such as Wi-Fi and 5G, are originally designed to be application agnostic. One major element in achieving this was to focus on the IP-convergence layer to create a data pipeline for many concurring users and applications. This came with certain trade-offs e.g., in terms of efficiency and latency, which made those technologies incapable of realizing URLLC (ultra-reliable and low-latency communication) use cases such as wireless microphones on a stage. Still, the number of targeted applications due to the agnostic approach is significant, resulting in commercially feasible highly integrated modem solutions that are able to make up for some disadvantages, especially in efficiency. In the recent past the standardization of these widespread technologies are beginning to broaden their scope to applications with deterministic latency requirements [3] [4]. This is driven by the respective technology stakeholders (e.g., modem manufacturers or network operators) interested in external investment, political weight in spectrum negotiations, and finally market growth. The example of 5G has shown that even years after standardization many promised features have yet to be commercialized. The gap between standardization and available implementations remains significant [2] [5] [6]. Professional audio applications being able to benefit from off-the-shelf Wi-Fi or 5G modems still remain a future vision [7].

C. *Consumer audio focussed*

In addition, there are some, also standardized, wireless technologies that are optimized for specific audio applications, e.g., Bluetooth and DECT. Both standards have had a narrow focus on mass market consumer use cases, wireless headphones and cordless telephony, with relatively relaxed reliability and latency requirements, and successful trade-offs for compatibility and unit price. The past has shown that also some (semi-) professional audio applications, such as wireless microphones for presentations with more relaxed latency requirements could be delivered based on DECT technology. To achieve this goal, only parts of the available mass-market modems could be used, as the available full-stacks are optimized for telephony. Although large parts of the stack needed to be customized and required some trade-offs in latency, the availability of mass-market physical layers made such implementations attractive.

III. DECT-2020 NR and Scope of this Work

After classic cordless telephone applications have lost relevance in recent years, DECT stakeholders shifted their focus first towards home automation, and now to data and IoT (Internet-of-Things) applications. For that purpose, a new standard called DECT-2020 New Radio (NR) is being developed and published since 2020. The new scalable physical layer (PHY) is OFDM-based and similar to the one of 3GPP 5G. According to the new standard different subcarrier spacings, modulation schemes, and frame sizes can be combined and traded-off to allow operation in different channel bandwidths with different data rates, latencies and robustness. The bandwidth can range from a minimum of 1.728 MHz up to 221.184 MHz. A radio frame is 10 ms of length, consisting of 24 slots of each 416.67 µs. Slots can be further split into a maximum of 16 subslots, potentially enabling very short transmissions. Additional features are modern turbo coding schemes and Hybrid ARQ (HARQ), as well as MIMO (multiple input multiple output) operation. [8] The medium access control (MAC) in DECT-2020 is fundamentally different from 3GPP 5G. Cellular 5G systems follow a synchronized and coordinated approach where the scheduling and control of medium access are centralized by a single base station. In DECT no central instance coordinates all devices using the same band. Devices are assumed to be asynchronous, so mitigation methods for transmission and scheduling collisions are required. Concurring DECT systems should be able to self-manage.

With its feature set DECT-2020 could in principle deliver a wide range of highly demanding use cases. DECT-2020 was approved as an IMT-2020 standard for massive machine type communications (MMTC) and URLLC applications [9] [10] [11]. As the standardization recently finalized release version 1 [12-16], the commercialization of implementations is about to begin. A first modem manufacturer will start to sell the implementation of the physical layer in 2024. All this makes the new DECT standard a promising technology candidate for delivering reliable low latency wireless audio for future professional live applications.

It is not to be expected that the first available DECT-2020 implementations will cover the full range of features described in the standard. Instead, radio or modem manufacturers will naturally focus on first viable business cases. In this work we present the evaluation of aforementioned first commercially available DECT-2020 physical layer implementation and place it in the context of professional live audio. Our goal is to capture the state of the art in order to highlight what is already feasible and identify room for optimization to potentially meet the use case requirements. In this work we have a strong focus on latency as one of the most important Key Performance Indicators (KPI) for professional live audio applications.

IV. Evaluation Setup

For our evaluation we used two nRF9151 System-in-Package (SiP) modems by the manufacturer Nordic Semiconductor. To the best of our knowledge, the nRF91 modems are currently the only available devices with DECT-2020 support on the market. The modems also support LTE-M, as the physical layers are very similar. For our measurements we used evaluation boards (nRF9151-DK) available for the SiP to enable physical access to interfaces. The modem SiP includes a 64 MHz Arm Cortex-M33 application processor to simplify interfacing with the modem. As already mentioned, the SiP currently only offers an implementation of the DECT-2020 physical layer. Control of medium access could be implemented on the application processor, but is currently not offered by the manufacturer. No scheduling or collision mitigation mechanisms are available, which would be necessary for the modem to operate in accordance to the DECT standard and therefore coexist with other (legacy, or 2020) devices. These mechanisms would most likely have major implications for latency and other KPIs of an application. Thus, as a first step we focus on a scenario where no concurring devices are nearby. This can be understood as a best-case latency estimation.

A. *Configurable modem parameters*

The nRF9151 DECT-2020 physical layer implementation supports a subset of the (partially optional) standardized parameter set. The modem operates in single input single output (SISO) mode only. The subcarrier spacing is fixed at

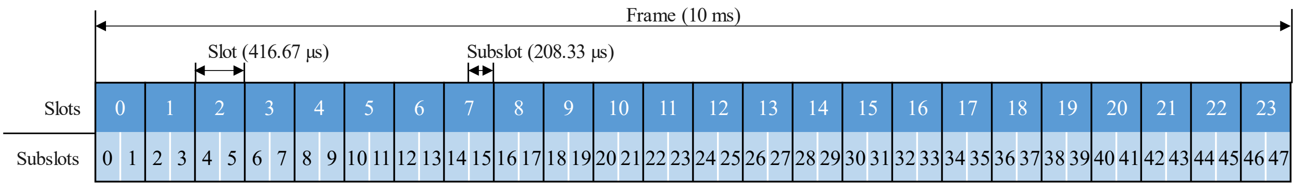

Fig. 2. DECT channel radio resource structure and nRF9151 parameter space

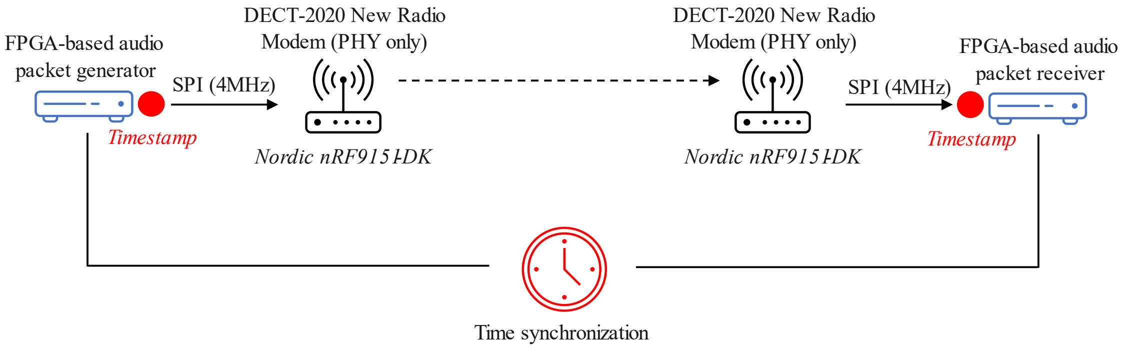

Fig. 3. Measurement setup to capture precise timestamps of individual audio packets transmitted over DECT-2020 New Radio

27 kHz, resulting in an also fixed bandwidth of 1.728 MHz, $(\mu,\beta) = (1,1)$ in standardization nomenclature. The radio frontend can operate in the 1.9 GHz band for DECT. Some parameters can be configured: the device supports five different modulation and coding schemes (MCS), BPSK 1/2 (termed as MCS0), QPSK 1/2 (MCS1), QPSK 3/4 (MCS2), 16-QAM 1/2 (MCS3), and 16-QAM 3/4 (MCS4), allowing the trade-off between data rate and robustness. Currently not supported are 64-QAM, 256-QAM, and 1024-QAM. Furthermore, the modem allows selection of different transmission lengths by granularity of half-slots, 208.33 µs length each, as illustrated in Figure 2. Our evaluation is based on modem firmware version 1.0.1, SDK version 2.7.0-rc3.

B. Audio stream emulator

In order to emulate a realistic professional live audio stream to be sent over DECT-2020 we used configurable FPGA-based audio packet generator and receiver devices. The generator device is constantly creating an audio stream of ~200 kbit/s. Depending on the configuration of an audio packet periodicity, the stream is split into precise periodic and equidistant audio packets. This allows to emulate real audio packet splits depending on the transmission system or parameters used. Whenever an audio packet is generated a unique packet number and a precise timestamp is logged. The audio packet receiver is able to take timestamps on received packets. Both devices synchronize their internal timestamping clock with a wired pulse-per-second (PPS) link. Logged packet numbers and timestamps allow high-precision analysis of transmission latency, jitter, packet loss, and reordering in nano seconds resolution.

C. Measurement system

Figures 3 and 4 give an overview of the measurement setup. The audio packet generator is connected via Serial Peripheral Interface (SPI) to a first nRF9151 modem, the audio packet receiver is linked to the second modem via SPI. The modem SiP offers multiple interfaces for data insertion and extraction, SPI being one with small added delay with sufficient data rate. The nRF9151 application processor firmware implemented by us acts as a middleware between our audio application emulator and the modem itself. Its main task is to configure the modem parameters and transfer the audio packet data between SPI interfaces and modem. The sender is sending audio packets as soon as possible after reception via SPI. The receiver is permanently listening for packets.

The spatial placement of the modems was selected in a way that RF conditions had minimal influence on measurement results. Modem antennas were placed about 30 cm from each other.

V. Design Space

As explained above the DECT-2020 standard allows the configuration of parameters to trade-off different characteristics. The implementation of any application in DECT-2020 requires a decision on how to use the available resources (see Figure 2) through selecting a matching parameter configuration. The parametrization influences KPIs such as latency, and also the number of simultaneously operable devices, as RF resources are shared in principle.

A subset of the full parameter set is implemented in the modem we used for our measurements. The potential parameter space is still significant in size, but not all configurations have the potential to produce KPIs matching the use cases requirements. In order to focus the design space exploration on meaningful areas we made some preliminary considerations.

As latency is an important optimization goal for our application, we start here. On the DECT-2020 physical layer there are two transmission parameters that are directly related to the application latency.

A. Periodicity of transmissions

The constant audio stream dictates steady periodic transmission of audio samples. Individual audio samples are generated at a fixed rate of 48000 samples / second. Samples could be transmitted individually or collected to form audio

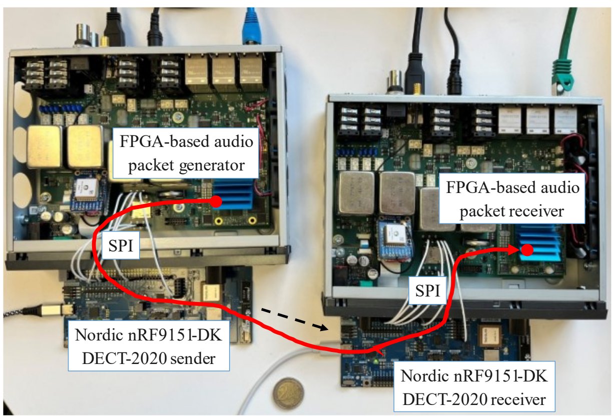

Fig. 4. Measurement system and spatial placement

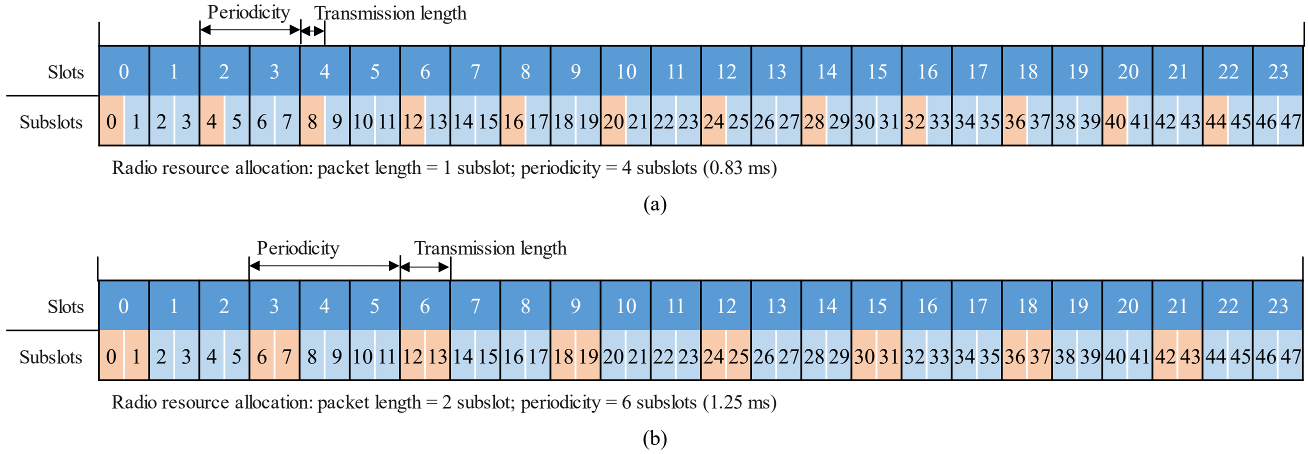

Fig. 5. Illustration of exemplary radio channel allocation. (a) packet length = 1 subslot, periodicity = 4 subslots (0.83 ms) (b) packet length = 2 subslots, periodicity = 6 subslots (1.25 ms)

packets for joint transmission. Duration of sample collection will result in additional application latency, but could be necessary in order to match the transmission system packetization scheme. In the case of our DECT-2020 modem the smallest packet granularity is one subslot of 208.33 µs, meaning that in theory every subslot a packet of audio could be sent over the air. This means that the minimum application latency is 208.33 µs for sample collection while waiting for the next transmission subslot, plus at least the latency for the actual RF transmission of 208.33 µs. Drawback of selecting smaller periodicities could be the occupancy of more resources in a DECT channel, leaving less room for other participants (e.g., other microphones).

B. *Transmission length*

Furthermore, the length of a transmission can be configured with subslot granularity. Selecting a longer TX length results in more bits being transferred per transmission. It could be necessary to allocate more than one subslot per transmission to meet the data rate requirements of our application. Again, increased transmission length results in added latency and allocation of more RF resources.

For illustration Figure 5 shows two exemplary configurations of different periodicities and transmission lengths.

C. *Other considerations*

Finally, to decide on operation points for our application, we need to consider the data rate. The available data rate for a device in DECT-2020 is a trade-off between a selected pair of periodicity and transmission length, and the selected MCS. While periodicity and TX length mainly trade-off the application latency, and the allocation of overall RF resources, they also have an impact on TX overhead. Generally, overhead is necessary with each individual transmission. Transmitting less often results in less overhead, and increased efficiency. For example, the configuration in Figure 5 (b) is more efficient than (a) in terms of overhead, but has an increased application latency. Furthermore, the selection of a modulation and coding scheme forces to trade-off available data rate and robustness.

Summarizing, the very flexible resource grid in DECT-2020 requires some trade-offs to meet application requirements while not simply taking all available RF resources. Table 1 gives an overview on the necessary trade-offs. Qualitatively speaking, for a professional live audio use case, the system design should aim for:

- latency as low as possible, to ensure best quality-of-experience
- occupation of as little RF resources as possible to allow the operation of as many microphones as possible
- most robust transmission in order to minimize audio drop-outs

In this work we start exploring this complex DECT-2020 design space with quantitative data from practical measurements with the first available PHY implementation.

VI. MEASUREMENT RESULTS AND DISCUSSION

For our measurement we selected a two-step approach, which is as follows:

First, we calculated available data rates for the three smallest available TX lengths (1 subslot, 2 subslots, and 3 subslots) in dependency of the available MCSs (MCS0-4) and potential periodicities up to half a DECT-2020 frame (Tables 2, 4, and 6). We selected only periodicities which are an even divider of the 48 subslots in a frame, as they would make backwards coexistence with legacy DECT devices more feasible. For better understanding, the tables also show the resulting RF resource allocation in percent of all 48 subslots in a frame of one DECT channel. This gives an indication on how many other devices might fit into the same channel.

TABLE 1: TRADE-OFF BETWEEN LATENCY, RESOURCE ALLOCATION, AND DATA RATE

		System parameters			
		Application latency	**Resource occupancy**	**Efficiency [Bits / Hz]**	**Robustness**
Configuration	**Periodicity ↑**	↑	↓	↑	-
	TX length ↑	↑	↑	↑	-
	MCS ↑	-	-	↑	↓

Second, we selected the configurations with a resulting data rate equal or larger than 200 kbit/s, as only those are potential candidates to deliver our application (marked in green in Tables 2, 4, and 6). Subsequently, we measured the latencies only for the selected configurations (Tables 3, 5, and 7) while limiting the transmitted data rate to about 200 kbit/s.

For all data rate calculations, we are assuming the smallest possible PHY header (physical layer control field type 1). Potential other overhead from other layers (e.g., MAC) was not considered here, as only the PHY is implemented.

Latency measurements were conducted from SPI-transfer in the sender to SPI-transfer in the receiver (see section IV.C). For each configuration we measured latency and jitter of 20,000 individual transmissions. The tables presented contain the respective maximum latency we observed. Generally, jitter was very low with little to none outliers, meaning the maximum latency is a good indication on the potential application latency. Exemplarily, for the configuration TX length of 2 subslots, MCS1, periodicity 1.25 ms the observed latency was between 1.058 and 1.062 ms with a mean latency of 1.060 ms and a standard deviation of 0.7 µs.

A. *TX length = 1 subslot*

Table 2 and 3 show the results of the data rate calculation and the measured latencies for a transmission length of 1 subslot. Green marked cells in Table 2 show that only five configurations in total produce enough data rate to potentially support our application. For those it is required to take at least 50 % of the DECT channel resources. And, only the higher modulations (MCS2-4) produce enough data rate. To evaluate the design space for our application we focus on only the green marked configurations for further measurements, whose results are shown in Table 3. We found that none of the parameter sets are feasible with the available modem implementation. After some investigation we found that with transmission periodicities below about 1 ms the modem starts to ignore increasingly more transmission requests. Our assumption is, that the modem has an internal processing overhead with each TX. The modem seems occupied with each transmission for some time, which is larger than our periodicity. Thus, the modem is not able to handle or queue TX requests during that time. Based on that we can state that our application is not feasible with the available modem implementation at a TX length of 1 subslot.

TABLE 2: AVAILABLE APPLICATION DATA RATE (TX LENGTH = 1 SUBSLOT), DATA RATES >= 200 KBIT/S HIGHLIGHTED IN GREEN.

TX length = 1 subslot							
Packet Periodicity		RF-ch. alloc.	Available data rate [kbit/s]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***100***	0	153.6	268.8	422.4	691.2
0.42	*2*	***50***	0	76.8	134.4	211.2	345.6
0.83	*4*	***25***	0	38.4	67.2	105.6	172.8
1.25	*6*	***16.7***	0	25.6	44.8	70.4	115.2
2.50	*12*	***8.3***	0	12.8	22.4	35.2	57.6
3.33	*16*	***6.25***	0	9.6	16.8	26.4	43.2
5.00	*24*	***4.2***	0	6.4	11.2	17.6	28.8

TABLE 3: MAXIMUM MEASURED LATENCY FOR 20000 PACKETS (TX LENGTH = 1 SUBSLOT) WITH TARGET DATA RATE OF 200 KBIT/S.

TX length = 1 subslot							
Packet Periodicity		RF-ch. alloc.	Latency [ms]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***100***			*not supported by modem*		
0.42	*2*	***50***				*not supported*	
0.83	*4*	***25***					
1.25	*6*	***16.7***					
2.50	*12*	***8.3***					
3.33	*16*	***6.25***					
5.00	*24*	***4.2***					

TABLE 4: AVAILABLE APPLICATION DATA RATE (TX LENGTH = 2 SUBSLOTS), DATA RATES >= 200 KBIT/S HIGHLIGHTED IN GREEN.

TX length = 2 subslots							
Packet Periodicity		RF-ch. alloc.	Available data rate [kbit/s]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***200***	*configuration not feasible*				
0.42	*2*	***100***	326.4	710.4	1094.4	1478.4	2246.4
0.83	*4*	***50***	163.2	355.2	547.2	739.2	1123.2
1.25	*6*	***33.3***	108.8	236.8	364.8	492.8	748.8
2.50	*12*	***16.7***	54.4	118.4	182.4	246.4	374.4
3.33	*16*	***12.5***	40.8	88.8	136.8	184.8	280.8
5.00	*24*	***8.3***	27.2	59.2	91.2	123.2	187.2

TABLE 5: MAXIMUM MEASURED LATENCY FOR 20000 PACKETS (TX LENGTH = 2 SUBSLOTS) WITH TARGET DATA RATE OF 200 KBIT/S.

TX length = 2 subslots							
Packet Periodicity		RF-ch. alloc.	Latency [ms]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***200***	*configuration not feasible*				
0.42	*2*	***100***	*not supported by modem*				
0.83	*4*	***50***		*not supported by modem*			
1.25	*6*	***33.3***		1.062	1.080	1.098	1.134
2.50	*12*	***16.7***				1.171	1.207
3.33	*16*	***12.5***					1.254
5.00	*24*	***8.3***					

TABLE 6: AVAILABLE APPLICATION DATA RATE (TX LENGTH = 3 SUBSLOTS), DATA RATES >= 200 KBIT/S HIGHLIGHTED IN GREEN.

TX length = 3 subslots							
Packet Periodicity		RF-ch. alloc.	Available data rate [kbit/s]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***300***	*configuration not feasible*				
0.42	*2*	***150***	*configuration not feasible*				
0.83	*4*	***75***	316.8	662.4	1027.2	1353.6	2083.2
1.25	*6*	***50***	211.2	441.6	684.8	902.4	1388.8
2.50	*12*	***25***	105.6	220.8	342.4	451.2	694.4
3.33	*16*	***18.8***	79.2	165.6	256.8	338.4	520.8
5.00	*24*	***12.5***	52.8	110.4	171.2	225.6	347.2

TABLE 7: MAXIMUM MEASURED LATENCY FOR 20000 PACKETS (TX LENGTH = 3 SUBSLOTS) WITH TARGET DATA RATE OF 200 KBIT/S.

TX length = 3 subslots							
Packet Periodicity		RF-ch. alloc.	Latency [ms]				
			MCS				
[ms]	*[subslots]*	*[%]*	*0*	*1*	*2*	*3*	*4*
0.21	*1*	***300***	*configuration not feasible*				
0.42	*2*	***150***	*configuration not feasible*				
0.83	*4*	***75***	*not supported by modem*				
1.25	*6*	***50***	1.267	1.296	*not supported*		
2.50	*12*	***25***		1.370	1.400	1.432	1.494
3.33	*16*	***18.8***			1.450	1.481	1.543
5.00	*24*	***12.5***				1.576	1.638

B. TX length = 2 subslots

With a transmission length of 2 subslots we found several configurations producing more than 200 kbit/s (green markings in Table 4). Selecting a TX length of 2 subslots, while transmitting each subslot is not feasible within one DECT channel (row 1 in Table 4), as it would require more RF resources than are available in one channel.

In the measurement phase (Table 5) we found again that some configurations (row 2 and 3) with a small periodicity result in the modem ignoring a significant number of TX requests. Successful measurements were possible with a periodicity of 1.25 ms and upwards. Looking at row 4 a slight increase in measured latency with higher MCS is evident, indicating that there is a (relatively small) interdependence between MCS and processing duration in the modem.

Furthermore, when comparing row 4 and 5 or 6, we see an increase in latency. This is most likely related to the increase in individual packet size. In average the data rate is the same, independent of selected periodicity. But, depending on periodicity, individual packets are of different size. Simply put, higher periodicity means fewer packets of larger size. Yet, on DECT-2020 PHY it is not intended to transmit smaller than a subslot granularity. Independent of your payload size, the full length of subslots are transmitted. In this case, the modem will always transmit two full subslots. The sender will fill the transmission with padding. Information about padding is not transmitted on PHY layer. Meaning the receiver is not aware of the padding. This could be implemented in a MAC layer. As a result, the duration of a transmission should not be related to the periodicity. Still, we measure an increase. The reason for that is most likely related to multiple overlapping effects. Although the RF transmissions itself are of the same length, the SPI transfers differ in number of bytes transferred, leading to more time required for SPI at higher periodicities. We also found, that the increase in SPI duration cannot be the only reason for increased latency. The longer SPI transfers would imply an even higher addition to latency than we measure. This implies that there is at least a second overlapping effect, resulting in slightly smaller latency with higher periodicities.

C. TX length = 3 subslots

Moving to 3 subslots as a TX length, even more configuration constellations are able to produce more than 200 kbit/s of application data rate (see Table 6, green cells). Naturally, this comes with the cost of generally using more RF resources. Latencies are higher than our measurements with a TX length of 2 subslots (Table 7 vs. Table 5). The increase in latency is consistent with one added subslot of about 208.33 µs.

With our latency measurement we found again that some parameter sets result in modem failures on RF transmissions. Interestingly, we see in row 4 (periodicity of 1.25 ms) that the point of failure is in-between switching MCSs from 1 to 2. This implies two things. First, when comparing to our measurement with a TX length of 2 subslots of the otherwise same configuration (Table 5, row 4), the threshold for failing seems to be related to the transmission latency. And second, that we were probably operating at the threshold of failure at MCS1 (same row). When switching to MCS2, the latency most likely increased a small amount (see section VI.B), meeting the threshold of the modem not being able to handle a new TX request every 1.25 ms. It is also noticeable that the threshold is very close to the actual periodicity which again supports our earlier assumption, that the modem is not able to handle new TX requests while the last is still on-going.

TABLE 8: SUMMARY OF MEANINGFUL CONFIGURATIONS FOR PROFESSIONAL AUDIO STREAMING; LATENCIES INCLUDE THE MEASURED SPI-TO-SPI LATENCY AND THE PERIODICITY.

	TX length = 2 subslots			**TX length = 3 subslots**		
Packet Periodicity [ms]	***Audio-Latency [ms]***	***MCS***	***RF-ch. alloc. [%]***	***Audio-Latency [ms]***	***MCS***	***RF-ch. alloc. [%]***
1.25	2.312	1	33.3	2.517	0	50
2.50	3.671	3	16.7	3.87	1	25
3.33	4.587	4	12.5	4.783	2	18.8
5.00	-	-	-	6.576	3	12.5

VII. SUMMARY

We want to place our measurement results in the context of a professional live audio application. Our work gives a first realistic overview on the state of the art of DECT-2020 for this use case. Based on that it is possible to estimate potential realistic latencies of a professional wireless microphone utilizing DECT-2020. Potential feasible configurations can be extracted from our Tables 3, 5 and 7. For a better overview we summarized all meaningful operation points in Table 8.

The table shows the following: for both feasible TX lengths we composed the entries for the different packet periodicities with the respective most robust MCS. Where multiple MCSs (one row in our Tables 3, 5 and 7) are able to produce the required data rate, it makes sense to always select the MCS with the smallest index. It gives more robustness and slightly lower latency, without any obvious downsides. The given latencies in Table 8 are audio application latency estimations and contain the sum of packet periodicity and measured transmission latency. These values are the minimum application layer latency estimation for a potential practical implementation of our use case. In addition, we show the related RF channel resource allocation in percent. Table 8 gives a valuable condensation of the design space for transmitting wireless audio over DECT-2020. For example, it can be read as: it is most likely not possible to achieve a smaller latency than 2.312 ms with the available DECT-2020 modem implementation, at a cost of about 1/3 of the RF resources of one channel. A configuration set with slightly increased minimum audio latency of 2.517 ms at TX length = 3 can be chosen. This operation point will require more resources (50 %), but will have a better robustness (MCS0).

It should again be emphasized that currently only the physical layer is available as an implementation. For a DECT-2020 compliant system, some parts of the MAC layer are required, namely the mechanisms to handle coexistence with other devices. Furthermore, many elements that will have relevant impact on the latency in a practical implementation were not considered in this work. These are for example jitter (processing, scheduling, RF-transmission, etc.), synchronization between devices, remote control channels, audio A/D and D/A conversion, and audio en- and decoding. For that reason, the results of our work have to be understood as a minimum latency estimation.

Lastly, other KPIs were not considered or only looked upon qualitatively in our work, but are equally important in delivering a professional live audio use case. First simulations have shown that the DECT-2020 physical layer alone might not be able to meet the strict reliability requirements of some factory automation use cases, which show some similarities to our live audio scenarios [17]. In [18] the bit- and packet error rates in different frequency bands were evaluated with SDR-based measurements.

VIII. ACKNOWLEDGEMENT

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