Performance of DECT-2020 NR and FCC-Based Mesh IoT Systems in DECT Bands

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***Abstract*—DECT-2020 NR is a recently standardized radio access technology (RAT) for massive machine-type 5G communications operating in the license-exempt and licensed bands. By relying on multi-hop communications and listen-before-talk (LBT) medium access, DECT-2020 NR allows for cost-controlled flexible deployments. However, the medium access procedures for some of the bands currently used by classic DECT systems are strictly regulated by long-standing policies in the USA. The goal of this study was to evaluate and compare the performance of DECT-2020 NR and medium access specified by the Federal Communications Commission (FCC) for the Unlicensed Personal Communications Service (UPCS) band. Our results demonstrate that in a mesh system, the use of FCC access rules leads to drastic performance degradation, resulting in less than 85% of delivered packets compared to 98-99% for DECT-2020 NR. This results in a slight 1-2% degradation for coexisting classic DECT devices. For efficient use of the UPCS band, we recommend revisiting current FCC rules, allowing for LBT-based operations.**

***Index Terms*—DECT-2020 NR; NR+; New Radio; multi-hop; IoT; topology; algorithms; mMTC.**

I. Introduction

Internet of Things (IoT) applications are already tightly integrated into our daily lives, enabling a wide range of remote functions from sensing to actuation [1]. Massive machine-type communication (mMTC) technologies, as a core component of 5G IMT-2020 systems, provide essential support for IoT [2]. NB-IoT [3] is a 3GPP-standardized solution for cellular IoT (CIoT) [4], whereas DECT-2020 NR [5] leads the way for non-cellular IoT standards.

DECT-2020 NR is the pioneering 5G mMTC enabler operating in the unlicensed frequency band: 1880-1900 MHz in Europe and Australia, and 1900-1920 MHz in other regions. Recent research [6], [7] has demonstrated its capacity to support millions of radio devices (RDs) per square kilometer, while meeting the performance requirements for 5G mMTC applications outlined in [8]. These requirements include a packet loss rate (PLR) of less than 0.05% and an end-to-end latency of no more than 10 seconds for 99% of packets. Aligned with 5G standards, DECT-2020 NR's physical layer offers flexibility in modulation and coding schemes (MCS), per-link hybrid automatic repeat request (HARQ) procedures, and various numerologies [9], [10].

In different countries, there are specific restrictions on the use of unlicensed bands in which DECT systems are currently operating. Specifically, in the USA, the FCC defines the operation in the Unlicensed Personal Communications Service (UPCS) band between 1920-1930 MHz in the §15.323 clause [11], where existing DECT-based systems have been used. The history of the UPCS band dates back to 1994 when asynchronous devices were allowed to operate in the 1910-1920 MHz sub-band based on the rules specified in §15.321 and isochronous devices – in the 1920-1930 MHz sub-band based on §15.323. Both §15.321 and §15.323 defined separate spectrum access rules for asynchronous and isochronous devices. For asynchronous devices, the spectrum access rules specified in §15.321 clauses were ensured by utilizing listen-before-talk (LBT) functionality with an exponential back-off, whereas for isochronous devices, access rules were very much aligned to current access rules in §15.323.

After 1994, the regulation remained stable until 2004 when the FCC introduced Advanced Wireless Services rules [12]. In this process, the 1910-1920 MHz sub-band and the corresponding §15.321 were removed, and modifications to §15.323 were introduced. According to them, asynchronous devices are also allowed in the 1920-1930 MHz sub-band, in addition to isochronous devices. However, the spectrum access rules defined in §15.321 for asynchronous devices were not introduced in §15.323; rather, only the spectrum access rules defined for isochronous devices were maintained.

The above process demonstrates that spectrum regulation is dynamic, evolving in response to new needs driven by emerging use cases, technologies, and service demands. This adaptability aims to maximize spectrum utilization, benefiting both commercial interests and the public. Along these lines, this study aims to evaluate and compare the performance of mesh IoT technologies in the 1920-1930 MHz band operating according to the DECT-2020 NR LBT access mechanism and the one specified by the FCC in §15.323. We will perform a system-level simulation campaign that captures the specifics of medium access control and physical layer implementation.

The main contributions of this study are:

- in large mesh deployments, the performance of FCC mesh systems degrades drastically resulting in less than 85% of delivered packets as compared to DECT-2020 NR showing 98-99% of delivered packets;

- non-aligned sensing across RDs constituting a mesh system is the major cause of packet losses in mesh system operating with FCC-based access rules;
- revisiting FCC rules allowing for either controlled operation of LBT based or relaxing currently strict timings for packet transmission at the air interface is recommended.

The remainder of this paper is organized as follows. Section II describes the essentials of the DECT-2020 NR LBT-based access method and the FCC requirements. In Section III, we introduce the comparison methodology, considering the deployment and scenarios. The numerical results are presented in section IV. The conclusions are presented in the last section.

II. DECT-2020 NR and FCC Rules

In this section, we first overview the requirements imposed by the FCC on operation in the UPCS band at 1920-1930 MHz. Then, we outline the basics of LBT-based access, as specified in the DECT-2020 NR.

A. FCC Requirements for UPCS Band

The set of rules imposed by the FCC on the operation in the UPCS bands is summarized in [11]. Existing FCC rules state that both asynchronous and isochronous devices may operate in these bands. However, current spectrum access rules only define the old isochronous access method, as discussed above. The isochronous access method is illustrated in Fig. 1. Specifically, according to Rule 1 in [11], before initiating transmission, devices must monitor the combined time and spectrum windows in which they intend to transmit for a minimum of 10 ms in systems with 10-millisecond or shorter frames or 20 ms in systems with 20-millisecond frames. Thus, spectrum resources are considered free if the device intends to use them full time. Peak measurements over each symbol were performed with the threshold set to -82 dBm, as according to Rule 2 in [11], this threshold must not be more than 30 dB above the thermal noise power for a bandwidth equivalent to the emission bandwidth used by the device, which is 1.728 MHz for DECT-2020 NR.

The initiating device may measure both downlink and uplink slots; that is, both packet transmission and acknowledgment (ACK) slots need to be simultaneously free. If both the intended transmit and receive time and spectrum windows meet the access criteria, then the initiating device can start a transmission in the intended transmit time and spectrum window 10 ms after the measurement. The responding device does not measure whether it detects the signal that it starts to use (Rule 10 in [11]).

Once the transmission is initiated for an uplink slot and repeated with either 10 ms or 20 ms periodicity, the response needs to be received within 1 s at the previously measured downlink slot. Subsequently, both uplink and downlink slots are considered reserved, and bidirectional transmissions may continue for up to 8 h without further channel assessment, with the requirement that periodic responses are received at least every 30 s, [11], Rule 4.

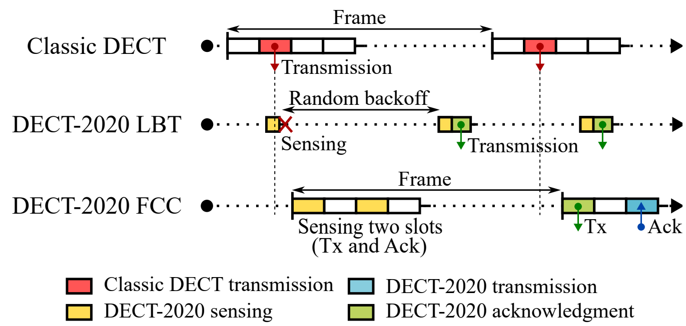


Fig. 1. Illustration of FCC and DECT-2020 NR channel access schemes.

If no access to the spectrum is available and the system utilizes at least 20 duplex access channels, a device may access the time and spectrum windows with the lowest power level. Therefore, it is expected that one device following FCC access rules may occasionally initiate a connection on top of another when the load is sufficiently high. In this case, the collision situation may remain long; either the connection remains on multiple frames or the initiating transmitter keeps trying to set up the connection. Furthermore, different systems, even synchronized with independent clock sources, will not have frame synchronization, and different clock drifts will impose non-optimum interference conditions.

B. DECT-2020 NR Topology and Channel Access

The DECT-2020 NR system is assumed to operate according to the DECT-2020 NR specifications, see [5] and references therein. DECT-2020 NR employs a cluster tree mesh topology for large-scale IoT deployments. DECT-2020 NR enables Radio Devices (RDs) to operate in fixed termination (FT) or portable termination (PT) modes or both simultaneously. During initialization, each Radio Device (RD) selects a Fixed Termination (FT) node for association based on the received link quality and announced cost, reflecting the quality of the path to external backend systems. RDs can initiate communication without first establishing and maintaining the entire data path, and connecting only to the next device in the cluster tree structure is sufficient. In FT mode, an RD functions as a router, coordinating local radio resources and allowing other PT RDs to connect to it. FT RDs routes data from connected PT RDs and their own data to the next FT RD in the network, finally reaching an FT RD as the sink of the system with an interface to external networks, and thus having necessary gateway functionality.

At the MAC layer, both FT and PT modes employ LBT with exponential back-off for uplink transmission, as shown in Fig. 1. The LBT sensing time for random access channel (RACH) transmissions is designed to be as brief as two symbols, facilitating rapid medium access [13].

III. Methodology, Deployment, and Scenarios

In this section, we first introduce the comparison methodology and the simulation tool. Then, we specify the considered

TABLE I

CONSIDERED SYSTEM AND EVALUATION PARAMETERS

Parameter	Value
DECT-2020 NR FT sink/gateway	1, height 25 m, outdoors
Carrier frequency	1900 MHz
Number of RDs	100/300
Number of channels	1
Channel bandwidth	1.728 MHz
RD deployment	Uniformly random
Building penetration loss	20 dB (ITU-R)
Indoor/outdoor fraction	80% / 20%
Channel model, Sink- RD	Urban macro
Channel model, RD-RD	Urban street canyon
Number of RD/sink antenna elements	1
Sink/RD noise figure	7 dB
Sink/RD antenna element gain	0 dBi
Thermal noise level	–174 dBm/Hz
Traffic model	Bursts of 2 packets
Application data message size	32 bytes
Mean interpacket time	10-50 s
Interpacket time distribution	Exponential
Channel access	LBT + extensions
Contention window size	min – 24, max – 768
LBT threshold	-75 dBm
Minimum link quality	15 dB
Error correction	HARQ with 3 attempts
Sensitivity	-99.7 dBm (TS 103.636-2)
DECT-2020 Tx power	10 dBm
Legacy DECT Tx power	10 dBm
Format	MSC 1,3,4 for 1,2,3 packets

deployment and scenarios under investigation, and define the metrics of interest.

A. Methodology and Simulation Tool

In our analysis, we capture the operation of the system at the MAC layer, including topology construction, routing, and forwarding capabilities. The physical layer implementation is assumed to be the same for the FCC and DECT-2020 NR systems, and its performance is abstracted by utilizing the set of common MCSs. To exclude potential side impacts, we disable some of the features provided by the physical layer, including energy conservation techniques and power control. The same carrier and bandwidth are considered so that the principal difference between the two systems is the way medium access is performed. Frame timings for the legacy DECT and DECT-2020 NR are not synchronized and the frame sift is random for a simulation run but does not drift during simulation. The remaining parameters common to both systems are shown in Table I.

The DECT-2020 NR system is implemented using the system-level simulation tool WINTERsim, which was utilized during the standardization process of DECT-2020 NR technology [6]. WINTERsim is a discrete event system-level simulation tool. For DECT-2020 NR, we employed node abstraction as the fundamental class representing RDs. This class encapsulates all node parameters, including position, mobility model, antenna characteristics, and power settings. Additionally, it serves as a container for layer 2 interfaces, forwarding mechanisms, flow tables, signaling engines, application handlers, traffic generators, and physical layer interfaces. To accurately simulate high-density deployments, we implement a physical layer abstraction that stores all bidirectional path loss states between the RDs, considering only the reception signal strengths that exceed the noise floor.

The simulation process commences with node placement and path loss calculations, adhering to the 3GPP guidelines outlined in TR 38.901. Whenever feasible, we utilized the ITU-R simulation guidelines in ITU-R M.2412 [14]. To collect the data, we use the method of replication. We conduct 25 simulation runs for each parameter set and gathered 10^5 observations in the steady state for each run. The steady-state period is identified using moving-average statistics. Owing to the substantial size of the statistical samples, we present only point estimates.

B. Deployment, Scenarios, and Metrics

To provide comparison between the FCC and DECT-2020 NR MAC access mechanisms, we consider three scenarios. First, we begin with the simple star topology scenario, where all RDs are connected directly to the sink. To ensure that no RDs are in the outage condition, the coverage around the sink, where the RDs are uniformly distributed, is limited to 20 m. In this deployment, the number of RDs was limited to 100, representing a large-scale home automation scenario.

In the second scenario, as illustrated in Fig. 2, we add the number of routers to the considered deployment and allow RDs to use them as relays. Here, we consider 100 RDs and a deployment area of 20 m radius. The reason for considering this deployment is to directly evaluate the impact of routing devices on the performance metrics of interest.

Finally, we consider a larger deployment with a higher number of RDs and routing devices. Here, the deployment radius is 40 m, while the number of RDs (leaf nodes) is 300, resulting in a three times higher system load with the same mMTC interpacket time from each device than in other scenarios. In all the considered scenarios, only one sink is

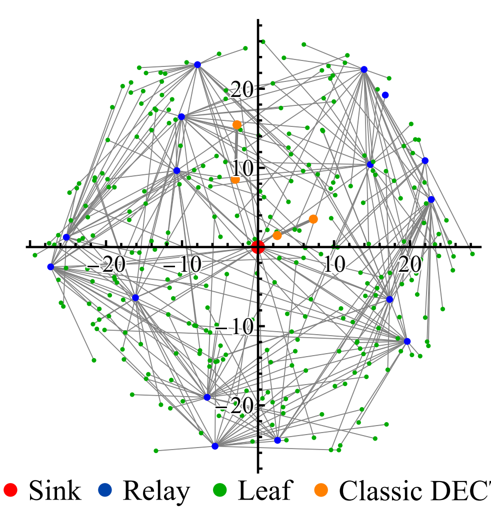
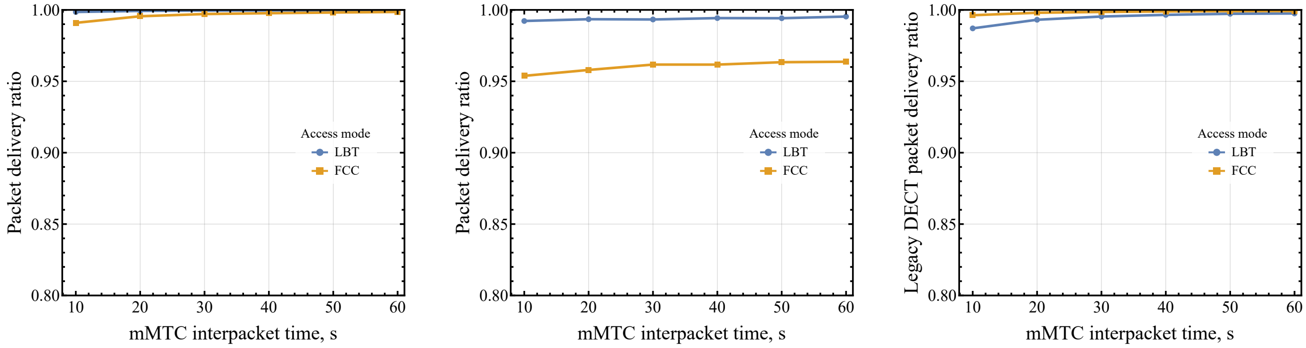


Fig. 2. Illustration of the considered multi-hop topology.



(a) No classic DECT (b) With classic DECT (c) Classic DECT performance

Fig. 3. Performance metrics for DECT-2020 NR and FCC mesh systems with star topology.

considered and is placed in the middle. The relay nodes are assigned automatically according to a uniform distribution over the deployment area. Each leaf node generates a single packet with Poisson-distributed interpacket time.

To assess the coexistence capabilities of DECT-2020 NR and FCC systems [15], for all scenarios we also consider classic DECT devices operating in the same frequency band. Accordingly, no classic DECT or two classic DECT-coupled device pairs are randomly and uniformly distributed around the sink FT RD, ensuring that the devices are always in the transmission range of each other.

We consider the packet delivery ratio of the DECT-2020 NR mesh, FCC mesh, and classic DECT systems as the major performance metric of interest.

IV. Numerical Results

In this section, we present our numerical results. We begin with the simplest star-based topology, where all RDs are directly connected to the sink. Then, we report the results for the case, where routers are added to the topology. Finally, we discuss the results of a large-scale scenario.

A. Scenario 1: Star Topology, Limited Coverage

We begin our assessment with a star topology, in which all leaf nodes are directly connected to the sink. Fig. 3 illustrates DECT-2020 NR LBT performance with and without interfering classic DECT devices (Fig.3(a) and Fig. 3(b), respectively), as well as classic DECT performance. By analyzing the presented data, we see that the star topology with only DECT-2020 NR devices shows an almost 100% delivery ratio under all considered interpacket generation times, Fig. 3(a). The same case shows a slight decrease in the delivery ratio for mMTC devices if random access is enabled according to the FCC rules. Some rare collisions causes packet losses because both the transmitter and interferer retransmit their packets at the same time but a frame later. The LBT scheme retransmissions undergo an additional randomized backoff, making it less probable for packets to collide again.

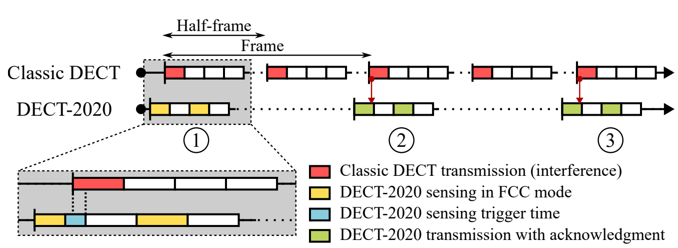


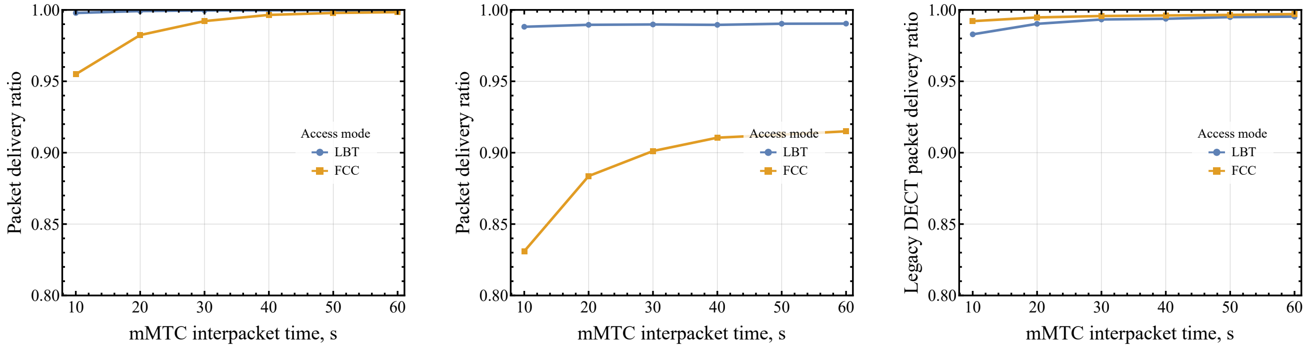
Fig. 4. Illustration of packet losses in FCC system.

Adding two coupled classic DECT device pairs that interfere with the DECT-2020 NR devices lowers the delivery rate by approximately 1% in the worst case, see Fig. 3(b). At the same time, Fig. 3(c) shows an increasing degradation in packet delivery ratio for classic DECT devices when the DECT-2020 NR load increases. This behavior is expected because of the constant and periodic nature of classic DECT transmissions and the lack of retransmissions or channel coding. The FCC scheme shows better performance for classic DECT devices as the FCC-enabled devices avoid some of the regular classic DECT transmissions by preemptively sensing the channel. However, this comes at the expense of degraded performance of FCC-based mesh system resulting in higher performance loss to DECT-2020 NR as compared to any potential performance increase in legacy DECT.

Fig. 4 illustrates the main reason for packet losses. First, FCC devices sense the channel trying to find a possible classic DECT transmission, which will reoccur exactly one frame later. However, there are cases when the interfering signal starts late (or early) enough for the device not to detect it. Once this happens, this FCC device starts its transmission a frame later, and this transmission is partially overlapped, which may lead to incorrect frame reception. As the FCC transmission slot was previously considered free, the device retransmits the packet one more frame later, and experiences interference again leading to consecutive packet losses.

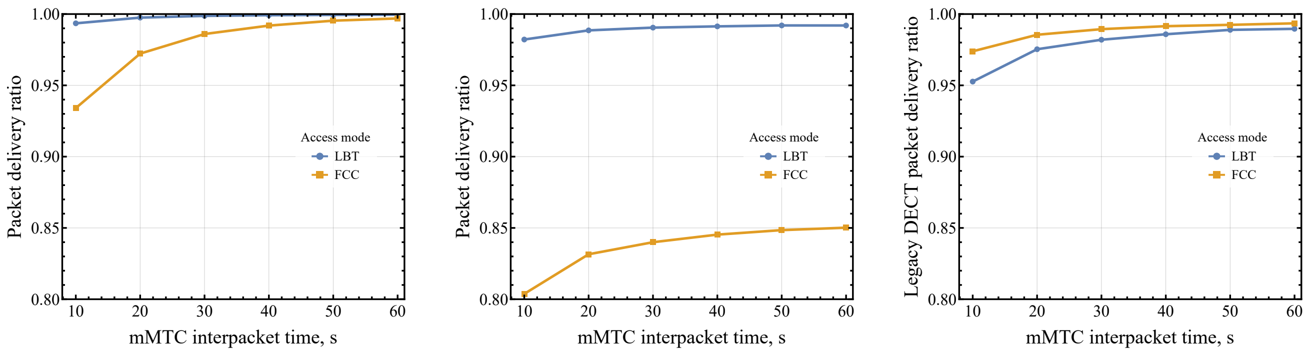
B. Scenario 2: Multi-Hop Operation, Limited Coverage

We now analyze the performance of the multi-hop system. The difference from the star topology is that a sink (or relay) can be connected to only 20 other devices; thus, several relay nodes are employed in the scenario to both increase the coverage and allow a larger number of devices to be



(a) No classic DECT (b) With classic DECT (c) Classic DECT performance

Fig. 5. Performance metrics for DECT-2020 NR and FCC mesh systems with multi-hop topology.



(a) No classic DECT (b) With classic DECT (c) Classic DECT performance

Fig. 6. Performance metrics for DECT-2020 NR and FCC mesh systems for larger deployment (3 times higher load compared to Fig. 3 and Fig. 5).

connected. This change does not affect the packet delivery ratio for the DECT-2020 NR devices in the LBT mode without any additional interferers, as shown in Fig. 5(a). However, the system in the FCC mode suffers up to 4% degradation compared with the previously described star topology. The decrease in performance is caused by additional constraints imposed by the FCC access rules. Specifically, they lead to an increase in the overall number of retransmissions performed by a relay node, which is sometimes unable to send ACK packets in a timely manner. The rationale is that there are strict timings when the ACK packet needs to be sent, as compared to the DECT-2020 NR LBT access, where it is not strictly regulated. This further deteriorates the performance as the relay nodes now have to align its sensing and transmissions together with the receptions, which require a longer contiguous time window than a regular LBT procedure.

The same logic applies to the case with additional interfering classic DECT devices illustrated in Fig. 5(b). Specifically, strict timings provide fewer opportunities to send an ACK when transmissions interfere in each frame. At the same time, due to more failed transmissions, classic DECT devices have slightly higher delivery ratios (by 1-2%) as compared to DECT-2020 NR LBT access (see Fig. 5(c)).

C. Scenario 3: Larger Deployment with Multi-Hop Operation

Finally, we consider larger-scale scenario with a deployment radius of 40 m, 300 RDs, and multi-hop operation. Fig. 6 shows DECT-2020 NR, FCC, and classic DECT delivery ratios for varying interpacket generation times. The results shown in Fig. 6(a), highlight that in the case when all devices use DECT-2020 NR LBT random access, the delivery ratio comes close to 100% even under the highest loads. On the other hand, FCC access rules show extremely poor performance even under very low loads (50-60 s interpacket generation time). This is primarily because relay nodes are unable to allocate time to both data reception from multiple uplink sources and data transmission to the next hop in the uplink direction. Indeed, according to the FCC rules, there is a need to allocate three consecutive slots dedicated to a single exchange between two nodes, which means that it is difficult to randomly distribute the required timings within a single frame (as there is no scheduling involved and some nodes might not even hear each other). This causes additional retransmissions, worsening the entire situation.

Similarly to the previously considered scenarios, the classic DECT performance is slightly better when the FCC system is utilized (see Fig. 6(b)), e.g., by 2% at 10 s interpacket generation time. However, this comes at the expense of completely malfunctioning mMTC service.

V. Conclusions

The aim of this paper was to compare DECT-2020 NR and FCC medium access schemes operating in UPCS band in multi-hop mode. We revealed that in a simple star topology with direct connections to the sink, performance of the FCC access mechanism is slightly lower than that of DECT-2020 NR. When the multi-hop capability is introduced, the performance of the FCC system starts to degrade drastically. The main reason is the strict timings for packet transmission at the radio interface, which leads to either an inability to gain access to the channel or overlapping of ACK transmissions. In large-scale mesh deployments, the performance of FCC systems degrades to unacceptable limits, resulting in less than 85% of delivered packets compared to DECT-2020 NR, showing close to perfect performance with 98-99% of delivered packets without significant impact on classic DECT performance.

Based on our results, to improve the resource utilization of the UPCS band when utilizing it for asynchronous mMTC systems, we recommend revisiting FCC rules allowing for controlled LBT-based operation.

Acknowledgment

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