

Performance of MAC Layer Mechanisms in DECT-2020 NR mMTC Technology

Andrey Samuylov¹, Dmitri Moltchanov¹, Mirza Alam², Juho Pirskanen², Jussi Numminen²,
Yevgeni Koucheryavy¹, Mikko Valkama¹

¹Unit of Electrical Engineering, Tampere University, Finland

² Wirepas Oy, Tampere, Finland

✉ Contact author's e-mail: andrey.samuylov@tuni.fi

Abstract—DECT-2020 is a recently standardized enabling technology for 5G massive machine-type communications operating in the unlicensed band. By relying upon multi-hop communications, DECT-2020 allows for cost-controlled flexible deployments, it requires an efficient solution for topology design, including the relay selection and next-hop selection mechanisms. The goal of this paper is to evaluate the impact of these algorithms on the fraction of successfully delivered packets for DECT-2020 technology. To this aim, we utilize the system-level simulation tool to capture the functionality of the physical and data-link DECT-2020 solutions. Our numerical results illustrate that the system is susceptible to the choice of the energy conservation parameters with the difference in the fraction of delivered packets reaching 10% and may effectively lead to non-operational conditions. Without simple analytical models, these parameters must be set with caution. The relay-selection mechanism procedure is generally insensitive to the parameters of the relay selection procedure, resulting in a deviation of at most 3%. Finally, the power control feature gives an additional gain of around 2-4% compared to the system without power control.

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

I. INTRODUCTION

Internet of Things (IoT) applications are gradually becoming a part of our everyday life, enabling many remote applications from sensing to actuation [1]. Massive machine type communications (mMTC) technologies specified as one of the three primary services for 5G IMT-2020 systems serve as enablers for IoT [2]. Nowadays, NB-IoT technology [3] represents a 3GPP solution for cellular IoT (CIoT, [4]) while the leading non-cellular standard is DECT-2020 [5].

DECT-2020 is the first 5G mMTC enabler operating in the unlicensed frequency band, 1880 – 1900 MHz band in Europe and Australia and 1900 – 1920 MHz band in other regions. The recent studies [6], [7] demonstrated that it can support up to multiple millions of radio devices (RD) per squared kilometer while satisfying the performance guarantees for 5G mMTC applications outlined in [8] of more than 0.05% packet loss rate (PLR) while ensuring that 99% of packets experience end-to-end latency of no more than 10 s. Being inherently compliant with 5G requirements, its physical layer supports flexible modulation and coding schemes (MCS), per-link hybrid automatic repeat request (HARQ) procedures, and various numerologies [9], [10].

The unique feature of DECT-2020 technology is that it utilizes multi-hop communications, enabling cost-controlled deployment flexibility [11]. To enable an efficient routing-free delivery spanning tree topologies are supported. However, in addition to these advantages, multi-hop communications pose new challenges for system designers. Indeed, the initial topology is created at the network initialization phase by the end devices choosing the operational mode – forwarding node or leaf node. This is enabled by two mechanisms that significantly affect the resulting topology and, consequently, the system performance: (i) relay selection and (ii) next-hop selection.

The goal of this paper is to propose and assess the performance of the medium access control and physical layer mechanisms for DECT-2020, including energy conservations, power control, relay, and next-hop selection mechanisms. We utilize the packet loss rate and fraction of delivered packets within a specific time constraint as the primary metric of interest for mMTC technology as specified in [8]. By utilizing ITU-R compliant system-level simulation (SLS) techniques, we assess the impact of parameters of the considered mechanisms and provide guidelines for configuring them.

The main contributions of our paper are:

- The system is susceptible to the choice of the energy conservation parameters with the difference in the fraction of delivered packets reaching 10% and may effectively lead to non-operational conditions.
- The performance of the DECT-2020 system is generally insensitive to the number of relay nodes in the radio neighborhood and the number of RDs associated with a single relay produced. The network density produces a much more noticeable impact.
- Although power control is beneficial for an overloaded system regime, the listen-before-talk (LBT) mechanism utilized by DECT-2020 is reliable enough to efficiently combat interference at conventional loads even in dense network conditions.

The rest of the paper is organized as follows. First, in Section II, we remind the basics of DECT-2020 technology. In Section II, we introduce the considered mechanisms. In Section IV, we outline the considered scenario, the utilized

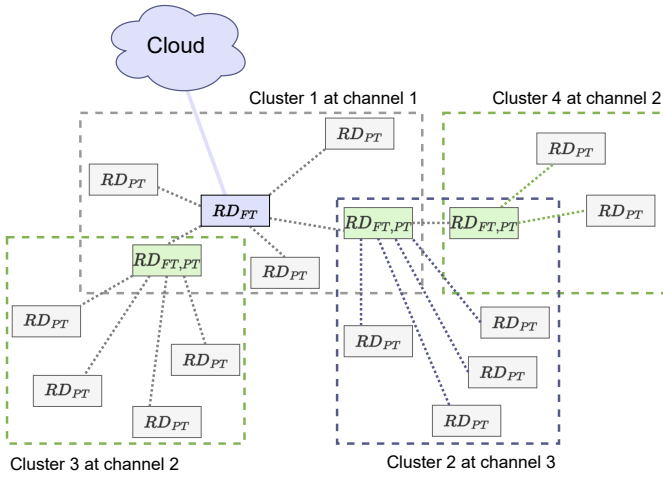


Fig. 1. Illustration of DECT-2020 network formation.

simulation tool, and the metrics of interest. Numerical results are provided in Section V. Conclusions are drawn in the last section.

II. DECT-2020 ESSENTIALS

DECT-2020 NR physical layer has been designed to meet modern radio technology requirements. The set of standards [5] commenced in 2021 and defined 19 operational bands. The most commonly used are classic DECT bands, 1880 – 1900 MHz band in Europe and Australia and 1900 – 1920 MHz band in other regions, supporting up to 11 channels with a bandwidth of 1.728 MHz each. Similarly to 3GPP NR, the physical layer supports multiple numerologies ranging from 27 KHz to 216 KHz. Time division duplex (TDD) is used to organize uplink and downlink channel, while Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are utilized for radio resource allocation. In general, the physical layer allows it to operate with different channel bandwidths, symbol lengths, and the number of symbols in a slot. It has been recently shown that these design choices allow for fair coexistence between classic DECT and DECT-2020 technologies [12].

At the medium access control (MAC) layer, DECT-2020 allows RDs to operate in fixed (FT) or portable termination (PT) modes or in both modes simultaneously, see Fig. 1. In the FT mode, an RD served as a router by applying a radio coordination function to manage local radio resources and enabling other RDs in PT mode to connect to it. The RD, operating in FT mode, routes data from these RDs and its data towards the next-hop RD operating in FT mode. Both FT and PT utilize the LBT approach with a binary back-off procedure for uplink transmissions. The minimum sensing time for the LBT in random access channel (RACH) transmission is designed to be as short as two symbols, allowing for rapid access to the medium.

Aiming to avoid explicit routing, the DECT-2020 standard specifies the use of tree topologies. Upon initialization, each device in PT mode selects the most optimum RD for association based on received link quality and announced cost, indicating how "good" the path towards the external backend systems is. Thus, RDs, being the source of the data, do not need to establish and maintain the data path before initiating communication, rather connection only to the next hop is required. Thus, relay and next-hop selection are crucial for network performance.

In addition to the functionalities mentioned above, the DECT-2020 MAC layer also allows for several advanced functions, including energy conservation mechanisms and power control functions. The former is aimed at increasing the RD's operational cycle, while the latter allows to decrease the impact of interference further. Operating over tree topologies, the ultimate effect of these functions on network performance is generally more complex than CIoT systems.

III. CONSIDERED MECHANISMS

In this section, we will introduce the considered mechanisms and their parameters, including energy conservation, power control, relay, and next-hop selection.

A. Energy Conservation

To reduce the power consumption of RDs (especially those operating in PT mode) DECT-2020 system offers an intelligent duty cycling regime. Accordingly, RD is periodically put into standby mode with its TRx module switched off. Every RD is supposed to be in standby mode by default and wakes up only when needed to either transmit and receive data and/or to maintain network connectivity.

Each RD can operate in a downlink (leaf node), uplink (sink), or down/uplink (relay) role. Depending on the role, a device is required to perform the following functions:

- Uplink devices need to wake up periodically every Beacon Interval to broadcast a beacon packet containing their duty cycle information, i.e., for how long the device will stay awake and ready to receive data from the coupled downlink RD. The uplink RD then remains awake for the

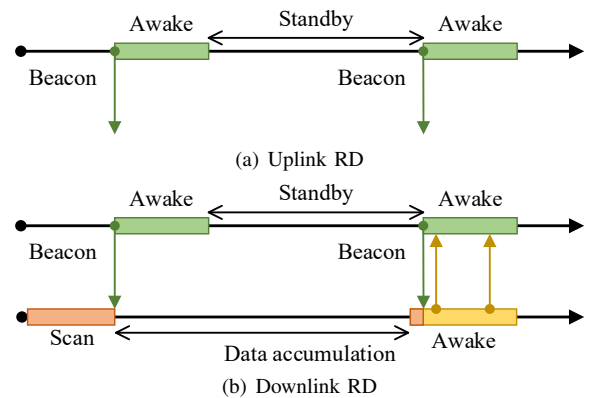


Fig. 2. Energy conservation approach in DECT-2020.

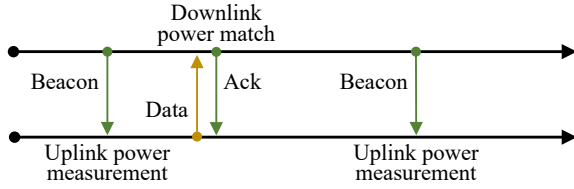


Fig. 3. Power control in DECT-2020.

announced period and switches back to standby mode. This procedure is presented in Fig. 2(a).

- Downlink RDs are first required to check for the uplink RD availability. When a downlink RD is coupled to an uplink RD, it should obey the uplink RD duty cycle, i.e., wake up just before the uplink RD broadcasts a beacon packet, receive it, and interpret the duty cycle information. Next, within the corresponding beacon interval, the downlink RD can send data only when the coupled uplink RD is awake; the rest of the time, the downlink RD can remain in standby mode. This operation is illustrated in Fig. 2(b).
- Down/uplink RDs follow both described procedures.

This way, each uplink RD is awake for only a fraction of its beacon interval, while the downlink RDs are required to be awake only to receive the corresponding beacon. The choice of the duty cycle interval is critical for RD power conservation and overall network performance.

B. Power Control

Power control is conventionally deemed efficient at reducing unwanted interference between different network RDs and further enhancing energy efficiency by reducing transmission power. In CIoT technologies it helps to ensure efficient spectral reuse while maintaining the constant error rate.

Efficient power control requires at least some degree of coordination between a downlink and the coupled uplink RDs. It is based on the power measurement of a beacon packet broadcasted by the coupled uplink RD – downlink RD assesses the path loss between the two devices by subtracting the measured received power from the announced transmission power in the beacon packet. The assessed path loss is then utilized for consecutive data transmission during this beacon interval. The data transmission power is calculated as

$$P_{\text{data}}^{\text{tx}} = P_{\text{noise}} + P_{\text{beacon}}^{\text{tx}} - P_{\text{beacon}}^{\text{rx}} + P_{\text{mcs}} + P_{\text{margin}}, \quad (1)$$

where P_{noise} is the noise power level on the chosen channel, $P_{\text{beacon}}^{\text{tx}}$ is the announced uplink transmission power for the latest beacon packet, $P_{\text{beacon}}^{\text{rx}}$ is the measured power of the received latest beacon packet, P_{mcs} corresponds to the SNR level needed for transmission for the chosen data MCS, and P_{margin} is a constant margin to offset any measurement errors. The uplink RD may then choose to match the transmission power for an acknowledgment packet or to use the full power for it. In this work, we will utilize the latter option.

C. Relay Selection Mechanism

For scalability reasons, RDs are allowed to choose the operational mode, either FT or PT, locally. Once RD in PT mode establishes a connection to an RD in FT mode, it can also start operating in FT mode to provide a link to other RDs. When designing the relay selection mechanism, one must account for several factors, including constrained RD power, network connectivity, and traffic performance.

In our implementation, each RD makes a local decision whether to switch to FT mode or not. The decision is based on a set of rules that are chosen to suit better a specific scenario and quality of service (QoS) requirements. When an RD decides to switch to FT mode, it should first make sure that it is coupled to an uplink RD in FT mode and then assess the environment for a specific period if there are no more than a specified number of other RDs in FT mode in the radio neighborhood. The number of other RDs in FT mode is a free parameter that needs to be chosen such that the network connectivity is provided at all times. Other devices in FT mode are only accounted for if the measured link quality to the RD meets the minimum link quality. The minimum link quality is based on the target data MCS. The length of the measurement period is chosen so that an RD can reliably receive at least one beacon packet from the neighboring RDs in FT mode and usually equals 3 beacon intervals.

D. Next-hop Selection Mechanism

DECT-2020 standard allows RDs to make autonomous routing decisions for each data packet. The next hop, however, needs to be chosen such that not only traffic service requirements are met, but the network is not overloaded.

Similarly to the relay selection mechanism, the next-hop selection is done locally on each RD. An RD is allowed to select the next hop at any time. However, it should initially execute the following procedure: (i) receive a broadcast beacon packet from another device in FT mode, (ii) assess the link quality based on the measured received beacon power and the announced beacon, (iii) discard the beacon packet if the link quality is below the minimum link quality. Then, if the RD currently has no next hop, it assigns the RD corresponding to the received beacon as the next hop. Otherwise, if the number of hops to the sink in the received beacon packet is less than the number of hops to the currently available next hop, the next hop is changed. If there is more than a single path to the sink having the same number of hops, the path with the best link quality is chosen.

IV. PERFORMANCE ASSESSMENT METHODOLOGY

In this section, we will describe the elements of the performance evaluation methodology. We will start with the employed SLS, illustrate the scenario, and discuss the data processing routines. Finally, the metrics of interest are introduced.

A. System-Level Simulation Tool

The complexity of the LBT-based channel access operating in a multi-hop communications environment forces the utilization of a system-level simulation tool for performance assessment of the considered relay and next-hop selection mechanisms. The system model has been implemented using the system-level simulation tool WINTERSim utilized during the standardization process of DECT-2020 technology [6]. To this aim, it has been extended to capture the specifics of the considered mechanisms under evaluation.

WINTERSim is a discrete event system-level (NS3-like) Python3 based simulation tool. For DECT-2020, we used node abstraction as the basic class for RDs, which contains all the node parameters (e.g., position, mobility model, antenna parameters, power) and serves as a container for L2 interfaces, forwarding implementation, flow tables, signaling engine, application handlers, traffic generators, physical layer interfaces, etc. To simulate such a high-density deployment, we implemented a particular physical layer abstraction that stores all the bidirectional path loss states between the RDs, having reception signal strengths higher than the noise level. During the simulation, all the components can gather component-specific and global statistics on packet deliveries, delays, power consumption, etc.

B. Considered Scenario

The simulation procedure starts with node placement and path loss calculations, done according to 3GPP guidelines [13]. The simulations have been performed according to urban macro-mMTC test Configuration A from ITU-R guidelines [14] with the exception of considering a single cell environment. RDs in TBSs are assumed to be equipped with omnidirectional antennas. As neither 3GPP nor ITU-R describes the procedure for calculating direct communications links specifically, we use different models for different types of links: for RD_{FT} -to-any we use the Urban macro model for $RD_{FT,PT}$ - RD_{PT} and $RD_{FT,PT}$ - $RD_{FT,PT}$ we used Urban Micro model if both RDs are indoor and closer than 25m we used Indoor Office (InH) model, for each indoor-to-outdoor penetration we also added random building penetration loss according to 3GPP model. The percentage of indoor devices is equal to 80. The simulation procedure consists of two periods: the “warm-up” period when all the RDs establish a tree topology using different biases, and the actual simulation. The default system parameters are provided in Table I.

C. Data Processing and Metrics of Interest

To gather the data and further calculate and obtain the metrics of interest, we employ the method replication procedure. For each set of parameters, we ran simulations 25 times, each time gathering 10^5 observations in the steady state. The steady-state period has been detected by utilizing the moving average statistics, and the data have been collected during this period only. Due to the large size of statistical samples, only the point estimates are shown.

TABLE I
CONSIDERED SYSTEM AND EVALUATION PARAMETERS

Parameter	Value
Simulation scenario parameters	
DECT-2020 NR FT	1, height 25 m, outdoors
Carrier frequency	1900 MHz
Number of channels	1
Channel bandwidth	1.728 MHz
Simulation area	radius of 170 m, 90800 m ²
Number of DECT-2020 NR RD	1000
DECT-2020 NR RD deployment	Uniformly random
Building penetration loss	20 dB (ITU-R)
Indoor/outdoor fraction	80% / 20%
Channel model, Sink-Node	Urban macro
Channel model, Node-Node	Urban street canyon
Number of node/sink antenna elements	1
Sink/UE noise figure	7 dB
Sink/UE antenna element gain	0 dBi
Thermal noise level	-174 dBm/Hz
Traffic model	Bursts of 2 packets
Application data message size	32 bytes
Mean inter-arrival time	10-50 s
Inter-arrival time distribution	Exponential
Channel access	LBT + extensions
Contention window size	min – 24, max – 768
LBT threshold	-75 dBm, -100 dBm
Minimum link quality	15 dB
Error correction	HARQ with 3 attempts
Sensitivity	-99.7 dBm (TS 103.636-2)
Tx power	10/19/23 dBm
Format	MSC 1,3,4 for 1,2,3 packets

As metrics of interest, we consider PLR and the fraction of packets delivered within 10 s to the sink. These metrics are utilized as a main traffic performance indicator in [8]. The power consumption of the routers is accounted for implicitly by trying to keep the number of FT devices at a minimum.

V. NUMERICAL RESULTS

In this section, we numerically evaluate the considered relay and next-hop selection schemes. We start with the impact of the energy conservation mechanism and then proceed to assess its effects jointly with power control, relay- and next-hop selection mechanisms. The default system and scenario parameters are provided in Table I.

We start with the energy conservation mechanism. The obtained results are shown in Fig. 4 as a function of the packet generation period for different values of the duty cycle time and the time RD is active during the duty cycle. The chosen parameters of duty cycle and active window of 4000/2000 ms and 500 ms, respectively in Fig. 4(a) are sufficient to handle the arrival traffic in the system. By decreasing the active window during the duty cycle from 0.5 s to 0.2 s (see Fig. 4(b)), the drop in performance is around 10% for both duty cycle duration in terms of the fraction of delivered packets for the packet generation period of around 100 s. Specifically for the drop in the considered metric is around 10% for (4000, 200) ms duty cycle and active window pair reaching 18% for (2000, 200) ms pair. This highlights that the system performance is sensitive to both considered parameters, i.e., 200 ms active window duration is too short to handle

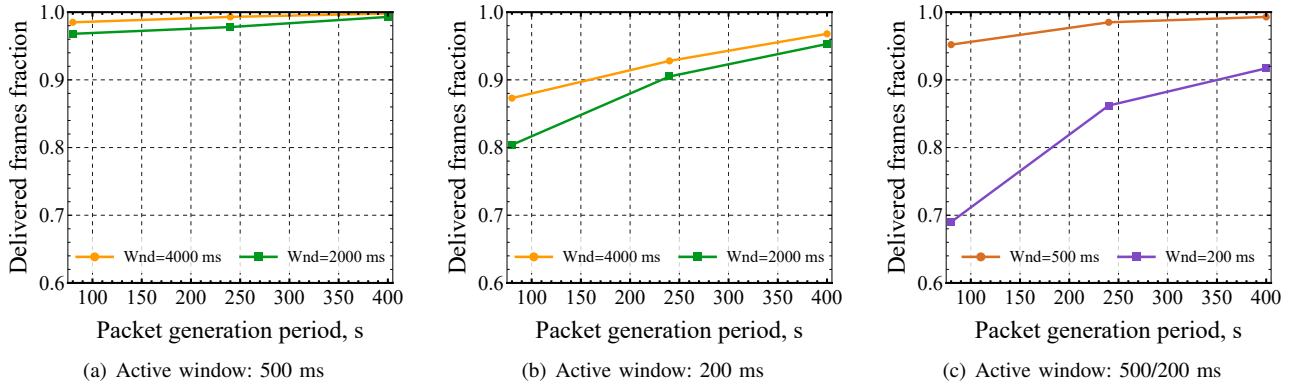


Fig. 4. The delivered packet fraction as a function of different sleep patterns.

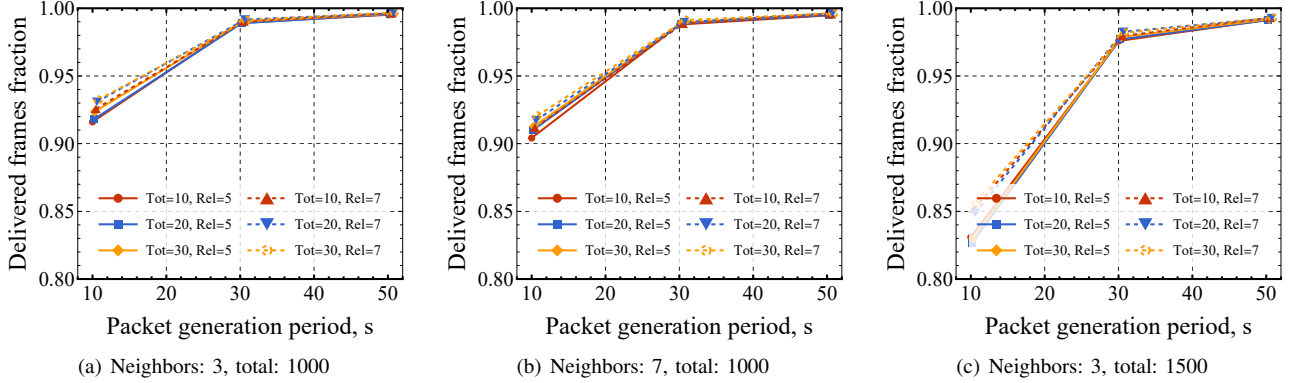


Fig. 5. Delivered packet ratio as a function of different number of relays and the number of RDs.

the arrival traffic and increasing the duty cycle from 2000 ms to 4000 ms decreases the amount of available resource even further. In general, we conclude that the DECT-2020 system is highly sensitive to the choice of these parameters. Results shown in Fig. 4(c) further illustrate that uneducated choice of these parameters could make the difference between good and unacceptable network performance. As these parameters also heavily depend on the RD density and network size, simple analytical models are needed to establish them, or they have to be set with caution, compromising the energy efficiency in favor of network performance.

Now, we proceed to investigate the impact of the relay selection procedure parameters. To this aim, Fig. 5 shows the delivered packet ratio as a function of the packet generation interval for a different number of relay nodes in the radio neighborhood, the number of RDs that can be associated with a single relay, and the overall number of RDs in the system. Here, we assume that leaves and relays are always active. As one may observe, the former two parameters provide insignificant impact on the considered metric. Specifically, by varying the number of RDs that can be associated with a single relay from 10 to 30, the observed performance difference is well within 2% for the packet generation period of 10 s. For the same traffic conditions (Fig. 5(a) and Fig. 5(b)), the increase in the number of relay nodes in the radio neighborhood results in a difference upper bounded by 3%. For a smaller packet generation period, e.g., 30 s, the impact

is non-detectable. The rationale is that for a given number of RDs in the system (1000) and considered deployment the value of 10 is sufficient to provide associations for all RDs.

The most impact, however, is observed by increasing the number of RDs in the system from 1000 to 1500 nodes, i.e., increasing the network density and load by 50% and leaving the deployment area intact. By cross-comparing the results shown in Fig. 5(a) and 5(c), we observe a 7-9% difference in the delivered packets fraction for 10 s of packet generation period and the same number of relay nodes in the radio neighborhood and the number of RDs that can be associated with a single relay. The difference remains noticeable even for a packet generation period of 30 s, which amounts to 2-3%. These observations, however, are mainly explained due to the increased system load.

Finally, we evaluate the impact of the power control option on the fraction of the successfully delivered packets illustrated in Fig. 6 for different maximum numbers of neighbors, connected relays, and total connected RDs. By cross-comparing the presented illustrations, one may observe that the power control allows for improvement in the fraction of delivered packets by approximately 1-3% depending on the parameters for the point where the system starts to be overloaded – packet generation period of 10 s. For less frequent traffic arrival process, e.g., 20 s between packet generation, the gain of power control is even smaller and generally less than 1%. These results show that although the use of power control

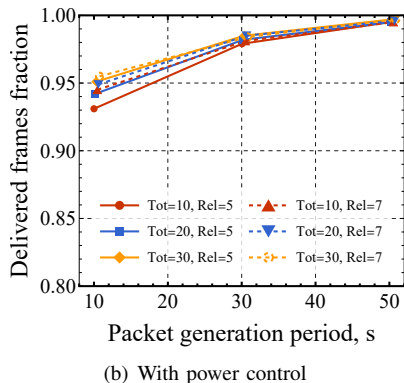
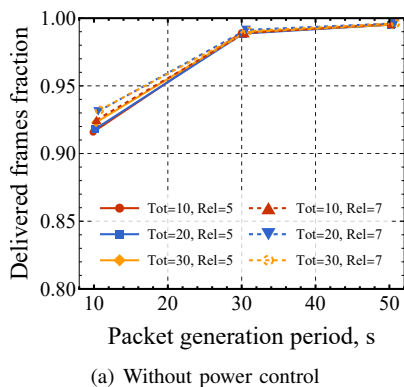


Fig. 6. The impact of the power control.

is beneficial for an overloaded regime of the system, the LBT mechanism utilized by DECT-2020 is reliable enough to efficiently combat interference at conventional loads even in dense network conditions.

VI. CONCLUSIONS

DECT-2020 NR is a recently standardized mMTC enabler satisfying the IMT-2020 5G performance requirements. However, the standard does not specify several critical mechanisms and/or makes some of those optional. Motivated by this, in our paper, we evaluated the impact of energy conservation patterns, power control, relay, and next hop selection mechanisms on the packet delivery performance in DECT-2020 system.

Our numerical results indicate that the impact of the sleep patterns in both routers and RDs have a linear impact on the system capacity, implying that the system can adapt well to different traffic conditions. The impact of relay selection mechanisms is relatively negligible in dense network conditions and generally depends on the number of connected RDs and relays having a packet to the sink. Specifically, the impact of the network density is an order of magnitude more significant as compared to the relay node selection parameters. Finally, power control has a mild effect on the packet delivery ratio, allowing it to improve it by around 3% even in dense network conditions. These observations highlight that DECT-2020 offers robust solutions suitable for different network deployments and the implementation of optional mechanisms.

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REFERENCES

- [1] A. Khanna and S. Kaur, "Internet of things (iot), applications and challenges: a comprehensive review," *Wireless Personal Communications*, vol. 114, no. 2, pp. 1687–1762, 2020.
- [2] M. R. Palattella, M. Dohler, A. Grieco, G. Rizzo, J. Torsner, T. Engel, and L. Ladid, "Internet of things in the 5G era: Enablers, architecture, and business models," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, pp. 510–527, 2016.
- [3] H. Fattah, *5G LTE Narrowband Internet of Things (NB-IoT)*. CRC Press, 2018.
- [4] L. Chettri and R. Bera, "A comprehensive survey on internet of things (IoT) toward 5G wireless systems," *IEEE Internet of Things Journal*, vol. 7, no. 1, pp. 16–32, 2019.
- [5] ETSI, "DECT-2020 New Radio (NR); Part 1: Overview," ETSI, TS 103 636-1 v1.3.1, December 2021.
- [6] R. Kovalchukov, D. Moltchanov, J. Pirskanen, J. Säe, J. Numminen, Y. Koucheryavy, and M. Valkama, "DECT-2020 New Radio: The Next Step toward 5G Massive Machine-Type Communications," *IEEE Communications Magazine*, vol. 60, no. 6, pp. 58–64, 2022.
- [7] A. Anttonen, P. Karhula, M. Lasanen, and M. Majanen, "Enabling Massive Machine Type Communications with DECT-2020 Standard: A System-Level Performance Study," 2021.
- [8] ITU-R, "Minimum requirements related to technical performance for IMT-2020 radio interface," ITU-R, M.2410-0, July 2017.
- [9] ETSI, "DECT-2020 New Radio (NR); Part 2: Radio reception and transmission requirements; Release 1," ETSI, TS 103 636-2 v1.3.1, December 2021.
- [10] —, "DECT-2020 New Radio (NR); Part 3: Physical layer; Release 1," ETSI, TS 103 636-3 v1.3.1, December 2021.
- [11] —, "DECT-2020 New Radio (NR); Part 4: MAC layer; Release 1," ETSI, TS 103 636-4 v1.3.1, December 2021.
- [12] A. Samuylov, D. Moltchanov, J. Pirskanen, J. Numminen, Y. Koucheryavy, and M. Valkama, "Performance assessment of dect-2020 nr and classic dect coexistence mechanisms," in *2023 IEEE 97th Vehicular Technology Conference (VTC2023-Spring)*. IEEE, 2023, pp. 1–7.
- [13] 3GPP, "Study on channel model for frequencies from 0.5 to 100 GHz (Release 14)," 3GPP TR 38.901 V14.1.1, July 2017.
- [14] ITU-R, "Guidelines for evaluation of radio interface technologies for IMT-2020," ITU-R, M.2412-0, July 2017.