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DB-LBT: Deterministic Backoff with Listen Before Talk for Wi-Fi/NR-U Coexistence in Shared Bands

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***Abstract*—The legacy approach to solve coexistence problems between multiple wireless networks operating in the same frequency bands is through network planning. However, this approach is often unfeasible in unlicensed (shared) bands, where different network owners and technologies work without any coordination. In this paper, we adapt an existing channel access scheme for fair resource sharing between Wi-Fi and NR-U (the unlicensed version of 5G), in a completely distributed manner. The idea is to find an ordered schedule of transmissions granted to the active transmitters (regardless of their technology) and repeat this schedule in a round-robin fashion until the set of active transmitters changes. The mechanism works as a special extension of a random access scheme with deterministic backoff counters. Simulation-based results prove that the scheme guarantees airtime fairness between network cells and technologies while optimizing channel efficiency and minimizing channel access delays. Unlike other coexistence solutions, the scheme does not require the exchange of information between the coexisting cells; moreover, it is backward compatible with legacy access schemes.**

***Index Terms*—Coexistence, deterministic backoff, fairness, IEEE 802.11ax, NR-U, Wi-Fi.**

I. Introduction

The coexistence of different radio technologies, including IEEE 802.11 (Wi-Fi) and cellular technologies (LTE LAA, NR-U) in shared (unlicensed) bands has been a vivid research topic for several years. Researchers address this problem using standard engineering methods [1]–[3] and machine learning-based methods [4]. Recent focus has been given to the coexistence of Wi-Fi (the predominant technology in shared bands) with LTE LAA and NR-U (the unlicensed versions of 4G and 5G, respectively) [5]. Channel access for both technologies is partially similar: both use intra- and inter-network collision avoidance based on a clear channel assessment (CCA) approach with exponential backoff, standardized by ETSI as listen before talk (LBT) [6]. However, in contrast to the fully random access operation of Wi-Fi, NR-U base stations (gNBs) must start their transmissions at the beginning of a synchronization slot boundary [7]. This requirement originates from the fully synchronized operation of NR in licensed bands. Therefore, NR-U implements two different channel access types: reservation signal-based access (RSA) and gap-based access (GA) [7]. In RSA, gNBs transmit reservation signals after winning channel access to keep the channel busy until the beginning of the next slot boundary. In GA, gNBs for which the backoff counter equals zero wait an additional time interval to reach the synchronization slot boundary and start transmitting if the channel is still idle. It has been shown that legacy RSA allows for fair coexistence with Wi-Fi nodes at the expense of additional overhead, while legacy GA is fair only under short synchronization periods [7].

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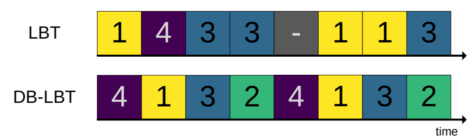


Fig. 1: Exemplary channel access sequence for four contending nodes using LBT (top) and DB-LBT (bottom). Colors and numbers refer to a node's successful transmission, the dash – to a collision. The sequence for LBT is taken from simulation (Section V). LBT's random access leads to short-term unfairness and collisions. DB-LBT finds a round-robin transmission schedule that improves fairness and reduces collisions.

Our recent work shows how to improve the coexistence fairness of gap-based NR-U nodes and Wi-Fi nodes [8] using contention window (CW) optimization. In fact, by compensating for the additional waiting times of gNBs, it is possible to opportunistically increase the CW values used by Wi-Fi nodes as a function of the number of co-existing cells and the length of the synchronization periods. In some scenarios, the optimal CW value can be higher than the maximum value considered in the legacy protocol. In this paper, we consider a different approach for the coexistence between Wi-Fi and NR-U cells, which does not require knowing the length of the NR-U synchronization period or to estimate the number of coexisting cells belonging to each technology. Our scheme, deterministic backoff for listen before talk (DB-LBT), is designed to find an ordered schedule of transmissions for active transmitters, regardless of their technology (Fig. 1). Once the schedule is found, all the transmitters use the same deterministic backoff counter (whose decrement starts right after their transmission grant) to repeat the same schedule over time, until a new transmitter enters the network or an active transmitter leaves the network. NR-U base stations implement reservation signals to keep their transmission schedule at the reset of the deterministic backoff counters.

The idea of deterministic backoff has already been proposed in the literature to minimize contention and collisions in CSMA/CA-based networks (Section II). To the best of our knowledge, this scheme has not been used before to improve the coexistence of heterogeneous technologies. However, we think that it can be an interesting approach to achieve fair sharing of channel access resources while guaranteeing a low collision rate. The main contributions of this paper are:

- a detailed review of the state of the art related to different deterministic backoff implementations proposed for IEEE 802.11 networks (Section II),
- DB-LBT – a listen before talk channel access scheme based on deterministic backoff (Section III) for fair channel access of different radio technologies in shared bands, e.g., NR-U and Wi-Fi (Section IV),
- the performance analysis of DB-LBT for static (constant number of nodes over time), dynamic (new nodes appear in the network in time), and mixed (nodes implementing DB-LBT coexist with legacy nodes implementing exponential backoff) scenarios (Section V).

Finally, conclusions are drawn in Section VI.

II. State of the Art

The idea of deterministic backoff attracted researchers' attention several years ago as a remedy to high contention in CSMA/CA-based networks. A summary of the most important solutions is given in Table I. Many proposals assume a deterministic backoff when observing successive successful transmissions and random backoff in case of collisions. The majority of works propose simple, distributed approaches, without any additional information to be sent between nodes. However, sometimes beaconing is necessary to ensure correct operation [10], [20]. In addition, a controller is employed to ensure synchronization [20]. Alternatively, the role of the AP is exploited to allocate the backoff counter to be used by each station [22]: after each successful uplink transmission, in case stations indicate that more packets are enqueued, the AP inserts the backoff counter value to be assigned to the station for the next channel access inside the acknowledgment frame. The counter is randomly extracted by the AP, but new extractions are performed to avoid collisions with previous allocations.

In most cases, the proposed solutions are evaluated using analytical and simulation models. The implementation of the proposed methods in real devices is less common. Authors usually show that the proposed approaches outperform the legacy CSMA/CA procedure (which is composed of CCA and exponential backoff), mostly in terms of throughput, collision probability, and delay.

To the best of our knowledge, deterministic backoff has not yet been considered to solve the problem of coexistence of unlicensed technologies. However, we believe that it is well suited to improve channel efficiency in the case of Wi-Fi vs NR-U. In this paper, we focus on downlink transmissions, and leave uplink transmissions for future study. Therefore, we assume that APs and gNBs are the only contenders. We argue that the proposed idea can be *unified for both technologies*, as opposed to the recently introduced:

- coexistence mechanisms that focus on collision resolution between gNBs [3],
- machine learning-based solutions, which adjust the operation of 3GPP unlicensed technologies (e.g., optimal duty cycling) to coexist with IEEE 802.11 [4].

Additionally, we avoid introducing (i) additional control overheads, as opposed to [23], [24], (ii) traditional time sharing of available resources, as opposed to [25], (iii) CW tuning, as opposed to [26], [27], to provide a simple yet effective general coexistence mechanism.

Among the proposed deterministic backoff solutions, we find the one proposed in [21] (which we refer to as DB throughout the remainder of the paper) to be the most promising one for the problem of multi-technology coexistence. The scheme achieves a round-robin deterministic schedule (Fig. 1), with the only extension being the use of reservation signals during the transmission attempts of NR-U nodes. It is fully distributed, simple to implement (all nodes can count their backoff freezes and do not need to read the information in the packet headers), and effective. Additionally, it was already validated for: DB-enabled nodes coexisting with legacy IEEE 802.11 stations, overlapping basic service sets, the presence of hidden nodes, and QoS-enabled networks. Finally, it is simple to implement. Therefore, with such a mature DB design, the open challenge remains how to adapt it to improve coexistence of heterogeneous radio technologies, which we face in this paper.

III. Deterministic Backoff

DB is based on general LBT principles, except that the backoff is mostly deterministic rather than random. Algorithm 1 shows the main rules of the deterministic backoff algorithm proposed in [21]. A node, when it sends its first frame, selects the backoff counter value $b = \alpha$, where α is the initial deterministic backoff value. Then, whenever the medium is idle for a predefined amount of time (the, arbitration inter-frame spacing, AIFS), the node decrements its backoff counter according to the standard LBT procedures. However, if the backoff countdown is interrupted, the node additionally increments the interrupt counter i, which signifies the number of CCA busy events during the backoff countdown. This number is then used during the process of selecting a new

TABLE I: Deterministic backoff schemes for scheduling uplink (UL) and downlink (DL) traffic in random access wireless networks. Evaluation types: analytical (A), simulation (S), experimental (E).

Key	Name	Details	QoS	Test scenarios	Conditions	Evaluation	Year
[9]	ZC	In case of success, the station chooses a fixed backoff. In the event of a collision, the station checks the slot occupancy in the previous schedule and randomly selects an empty one.	Yes	over 150 stations, carrier sensing errors, hidden and exposed nodes	saturation	A, S	2008
[10]	Z-MAC	Combines time division multiple access (TDMA) and carrier sense multiple access (CSMA). Access point (AP) assigns a slot to each station; however, other stations can borrow this slot if it is not used by the owner (this process is contention-based). Z-MAC needs extra information to be sent in beacons. Introduces high complexity, .e.g., neighbor discovery, global time synchronization.	No	up to 42 stations, multi-hop setting, hidden nodes	saturation, non-saturation	E, S	2008
[11]	L-BEB	Stations perform a random search to find empty slots. Stations use deterministic backoff after each successful transmission and return to random backoff after each collision.	No	up to 40 nodes, perfect channel	saturation, non-saturation	A, S	2009
[12]	CSMA/ECA						2009
[13]							2010
[14]	CSMA/ECA	Extends [12] with QoS support.	Yes	up to 20 nodes, perfect channel	saturation, non-saturation	A, S	2009
[15]	SRB	Stations use deterministic backoff after each successful transmission. In case of a collision, stations perform random backoff and search for new empty slots. Traffic differentiation is realized with different deterministic backoff values for each access category (AC).	Yes	UL, up to 30 nodes, multi-hop setting (hidden and exposed nodes, channel errors)	saturation, non-saturation	A, S	2013
[16]	L-ZC	A modification of ZC [9], which uses learning to achieve collision-free schedules. First stations choose their slots uniformly from all available slots. After a successful transmission or when the slot is idle (i.e., station does not transmit), the slot is used by the next station in the schedule. Otherwise, it randomly chooses a slot: the old with probability γ and the new with probability $(1-\gamma)$ from the idle slots available.	No	from 8 to 20 stations, channel errors	non-saturation	A, S	2013
	L-MAC	A modification of L-BEB [11], which determines the probability of choosing each slot in a periodic schedule $\{1,\dots,C\}$. Each station updates its probability vector after each successful transmission (sets the probability of this slot to 1, and 0 for all other slots) or failure (reduces the probability of transmitting in the same slot by β). Each station selects backoff (b) as follows: on success $b=C$, and on failure $b=C-s(n)+s(n+1)$, where $s(n)$ is the selected slot.					
[17]	CSMA/ECA	Extends previous works related to CSMA/ECA. Three versions of the algorithm are given: CSMA/ECA, CSMA/ECAHys+FS (with multiple packet dropping to achieve fair share of medium access), Schedule Reset Mechanism for CSMA/ECAHys+FS (it is used to find the smallest collision-free schedule between a contender's transmissions and then change the node's deterministic backoff to fit in that schedule).	No	up to 70 contenders, hidden nodes, channel errors	saturation, non-saturation	A, S, E	2016
[18]	CSMA/ECA	Extends [17] to support QoS	Yes	up to 50 nodes, perfect channel for saturation, channel errors for non-saturation	saturation, non-saturation	S	2018
[19]	AB	First, station grouping is performed by the AP. Then, backoff timer is set in ascending order of association identifiers (AIDs) of the group members. After successful transmissions, backoff is set to the number of stations in a group.	No	UL, AP with uniformly distributed nodes, hidden nodes, channel errors	saturation, non-saturation	A, S	2019
[20]	HA	Based on [16], requires synchronization. Slot reservation tables store neighbors' transmission sequence numbers. First, backoff is chosen from $(0, CW]$. After a successful transmissions, sequence numbers are assigned to each node. For the next transmission, backoff is set to $j+(j-1)\times\theta$, where θ is the interval of two adjacent reservations.	No	up to 120 vehicles, one-way traffic	saturation, non-saturation	S	2021
[21]	DB	Based on EDCA. Assumes round-robin ordering of stations. Each backoff interruption is interpreted as the presence of another node. In case of repeated collisions, it uses a random backoff approach to find an idle slot.	Yes	DL traffic if more than one AP cluster, DL/UL traffic if one AP cluster, hidden nodes	saturation	S	2021

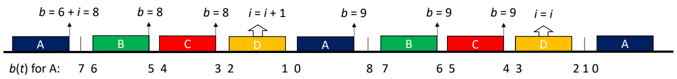


Fig. 2: Channel access for four contending nodes using DB. The initial backoff value α is set to 6.

backoff value. An interruption in backoff is interpreted as the presence of another node; including interruptions in the setting of the backoff counter allows for quick scaling of the backoff as a function of the number of active nodes.

When b is decremented to zero, the node starts a transmission. If the transmission is successful, the node sets the retransmission counter $r = 0$ and selects a new backoff value (if pending frames are waiting in the transmission queue). In the event of a collision, the node increments the retransmission counter r and selects a new backoff value. If the number of retransmissions modulo the m parameter (which determins how often we switch between selecting a deterministic or a random backoff for consecutive collisions) is lower than the β threshold, the node sets $b = \alpha + i$ and sets $i = 0$, otherwise the node selects a random backoff value from the range $[0, m-1]$ and does not change the i value. This procedure is repeated until a successful frame transmission or a frame drop. Additionally, the β threshold is used to speed up convergence under high contention. For example, when $\beta = 3$ and $m = 7$, deterministic backoff will be used for $r = 1$ or $r = 2$ (i.e., twice every seven consecutive collisions). During the DB countdown, i will increase for every CCA busy event. This procedure will increase the size of the next deterministic backoff.

Fig. 2 shows the solution proposed in [21]. The deterministic backoff counter set by a reference node at the end of a transmission is given by the sum of two values: a fixed value that represents the number of idle slots left in the schedule for incoming nodes (α) and a variable value i representing the number of backoff freezes experienced in the previous countdown. Assuming that the schedule of three nodes (labeled A, B, and C) was already found, node A has a value i equal to 2 at the end of its first transmission attempt. Since all nodes employ the same backoff counters starting from the end of their previous transmission, they can repeat the same order of transmissions, without any collision. When a new node D performs its first random access, nodes A, B, and C increase their backoff counter by one (because they notice an additional interruption during their backoff countdown, therefore $i = 2 + 1$ and $b = 6 + 3 = 9$), leaving space for the new node in the deterministic backoff schedule while keeping the same number of idle slots (i.e., $\alpha = 6$) for other incumbents. Only the first transmission attempt for node D is random; although at the first attempt the i value depends on the number of transmissions seen by node D during the first backoff countdown, we have observed that the scheme converges (a formal proof is left for future study).

Algorithm 1 Deterministic backoff rules

Initialize: $i \leftarrow 0$, $b \leftarrow 0$, $r \leftarrow 0$, m, β, α
Select a new backoff value
if $r \mod m < \beta$ **then**
  $b \leftarrow \alpha + i$
  $i \leftarrow 0$
else
  $b \leftarrow \text{rand}(0, m-1)$
  $i \leftarrow i$
end if

Decrement b using the standard EDCA procedure
while $b > 0$ **do**
  for each backoff countdown interruption **do**
    $i \leftarrow i + 1$
  end for
end while

Transmit data when $b = 0$
Increment r after collision
Reset r after successful transmission

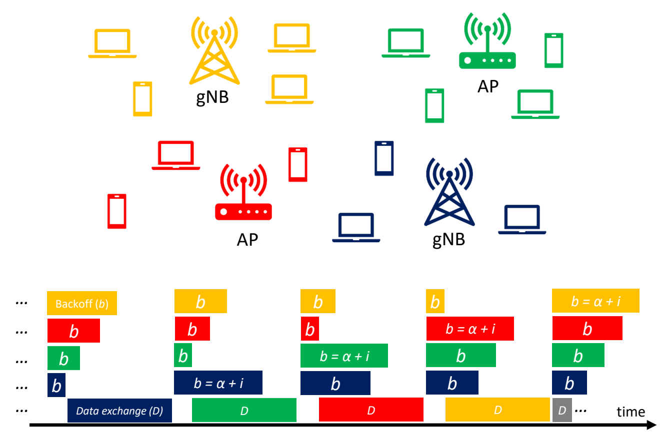


Fig. 3: DB-LBT coexistence example.

IV. Proposed Coexistence Scheme - DB-LBT

In this paper, we propose that coexisting APs and gNBs use a similar deterministic backoff procedure as described in Section III, which we call DB-LBT. In the proposed scheme, each AP/gNB observes the channel state (with the LBT mechanism) and counts interruptions during the backoff countdown. Additionally, we focus on downlink transmissions, i.e., transmissions initiated by APs and gNBs. Furthermore, we assume that after the channel is accessed, APs start transmitting data, and gNBs start either a reservation signal transmission (awaiting the beginning of the synchronization slot boundary) or a data transmission (if the backoff is decreased to zero exactly at the beginning of the NR-U synchronization slot).

An exemplary operation of the envisaged DB-LBT NR-U/Wi-Fi coexistence is shown in Fig. 3. In this example, two APs and two gNBs contend for the channel. After the

TABLE II: Default simulation parameters

Parameter	Value
Operation band	5 GHz
Wi-Fi AP CWmin, CWmax	15, 63
NR-U gNB CWmin, CWmax	15, 63
Wi-Fi transmission duration	2 ms
NR-U transmission duration	2 ms
NR-U synchronization slot duration	250 µs
DB-LBT m parameter	4
DB-LBT retransmission threshold β	3
DB-LBT initial backoff α	11

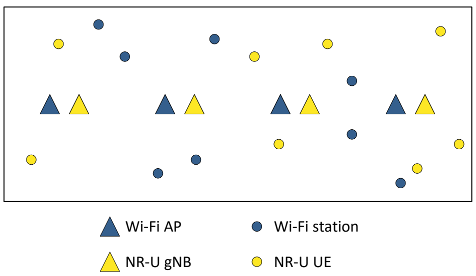


Fig. 4: Default simulation scenario: 3GPP indoor.

convergence of DB-LBT, each AP and each gNB selects a deterministic backoff value ($b = \alpha + i$, where $i = 3$ since each node observes three interruptions during their backoff countdowns). This schedule will be repeated by the nodes and collisions will be avoided.

Additionally, the initial backoff value α allows for empty channel space, e.g., for legacy devices or arriving nodes supporting DB-LBT, since nodes using the deterministic backoff schedule will never select $b < \alpha$. This situation is depicted with the gray rectangle in Fig. 3. If a new node appears, it is allowed to access the channel. This happens without damaging the DB-LBT schedule since when the new node starts transmitting data (cf. the gray rectangle in Fig. 3), all APs and gNBs using DB change the deterministic backoff value by one, i.e., $b = \alpha + i + 1$, after noticing an additional CCA busy event during their backoff countdown.

V. Performance Analysis

We evaluate the performance of DB-LBT by extending a proprietary Monte Carlo simulator written in Matlab, previously used and verified both analytically [8] and experimentally [7]. The simulator implements only the channel access rules for Wi-Fi and NR-U by iterating over *contention rounds*. Each round consists of a waiting period (mainly the backoff countdown) and a transmission period. We consider perfect channel conditions, network saturation (full buffer model), no hidden nodes, downlink transmissions (unless indicated otherwise), and that NR-U uses RSA. Furthermore, Wi-Fi data frames are followed by acknowledgment frames, while NR-U acknowledgments are sent over the licensed channel. Each simulation run consists of 10^5 contention rounds.

We measure the following performance metrics:

- **normalized effective airtime** – the total channel occupancy time related to effective data transmission (i.e., excluding acknowledgements for Wi-Fi and reservation signals for NR-U) related to successful transmissions of either technology, normalized to the total simulation time,
- **channel access delay** – the time between the end of a successful transmission by a node and the beginning of the next successful transmission.

The **normalized effective airtime** metric shows the portion of wireless resources used by each radio technology. If the effective airtime values for the coexisting technologies are close to each other, this indicates high airtime fairness.

Additionally, to illustrate the backoff convergence properties of DB-LBT, we present the evolution over time of the backoff values selected by each node. For clarity of presentation, instead of directly reporting simulation time, we discretize time into the simulator's contention rounds, the average duration of which is slightly larger than the transmission duration used (2 ms in our case).

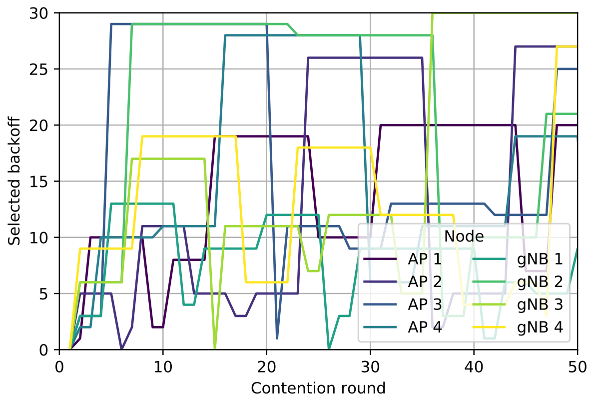
Fig. 4 and Table II show the default simulation topology and parameters, respectively. For a fair comparison, we set the transmission durations of Wi-Fi and NR-U to the same value. Since we assume a perfect physical layer and report airtime instead of throughput, our simulator is compatible with the basic channel access scheme of all mainline 802.11 amendments, i.e., 802.11a/b/g/n/ac/ax. Therefore, the chosen transmission duration corresponds to, e.g., a 1500 B 802.11a frame at 6 Mb/s or a 22 kB aggregated 802.11ac frame at 86.7 Mb/s. To reduce the impact of reservation signal overhead, we set the NR-U synchronization slot duration to 250 µs, the lowest value available in the 5 GHz band [28].

A. Static Scenario

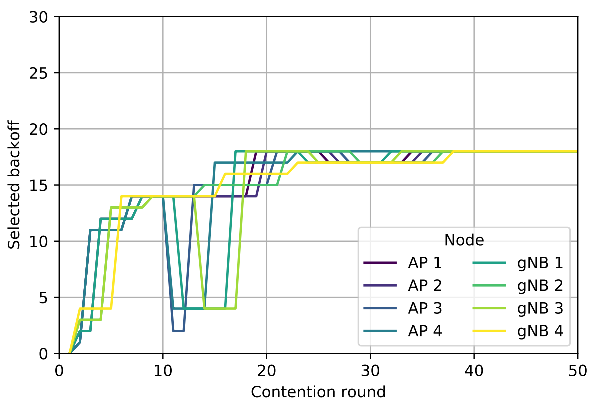
We analyze a static scenario, i.e., where the number of transmitting nodes is constant over time. Initially, there are four transmitting nodes of each technology (Fig. 4). Fig. 5 presents the evolution of selected backoff values when all transmitting nodes use either LBT or DB-LBT. In the former case, we see the random backoff selection of LBT. Nodes that select high backoff values (e.g., AP 3 and gNB 2) are penalized in accessing the channel. This leads to short-term unfairness, a well-known phenomenon of 802.11 [29]. Meanwhile, DB-LBT can converge to a predictable value[1] in less than 40 contention rounds. The chosen backoff value remains fixed unless circumstances change (which is not the case in the static scenario considered).

One of the benefits of DB-LBT lies in reducing jitter, i.e., equalizing channel access delay. Fig. 6 presents the empirical cumulative distribution function (CDF) of delay for the two cases (all nodes use LBT or all nodes use DB-LBT). Although LBT gives the possibility of short delays, long delays also occur. On average, DB-LBT's delays are smaller and DB-

[1] This value is the sum of the initial backoff α and the number of transmitting nodes minus one (because nodes do not record their own transmission when incrementing i.)



(a) LBT



(b) DB-LBT

Fig. 5: Evolution of backoff in the 3GPP indoor scenario.

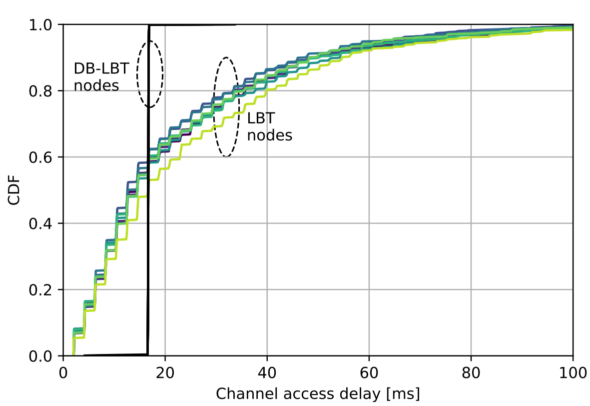
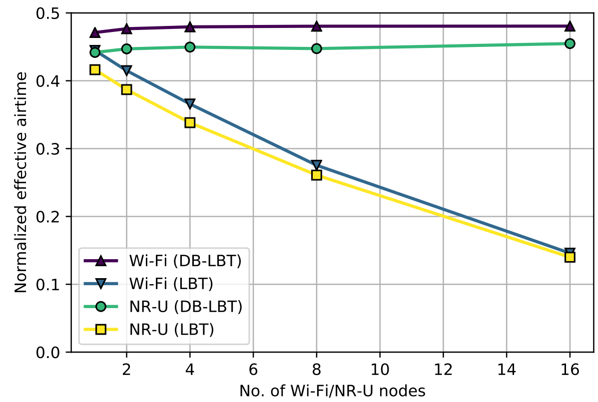


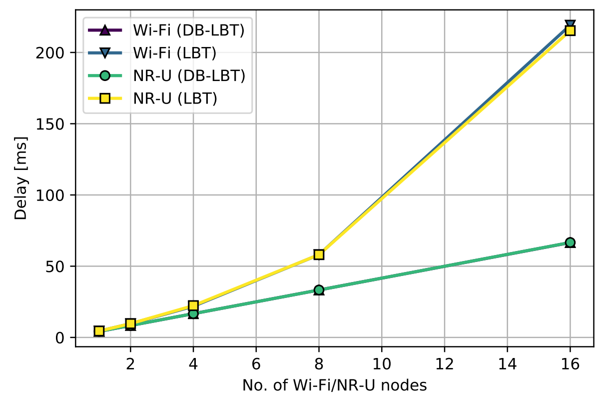
Fig. 6: Empirical CDF of channel access delay in the 3GPP indoor scenario.

LBT provides greater fairness in channel access for contending nodes.

Next, we study the performance when the number of contending nodes increases. We increase the number of nodes symmetrically so that there is always the same number of transmitting APs and gNBs. Fig. 7a presents the per-technology airtime when either all nodes use LBT or all nodes



(a) Effective airtime



(b) Channel access delay

Fig. 7: Performance in a static coexistence scenario for an equal number of APs and gNBs in two cases: all nodes use LBT or all nodes use DB-LBT. The 3GPP indoor scenario corresponds to 4 on the X-axis.

use DB-LBT. Both LBT and DB-LBT provide airtime fairness for both technologies. The slightly lower airtime for NR-U is caused by the need to transmit an RS at the beginning of each transmission to align with the slot boundary[2]. For LBT, the increased number of nodes causes collisions, which leads to a large drop in effective airtime. Meanwhile, DB-LBT can maintain network efficiency regardless of the number of nodes[3]. Similarly, for channel access delay (Fig. 7b), the delay using LBT increases exponentially while DB-LBT manages to maintain a linearly increasing delay.

B. Dynamic Scenario

We next show DB-LBT's performance in a dynamic scenario, where the number of contending nodes changes over time. We again consider the 3GPP indoor topology (Fig. 4) but enable the APs/gNBs every 10 contention rounds ($\approx$ 20 ms) to

[2]Fairness would not be achieved if NR-U used the alternative gap approach, which requires other solutions [8].

[3]With more nodes the convergence time increases. This duration can be optimized with the parameters of DB-LBT (α, β, m) but we leave this for future study.

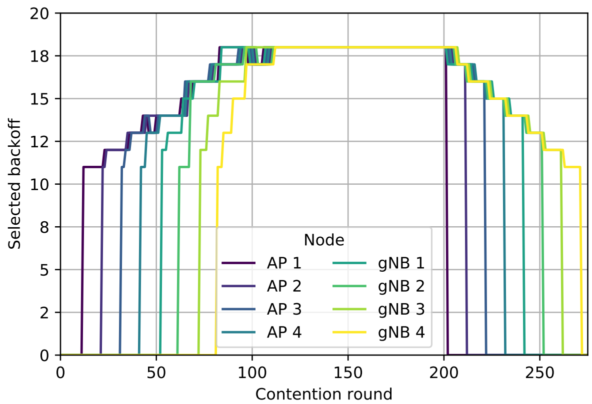


Fig. 8: Backoff evolution in a dynamic 3GPP indoor scenario: nodes join every 10 contention rounds (≈ 20 ms) and transmit for 200 contention rounds (≈ 400 ms).

transmit for a further 200 contention rounds (≈ 400 ms). Fig. 8 shows how the selected backoff evolves at each node. In the startup (shutdown) phases we clearly see brief periods where the selected backoff remains unchanged. Only nodes joining (or leaving) the network influence a change in the selected backoff. Also, the backoff of nodes joining the network quickly merges with that of the already transmitting nodes. These observations confirm that DB-LBT can quickly converge regardless of whether nodes join or leave the network.

C. *Legacy Scenario*

The newly opened 6 GHz band represents a greenfield scenario and the operation of Wi-Fi/NR-U in this band could follow modified rules [30], such as the proposed DB-LBT. In the 5 GHz band, however, nodes following DB-LBT would be forced to coexist with nodes following legacy LBT. Since Wi-Fi is the predominant technology in the 5 GHz band, these legacy nodes would mainly be IEEE 802.11 APs and stations. Therefore, we study the performance of DB-LBT in the presence of legacy nodes: we compare the performance of a configuration where all nodes use LBT (the baseline) with a configuration where APs and gNBs using DB-LBT contend with legacy Wi-Fi nodes. To reduce the configuration space, we always have an equal number of (non-legacy) APs, gNBs, and legacy nodes. The latter can either be IEEE 802.11 APs (with CWmax of 63) or IEEE 802.11 stations (with CWmax of 1023)[4].

Fig. 9 presents the effective airtime for the two configurations ("All LBT" and "DB-LBT + LBT"). The total effective network airtime always drops with the increase in the number of stations, but less so for the configuration with DB-LBT than when all nodes use LBT. Furthermore, if the legacy nodes are stations (with a higher CWmax), DB-LBT achieves a normalized effective airtime above 0.8 even for $3 \times 2^3 = 24$ nodes. In terms of the distribution of airtime between the three node types:

[4]The CW values are configured according to the IEEE 802.11 standard [7].

- If the legacy nodes are APs, DB-LBT APs and DB-LBT gNBs achieve a similar airtime share (fairness), which is also similar to what legacy APs achieve in the "All LBT" configuration. This means that the airtime increase when switching to DB-LBT is given to the legacy nodes.
- If the legacy nodes are stations, they achieve airtime similar to that of the "All LBT" case. The airtime increase when switching to DB-LBT is given to the DB-LBT nodes. This gain increases up to 24 nodes in the network (legacy stations lose their airtime share because of doubling their CW up to CWmax) and decreases for higher values (because of increased overall network contention). The chosen DB-LBT parameters may impact this behavior, which we leave for further study.

We conclude that DB-LBT is a fair neighbor for LBT in downlink transmissions: legacy Wi-Fi stations are not significantly worse off and legacy Wi-Fi APs are better off with DB-LBT nodes present. For uplink, the use of DB-LBT with trigger-based channel access is worth investigating.

VI. Conclusions

In this paper, we have analyzed different approaches to provide deterministic channel access in IEEE 802.11 networks. We have selected the best candidate to be used as a possible remedy for the unfairness problem in unlicensed bands. We have proposed the deterministic backoff-based listen before talk (DB-LBT) scheme, which could be considered for coexisting Wi-Fi nodes and NR-U nodes using reservation signals. We have verified the performance of the proposed solution in several scenarios and showed its main advantages over legacy random backoff-based channel access. We have also confirmed that in the case of coexistence with legacy nodes, the DB-LBT nodes are good neighbors.

As future work we consider studying topologies with hidden and exposed nodes (including asymmetric scenarios, observed in real-world LAA deployments [31], which will require additional mechanisms to prevent traffic starvation), the impact of non-full buffer stations (with varying traffic load) and channel errors on DB-LBT performance, extending DB-LBT to support QoS, as well as providing an analytical proof of DB-LBT convergence and validation in an experimental testbed. Additionally, we plan to compare the performance of DB-LBT with other state-of-the-art solutions, e.g., modifying the reservation signal scheme [3], using traditional time sharing [25], and tuning CW [26].

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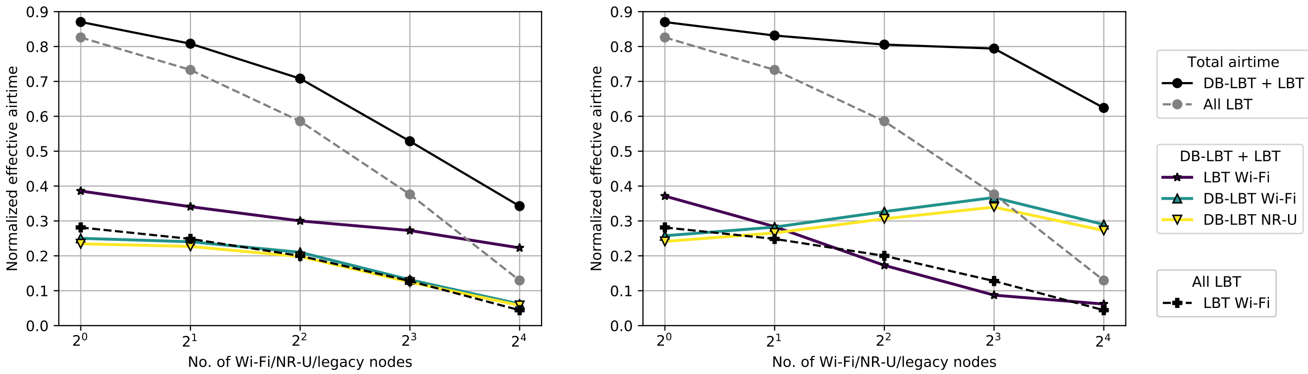

(a) Legacy nodes are APs

(b) Legacy nodes are stations

Fig. 9: Effective airtime for an equal number of APs, gNBs, and legacy (Wi-Fi) nodes in two scenarios: all nodes use LBT ("All LBT") and non-legacy Wi-Fi and NR-U use DB-LBT while legacy Wi-Fi use LBT ("DB-LBT + LBT"). For both scenarios, we present aggregate airtime of all nodes, for the former – airtime of legacy Wi-Fi, and for the latter – the airtime of each technology. The X-axis uses a log base 2 scale.

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