Exploiting Scheduled Access Features of mmWave WLANs for Periodic Traffic Sources

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Abstract—Multimedia applications, like video streaming, tele-conference, tele-control of vehicles/drones, tactile internet, just to mention a few, require guaranteed transmission resources at regular intervals. In an effort to meet the stringent demand of such quasi-periodic QoS-constrained traffic sources, the Wireless Gigabit (WiGig) standard supports a contention-free channel access mechanism that makes it possible to allocate dedicated time intervals, named Service Periods (SPs), to traffic sources that require guaranteed access to transmission resources at regular intervals. As usual, however, the standard only covers the fundamental aspects that ensure interoperability, while the actual schedule logic is left open to different implementations.

In this paper, we propose two algorithms for joint admission control and scheduling of periodic traffic streams with opposite performance objectives, specifically acceptance rate vs allocation time. The schemes are compared in two different scenarios, in order to shed light on some fundamental trade-offs. This work paves the way to more advanced studies, which may include more realistic traffic sources, advanced transmission mechanisms (such as direct mmWave links), and user mobility.

Index Terms—WiGig, periodic, scheduling, QoS

I. INTRODUCTION

The always-increasing capacity of wireless systems is promoting the design of applications and services with even more challenging demands, such as wireless high-resolution monitors, eXtended Reality (XR), mass-video distribution, among others [1]. In order to meet the rate demand of such a class of applications, the new versions of the Wireless Fidelity (Wi-Fi) standard, like the IEEE 802.11ad and 802.11ay standards (also known as Wireless Gigabit (WiGig)), exploit the mmWave band at 60 GHz, where at least 2.16 GHz of bandwidth is available. By using well-established techniques, like channel bonding and Multiple Input, Multiple Output (MIMO), these standards can provide data rates over 100 Gbps [2].

However, these applications also have very stringent requirements in terms of delay and jitter, which may be incompatible with the stochastic nature of contention-based channel access mechanisms generally supported by Wireless Local Area Network (WLAN) standards. To address this problem, the WiGig standard also defines a contention-free access mechanism that makes it possible for a traffic source to reserve radio resources at regular time intervals, called Service Periods (SPs). The standards only specify the procedures to request and assign resources, which are subject to a number of constraints, as better described in Sec. II, that need to be accounted for when designing practical scheduling algorithms based on such procedures.

Handling multiple periodic traffic streams can be problematic, especially when different periodicities need to coexist, possibly creating collisions among different allocations or excessive fragmentation of the contention-free allocation interval, which would increase the overhead. Furthermore, even in the simpler case of all equal resource requests, upon receiving a new request the Access Point (AP) needs to decide whether to rearrange the previously allocated resources to improve fairness and efficiency, possibly varying the schedule timing of already established data flows, or to maintain the original schedules and then best accommodate the new request, in order not to perturb the delay and jitter performance of the flows.

In this work, we propose some algorithms for handling multiple requests for periodic resource allocations, following the constraints given by the WiGig standards, addressing both admission control and scheduling. More specifically, we cast the periodic scheduling problem within the framework defined by the WiGig allocation procedures, then propose two algorithms for joint admission control and scheduling in this framework and, finally, compare them and shed some light on basic tradeoffs.

The remainder of the paper is organized as follows. The resource allocation framework is described in Sec. II. Sec. III provides an overview of the State of the Art on related problems. Then, we present the proposed algorithms in Sec. IV, whose performance is compared in Sec. V. Finally, in Sec. VI we draw our conclusions and propose possible extensions of this work.

II. FRAMEWORK DESCRIPTION

Based on [3], Stations (STAs) can request the AP to reserve periodic transmission intervals by sending a control frame containing the required periodicity and duration of each allocation. The AP advertises the allocated SPs to the STAs at each Beacon Interval (BI), specifying the starting time, duration, and periodicity of each block. The allocation needs to comply with a number of constraints:

1) Periodicity ($p$) can only be an integer multiple or an integer fraction of a BI ($T_{BI}$), thus the block periodicity interval will be $T_p = p T_{BI}$;
2) Allocation blocks cannot be scheduled across the BIs boundaries;
3) The allocated block duration $T_{blk}$ should fall in the range $[T_{min}, T_{max}]$ specified in the resource request.

A more detailed description of the constraints imposed by the standard can be found in [3] and [4].

Since this work is focused on allocation algorithms for periodic traffic sources, we neglect the Contention-Based Access Periods (CBAPs), which is present in each BI for asynchronous traffic. In addition, to compare the scheduling algorithms in challenging conditions, we assume that the allocated resources will be maintained indefinitely, so that the channel load increases progressively as new resource reservations are accepted. For the sake of simplicity and clarity, we also assume that the allocation blocks of a given accepted request are not fractioned in multiple disjoint intervals (i.e., each SP will consist of a one single time interval of duration $T_{blk}$). Finally, we consider a strict periodicity constraint, which prevents the scheduler from changing the starting time of already allocated blocks, while the block duration $T_{blk}$ can be freely changed within the interval $[T_{min}, T_{max}]$.

III. STATE OF THE ART

To the best of our knowledge, little work has been done on contention-free scheduling for WiGig networks. In [5], [6], the authors analyze the case where all contention-free allocations occupy the beginning of each BI, while the rest of the interval is left for a single CBAP. This allocation strategy, however, cannot support requests for periodic resource allocations with time period shorter than $T_{BI}$. The authors of [7], instead, propose an accurate mathematical analysis of the performance of a realistic Variable Bit Rate (VBR) traffic source in the presence of channel errors, when using a periodic resource allocation scheme, but do not tackle the problem of scheduling multiple periodic allocations at once.

On the other hand, the problem of periodic scheduling has been widely studied in other areas as, e.g., real-time computation and task-scheduling, where the objective is to complete tasks in a given time, while minimizing the resource utilization. For example, the authors of [8] develop and compare heuristic algorithms for scheduling tasks with hard periodic deadlines and constant resource-utilization, showing that a deadline-first approach ensures maximum resource utilization. In [9], the authors try to schedule safety-critical periodic tasks with precedence constraints, distributed over multi-processor systems using an adapted deadline-first approach, while the authors of [10] use simulated annealing to optimize a similar problem. Finally, [11] finds a low-overhead optimal solution (from a resource utilization point of view) assuming that tasks have a fixed resource requirement.

IV. SCHEDULING ALGORITHMS

We denote by $A_n = (t_{n,start}^n, T_p^n, T_{blk}^n)$ the $i$th resource allocation, where $t_{n,start}^n$ is the starting epoch, $T_p^n$ is the periodicity, and $T_{blk}^n$ is the duration of each reserved block. Therefore, the allocation consists of a sequence of SPS $A_j = (t_{j,start}^n, t_{j,end}^n)$, with

$$
t_{j,start}^n = t_{j,start}^n + jT_p^n ;
\quad t_{j,end}^n = t_{j,start}^n + jT_p^n + T_{blk}^n ;
\quad (1)
$$

for $j = 0, 1, 2, \ldots$. A graphical representation of the notation is shown in Fig. 1.

Before describing the algorithms, we first introduce some basic properties related to the constraints and assumptions of Sec. II.

Property 1 (Joint Periodicity). Given $N$ allocations $A_1, \ldots, A_N$, they are jointly periodic over a period $T_p^{1,...,N} = \text{lcm}(T_p^1, \ldots, T_p^N)$.

Since all block periods are integer multiples or fractions of $T_{BI}$, the least common multiple (lcm) can always be properly defined. An example is shown in Fig. 1.

Given the periodicity of the allocation patterns, a new allocation $A_N$ should start within a time interval $T_p^{N}$ since the beginning of the BI, and should not overlap with any of the already allocated blocks in an interval of duration $T_p^{1,...,N}$. 

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Fig. 1: Example of allocations $A_1$ (orange) and $A_2$ (blue), with $p_2 = 2p_1$.

Fig. 2: Scheduling algorithm for an infeasible pair of allocations, where $A_1$ (blue) was a pre-existing allocation with $p_1 = \frac{1}{2}$, and the algorithm is checking whether a new allocation $A_2$ (orange) with $p_2 = \frac{1}{4}$ is compatible.

All these approaches, however, cannot be directly used in WiGig systems, either because they are not compliant with the constraints imposed by the resource allocation procedures (i.e., granularity of the allocation periods, BI boundaries), or because they cannot exploit its flexibility (e.g., the dynamic allocation of $T_{blk}$).
Algorithm 1 Feasibility check under strong periodicity conditions (see Fig. 2).

Require: \{A_1, \ldots, A_{N-1}\} (fixed), A_N (new allocation), [t_{min}, t_{max}]
1: Compute T^{1,\ldots,N}_{\text{start}} (Fig. 2a)
2: t_{N,\text{start}}^{N,0} = t_{\text{start}}^{N,0} \leftarrow t_{\text{min}} \{Fig. 2a\}
3: while t_{\text{end}}^{N} < t_{\text{max}} do
4: Check for collisions in \([t_{\text{min}}, t_{\text{min}} + T^{1,\ldots,N}_P]\)
5: if no collisions then
6: \quad t_{\text{feas}} \leftarrow t_{N,\text{start}}^{N,0} \{Fig. 2a\}
7: \quad return A_N is a feasible allocation \{Fig. 2c\}
8: else
9: Allocation block \(k \in A_N\) collides with allocation block \(k \in A_i\), for some \(i \in \{1, \ldots, N-1\}\)
10: \quad \Delta t \leftarrow t_{\text{end}} - t_{N,\text{start}}^{N,0} \{Figs. 2a and 2b\}
11: \quad t_{N,\text{start}}^{N,0} \leftarrow t_{N,\text{start}}^{N,0} + \Delta t
12: \quad end if
13: \quad end while
14: return A_N is not a feasible allocation \{Fig. 2c\}

Such a feasibility check can be performed as described in Algorithm 1. The algorithm's input consists in the existing allocations A_1, \ldots, A_{N-1}, which are assumed to be fixed, and the new request A_N, whose periodicity T^N_P and block duration T^N_{\text{blk}} are assumed to be fixed, while the starting time t_{\text{start}} can be varied in a search interval \([t_{\text{min}}, t_{\text{max}}]\), which is the last input of the algorithm. The algorithm progressively shifts forward the starting time of the new allocation until either all feasibility conditions are met, or the right-most limit t_{\text{max}} is reached, in which case the allocation for such a T^N_{\text{blk}} is declared infeasible. A graphical example of the algorithm behavior is shown in Fig. 2.

If the allocation is feasible, Algorithm 1 returns the earliest starting time t_{\text{feas}} that yields a valid configuration. Notice that, in the basic configuration, t_{\text{min}} will be set to the start time of the first BI following the reception of the resource allocation request from a STA, while t_{\text{max}} = T^P_P. However, the algorithm can be used with other input parameters by more advanced algorithms, as explained later.

Given any t_{\text{feas}}, it is useful to compute the margin of the allocation, i.e., the maximum interval \([t_{\text{feas}}, t_{\text{lim}}]\) such that any allocation whose first block falls entirely in this range, a_0 \in [t_{\text{feas}}, t_{\text{lim}}], will be feasible. The margin T_{\text{lim}} can be computed by finding the closest block of any other allocation A_i, n \neq N, to any block of A_N.

In general, multiple feasible intervals exist and can be easily found by running Algorithm 1 multiple times with initial t_{\text{start}} set to the last computed t_{\text{lim}}, until the allocation becomes infeasible. We define these intervals (which, in general, depend on T^N_{\text{blk}}) as I^N_N = \{I^N_1, \ldots, I^N_M\}, where I^N_m = [t_{\text{feas}}, t_{\text{lim}}]_m, m = 1, \ldots, M.

A. Simple Scheduler

The Simple Scheduler allocates new resources assuming that those already established cannot be changed. Then, a new resource request A_N with a block request of T^N_{\text{blk}} can be accepted only if there exists a feasible interval in I_N with a duration of at least T^N_{\text{blk}}. Therefore, the maximum amount of available resources that can be allocated to A_N is determined by the longest feasibility interval, or by T^N_{\text{max}}, whichever is smaller. Clearly, t_{\text{start}}^N and T^N_{\text{blk}} need to be set accordingly.

B. Max-Min Fair Scheduler

A more flexible approach, instead, consists in dynamically adapting the duration of the allocated intervals within the admissible range, T^N_{\text{blk}} \in [T^N_{\text{min}}, T^N_{\text{max}}], \forall n = 1, \ldots, N, in order to obtain a fairer allocation.

Assuming the following parameterized block duration:

\[ T^N_{\text{blk}}(r) = T^N_{\text{min}} + r_n(T^N_{\text{max}} - T^N_{\text{min}}), \quad r_n \in [0, 1]. \quad (2) \]

We consider a scheduler to be fair if \( r_n = \min_n \{r_n\} \) cannot be increased without breaking the limits imposed by some allocation under the strict periodicity constraint. The scheduling algorithm, then, should assign the largest possible SP to each allocation, while respecting all the constraints.\(^1\)

To fit a new allocation A_N, the pre-existing allocations will thus have to either maintain or reduce their block duration, depending on whether and how the new allocation collides with them. This should allow the scheduler to reach a lower rejection rate with respect to the Simple Scheduler (Sec. IV-A), and fairer scheduling among allocations requested at different times.

The proposed scheduler is here presented in two parts: the first part describes how the allocation algorithm works (Sec. IV-B1), while the second part describes the fairness paradigm (Sec. IV-B2).

1) Allocation Algorithm: To reduce the rejection rate, we assume that a new allocation A_N is feasible when the feasibility check (Algorithm 1) is performed by setting the minimum duration to all allocations, i.e., when T^N_{\text{blk}} = T^N_{\text{min}} for \( n = 1, \ldots, N \).

We recall that, based on the strict periodicity assumption, the starting times of the already allocated blocks cannot be changed, while the block durations can be adjusted within their range \([T^N_{\text{min}}, T^N_{\text{max}}]\). From now on, we use the symbol * to represent the value obtained at the end of the execution of the scheduling algorithm.

Note that, given a set of feasible allocations, reducing any r_n (i.e., the T^N_{\text{blk}}) still yields a valid configuration. Similarly, a valid configuration for A_N with T_{\text{start}}^N and r_n \geq 0, will maintain its validity if t_{\text{start}}^{N,*} \geq t_{\text{start}}^N, r_n \leq r_n, and t_{\text{end}}^{N,*} = t_{\text{end}}^N + T^N_{\text{blk}}(r_n^*) \leq t_{\text{lim}}^N. We thus consider the following constraints:

\[ r_n \leq r_n^*; \quad t_{\text{start}}^{N,*} \geq t_{\text{start}}^N; \quad r_n \leq r_n^*; \quad t_{\text{end}}^{N,*} \leq t_{\text{lim}}^N. \quad (3) \]

By design, the algorithm ensures that at least one block of the new allocation A_N will closely follow a block from another allocation, or it will start right at the beginning of the Data Transmission Interval (DTI).

Since each feasible interval I^N_N \in I_N has one locally fairest configuration, the exhaustive search described in Algorithm 2 is able to find the globally fairest configuration.

\(^1\)When T^N_{\text{min}} = T^N_{\text{max}}, r_n can take any value. For convenience, this case has not been included in this study.
Algorithm 2 Max-min fair scheduling.

Require: $A_1, \ldots, A_N$, $T_p$.

1: Compute $T_{\text{lim}}$ considering $T_{\text{blk}}^n = T_{\text{min}}^n \forall n = 1, \ldots, N$.

2: for all $T_{\text{min}}^n = \{T_{\text{start}}^n, T_{\text{lim}}^n\} \in N$ do

3: \hspace{1em} $t_{\text{start}}^n \leftarrow t_{\text{gas}}$

4: \hspace{1em} Set $r_N$ such that $T_{\text{blk}}^n = \min \{T_{\text{max}}^n, T_{\text{lim}}^n - t_{\text{gas}}\}$ \{Eq. (2)\}

5: for all $A_n, n = 1, \ldots, N - 1$ do

6: \hspace{1em} for all block $k \in A_n \ni T_{\text{blk}}^n \ni T_{\text{lim}}^n$ do

7: \hspace{2em} if block $k$ collides with $A_N$ then

8: \hspace{3em} Get $r_{\text{start}}^n$, $r_{\text{end}}^n$, $T_{\text{start}}^n$, $T_{\text{end}}^n$.

9: \hspace{3em} $T_{\text{lim}}^n$ \{Sec. IV-B2\}

10: \hspace{3em} if $r_{\text{start}}^n < r_N$ then Add/update $A_n$ to a list of colliding allocations

11: \hspace{3em} Memorize $r_{\text{prev}}$.

12: \hspace{3em} end if

13: \hspace{2em} end if

14: \hspace{1em} end for

15: \hspace{1em} end for

16: end for

17: for all $A_n \in \mathcal{C}$ do

18: \hspace{1em} Compute $\Delta t = T_{\text{lim}} - t_{\text{start}}^n$ for $A_n$ given $A_N$ \{see Sec. IV\}

19: \hspace{1em} $T_{\text{blk}}^n \leftarrow \min \{T_{\text{blk}}^n(r_{\text{prev}}), \Delta t\}$ \{Try to improve the allocation duration if $A_N$ has been further reduced\}

20: end for

21: Compute allocation score $s_m \leftarrow \min_{n=1, \ldots, N} r_{\text{end}}^n$

22: end for

23: return The configuration which maximizes the allocation score $\{s_m\}$

![Fig. 3: Representation of a collision between $A_n$ and $A_N$.](image)

We now consider the allocations $A_n, n = 1, \ldots, N - 1$ and $A_N$ such that by allocating $T_{\text{blk}}^n(r_n)$ they collide, as shown in Fig. 3. The objective is to find $t_{\text{end}}^n$, $r_{\text{N}}$, and $r_{\text{end}}^n$ trying to allocate the largest possible amount of resources to both $A_n$ and $A_N$, while fairly distributing them between the two allocations, respecting the constraints.

The optimization is done iteratively, block by block. For example, if blocks $A_n$ (starting at $t_{\text{start}}^n$ and with allocation ratio $r_{\text{end}}^n$) collide with blocks of $A_N$ (starting at $T_{\text{start}}^n$ and with allocation ratio $r_{\text{end}}^n$), this would mean that

$$t_{\text{start}}^n + T_{\text{blk}}^n(r_{\text{end}}^n) \geq T_{\text{start}}^n.$$ \hspace{1em} (4)

In this case, $t_{\text{start}}^n$, $r_{\text{N}}$, and $r_{\text{end}}^n$ have to be updated following the constraints in Eq. (3), as described in Sec. IV-B2. If no collision happens between these two blocks of $A_n$ and $A_N$, we can proceed to check the following blocks.

2) Optimally fair allocation: For the sake of clarity, in this section we will drop the notation on the specific colliding blocks, e.g., considering $t_{\text{start}} = t_{\text{start}}^n$. Furthermore, $t_{\text{gas}}$ and $T_{\text{lim}}$ are considered to be shifted in the colliding period of $A_N$. To avoid wasting useful resources, let’s force $T_{\text{end}} = t_{\text{end}}^n$ and let there be a limit such that $t_{\text{end}}^n \leq t_{\text{lim}}^n$.\hspace{1em}While possibly not being optimal, this is still a sensible choice for a greedy approach that tries to maximize the fairness of the current configuration. By doing so and by imposing the fairness equation $r_n = r_N = r^*$, we have that

$$r^* = \min \left\{1, \frac{T_{\text{lim}} - t_{\text{start}}^n + T_{\text{min}}^n - T_{\text{N}}}{T_{\text{max}}^n - T_{\text{min}}^n} \left(1 + \frac{T_{\text{max}}^n - T_{\text{min}}^n}{T_{\text{max}}^n - T_{\text{min}}^n}\right)\right\}. \hspace{1em} (5)$$

It is possible to analyze four different cases:

- Case 1: $r_{\text{end}}^n \leq r^*$. Allocation $A_N$ cannot be extended either. Being both $r_{\text{end}}^n, r_N \leq r^*$, both allocations fit within $T_{\text{lim}}$.

- Case 2: $T_{\text{lim}} > r^*$. This implies that $r^* < 1$, thus both allocations should be trimmed to fit within $T_{\text{lim}}$. Allocation $A_N$ can be further extended, i.e., $T_{\text{blk}}^n = \min \{T_{\text{lim}} - t_{\text{lim}}^n, t_{\text{lim}}^n - t_{\text{start}}^n\}$.

- Case 3: $r_{\text{end}}^n > r_{\text{end}}^n$. Similarly to the previous case, $r_{\text{end}}^n > r^*$ and both allocations should be trimmed to fit within $T_{\text{lim}}$.

- Case 4: $r_{\text{end}}^n > r_{\text{end}}^n$. Both allocations must be trimmed and are fairly allocated, i.e., $r_{\text{end}}^n = r_{\text{end}}^n$. Since $A_N$ cannot be extended without possibly reducing the allocation ratio of other allocations, $T_{\text{end}} = t_{\text{end}}^n$ and $r_{\text{end}}^n = r_{\text{end}}^n$. Since, by assumption, $t_{\text{end}} > t_{\text{end}}^n$, $T_{\text{blk}}^n = t_{\text{end}}^n - T_{\text{start}}^n$.

V. RESULTS

In this section, we compare the results achieved with the two algorithms described in Sec. IV, when varying three parameters, namely the average allocation request $T_{\text{avg}} = \frac{\sum_{n=1}^{N} T_{\text{avg}}^n}{N}$, the interval ratio $\rho = \frac{T_{\text{avg}}}{T_{\text{lim}}}$, and the load factor $\lambda = \frac{\sum_{n=1}^{N} T_{\text{avg}}^n}{N}$. This means that for a given load factor $\lambda$, a low interval ratio $\rho$ corresponds to very flexible allocations while $\rho = 1$ corresponds to rigid allocations where $T_{\text{min}} = T_{\text{max}}$.

The proposed algorithms are compared in two different simulation scenarios:

- Scenario 1: all allocation requests have the same parameters. Specifically, they all have periodicity $T_p = \frac{T_{\text{lim}}}{2}$, load factor $\lambda = 0.1$, and $\rho \in (0, 1)$.

- Scenario 2: allocations can be of two classes, $T_1$ and $T_2$, with periodicity $T_p = \frac{T_{\text{lim}}}{2}$ and $T_{\text{lim}} = \frac{T_{\text{lim}}}{2}$, respectively. Both classes have load factor $\lambda = 0.1$ and interval ratio $\rho = 0.1$.

To evaluate the fairness of the two algorithms, Jain’s Fairness Index was used, defined as:

$$J(x) = \frac{(\sum x_n^2 \cdot \sum x_n^2)}{n^2 \cdot \sum x_n^2}, \hspace{1em} (6)$$
where only accepted allocations are counted and $x_n$ is a parameter for $A_n$, e.g., the block duration $T_{\text{blk}}^n$ or the block duration ratio $r_n$.

Fig. 4 shows the results from Scenario 1. Note that, given the discrete behavior of the problem, the plots cannot be smoothed in any way.

First of all, we evaluated the acceptance rate of the algorithm (Fig. 4a). Note that if all allocations share the same parameters, the maximum number of allocations which can be scheduled is equal to $N_{\text{max}}(\rho) = \lfloor \min\{T_{\text{min}}(\rho), T_{\text{max}}(\rho)\} \rfloor$, and the acceptance rates can thus be normalized in the interval $[0,1]$, where 1 means that the scheduler reaches the maximum possible acceptance rate. To stress-test the proposed algorithms, we consider at most 100 allocations which arrive in successive BIs. As expected, the simple scheduler suffers from a lower normalized acceptance rate than the max-min fair one, although starting from $\rho = 0.5$, the two algorithms tend to behave similarly. In fact, more rigid allocations do not give enough flexibility to the max-min fair scheduler to perform its optimizations, thus yielding similar performance to the simple algorithm.

Fig. 4b shows that both algorithms behave fairly with respect to the accepted allocations, while a different perspective is shown in Fig. 4c, where the average normalized block duration $T_{\text{blk}}/T_{\text{max}}(\rho)$ is plotted against the interval ratio $\rho$. As expected, the simple scheduler shows an oscillating trend, due to the discrete behavior of the allocations. In fact, the last scheduled allocation will only reduce $T_{\text{blk}}$ down to $T_{\text{min}}(\rho)$ making it sometimes impossible to fit an additional allocation. On the other hand, the max-min fair scheduler will try to reduce all allocations up to their minimum duration in order to avoid rejecting new ones, thus granting more accepted allocations at the cost of an overall lower block duration.

Finally, the different metrics are plotted against each other in Figs. 4d to 4f. In general, the simple scheduler tends to favor higher average block duration for a lower acceptance rate, while, in contrast, the max-min fair scheduler tends to favor acceptance rate at the cost of a lower average block duration, as expected. Both algorithms are able to ensure high fairness to the accepted allocations, generally well above 0.85.

Similar behaviors were observed for load factors $\lambda \in \{0.025, 0.4\}$, which are not shown for space saving.

As expected, higher loads tend to have more pronounced variability in both the average block duration and the fairness granted to the accepted allocations. Curiously, regardless of the load factor for high interval ratios starting from $\rho \approx 0.5$ the two algorithms tend to have very similar performance due to the more rigid allocation structure which does not allow the max-min fair algorithm to exploit its agility.

In Scenario 2 (Fig. 5) we analyze the impact allocations with different periodicities when varying the fraction $P(T_1)$ of $T_1$ requests with respect to the total. We notice that the aggregate acceptance rate (Fig. 5a) remains rather constant when varying $P(T_1)$, however the max-min fair scheduler tends to favor $T_2$, the allocation with the shortest period, even when the majority of allocation requests are of type $T_1$ (Fig. 5b). Allocations with shorter periods tend to be a bottleneck in the scheduling process since allocations are not allowed to be fragmented nor shifted in the proposed framework. For this reason, whenever an allocation of type $T_2$ is accepted, allocations of type $T_1$ are more easily rejected thus giving more room for allocations of type $T_2$, which all have the same period and are thus easier to schedule.

Fig. 5c shows that, while the simple scheduler only accepts few allocations, it is able to use almost all available resources. This is due to the fact that the periods of the two allocation types are incompatible as they have a joint periodicity of an entire BI. As the simple scheduler lazily tries to fit new allocations, in this analyzed case the two periods are incompatible when choosing $T_{\text{blk}} = T_{\text{max}}$, thus only allocations of the same type as the first one will be accepted, increasing the
rejection rate but being able to easily fill the entire BI. On the other hand, the max-min fair scheduler successfully fits multiple allocations of both types, but the constraints on the periodicity and the minimum block duration $T_{\text{min}}$ prevent it from fully utilizing the whole BI when a mixture of the two types is presented. Nonetheless it ensures very high occupancy ratios.

Finally, Fig. 5d shows a fairness metric for the accepted allocations of the two algorithms. Since, differently from scenario 1, the two types of allocations have different block durations $T_{\text{blk}}$, and ranges $[T_{\text{min}}, T_{\text{max}}]$, we compute Jain’s fairness index on the block duration ratios $r$. Both schedulers are still able to obtain high and similar fairness, though lower on average when both allocation types are present, due to the added complexity of jointly scheduling them.

VI. CONCLUSIONS

In this paper, we presented a framework for periodic scheduling in WiGig-compatible devices.

We proposed two heuristic algorithms, simple and max-min fair schedulers, and accurately described their inner workings. Finally, we showed their performance in two different scenarios, showing that the max-min fair scheduler tends to trade resource availability for a much higher acceptance rate, contrarily to the simple scheduler’s behavior, while both schedulers obtained a high Jain’s fairness index for the accepted allocations.

Future works will focus on multiple objectives. A first objective is to implement these algorithms in a full-stack simulator, allowing the study of APP-layer performance metrics for a range of possible applications. A second objective is to extend the framework by relaxing some of the assumptions made in Sec. II and test the impact of each one of them on the overall performance of a WiGig system. A third objective is to extend the study for scheduling multiple allocations at once, a possibility given by MIMO techniques.

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