Coordinated Spatial Reuse for WiFi Networks: A Centralized Approach

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***Abstract*—With ever-increasing throughput-hungry applications running over WiFi, such as Virtual and eXtended Reality (VR/XR), on the one hand and the need for deterministic communication on the other, network densification is not an option. With dense network deployment interference between overlapping basic service set (OBSS) become the main source of system throughput drop and packet delays, decreasing the benefits of dense network. With the latest WiFi 7 standard being standardized, access point (AP) coordination is one of the key features foreseen to be added. With increased interactions between APs from different OBSS, spatial reuse feature can benefit in determining accurately the levels of interference and modulation and coding scheme (MCS) index to be used for concurrent transmissions. In this paper we show a centralized Coordinated Spatial Reuse (C-SR) algorithm implemented in the network controller that determines the transmit powers of the concurrent AP transmitters based on calculated interference levels in the main receiver. In addition, the algorithm determines the MCS index for each concurrent transmission. In a test-bed measurement setup, we show that the overall system goodput is increased by 20% and 33%, respectively, for the network topology where receivers are positioned in the inner zone between APs. In addition, the communication latency is maintained below certain threshold, compared to cases where C-SR is not activated.**

***Index Terms*—coordinated spatial reuse (C-SR), openwifi, WiFi 7, IEEE 802.11be**

I. Introduction

Industrial Wi-Fi networks have faced the challenge of increasing the overall network throughput for diverse bandwidth-intensive applications such as virtual reality and eXtended reality, to make it easier for the workers to deal with different processes in the workshop. Network densification to increase overall throughput comes with a hindrance in increased interference, resulting in higher channel access delays, subsequently impacting throughput as well. Historically, WiFi standards primarily focused on advancing achievable throughput at the physical layer until IEEE 802.11ax, which introduced new efficiency-oriented features. Enhancements such as uplink (UL)/downlink (DL) orthogonal frequency-division multiple access (OFDMA) and multi-user multiple-input and multiple-output (MU MIMO) improved resource usage efficiency but were not sufficient to address network efficiency in dense deployment scenarios. The main cause of throughput decline and increased delay in dense networks, which is interference between overlapping basic service sets (OBSS), remained unresolved.

With the advent of the new Wi-Fi standard, IEEE 802.11be, more AP coordination is expected, increasing the resource usage efficiency and possibility for higher quality of service even for industrial applications. Multi-AP coordination is foreseen for spatial reuse (C-SR), OFDMA (C-OFDMA), and beamforming (C-BF) [1]. Coordinated OFDMA deals with supporting OFDMA for different OBSS stations at the same time [2]. Coordinated beamforming enables concurrent transmissions from different APs ensuring spatial radiation nulls at the targeted receivers [2]. C-SR deals with concurrent transmissions from different stations, while the concurrent traffic flow(s) do not interfere with the main traffic flow that has gained the transmission opportunity [2].

In this paper, we focus on C-SR as one of the features that is expected to improve the overall throughput and channel access delay under OBSS interference. Though spatial reuse was introduced with the basic service set (BSS) coloring feature in Wi-Fi 6 standard, there is still no standardization on how AP coordination can be achieved, and even more no algorithm for how to select the destinations for concurrent transmissions. While the DL C-SR can be feasible including a reporting phase by stations regarding experienced interference levels from APs, UL C-SR is even more challenging. For UL C-SR each station should report the interference caused by all other stations in the network. While there is periodic traffic from APs (e.g. beacons), UL traffic depends on the station' needs, making it difficult for other stations to understand the interference level when such traffic is absent.

To solve coordination issue this paper shows a DL C-SR algorithm that is implemented in the central network controller, which based on the received signal strength indicator (RSSI) measurements reported by the clients determines the transmit powers from concurrent APs as well as their MCS indexes for each destination in their BSS, respectively. Such information is given for each combination of the main receiver and concurrent receiver(s). Then based on the combination of the MCS indexes, two destination nodes are selected that increase the overall network throughput.

The paper is organized as follows: section II gives related works, section III gives an introduction to how SR and C-SR have been/are foreseen to be standardized, section IV presents the implemented algorithm in detail, section V describes the measurement setup while section VI shows the achieved results, section VII concludes the paper.

II. Related Work

Coordinated spatial reuse is just a new feature that is proposed to be included in the upcoming standard IEEE802.11be. As such, the research papers that target the coordination directly are limited.

In [3], the authors assess two coordinated transmission opportunity-sharing methods: TDMA and C-SR-based. They conduct experiments in two scenarios involving 4 APs, where client distributions are either in the inner zone between APs or in the outer zones from APs. The results show a significant overall system throughput increase ranging from 90% to 140% in the respective scenarios. Further, in [4], the authors introduce two algorithms for creating groups of APs that can transmit simultaneously. The grouping is based on whether the interference level of interfering AP(s) exceeds a given threshold for all the clients in the main BSS. This approach is conservative as it does not assess interference on a per-station basis, a methodology we will present in this paper.

Finding the right combination of the transmitter and receiver for concurrent transmissions is the first step. The second step is to determine the MCS index to be used for each concurrent transmission. In [5] authors present a statistical-based algorithm that selects the MCS index under the C-SR effect. In our case, we will use the actual RSSI and interference levels to determine the MCS indexes for each concurrent transmission. In [6] authors discuss power impact on C-SR for a simple two-link operation. They analyze three different C-SR approaches: the legacy C-SR (packets are transmitted sequentially since both APs sense each other), OBSS-PD-based C-SR (both APs transmit sequentially without aiming to decrease the interference at the receiver), and enhanced C-SR (both APs transmit with an updated transmit power to decrease the interference in the receiver). The latter C-SR algorithm is presented in [7] identifying the best set of MCSs for both concurrent links that maximize the overall system throughput.

In [8] authors present a work where they utilize artificial neural networks to improve spatial reuse in dense WiFi networks. However, they do not foresee any coordination between nodes or dynamic selection of node pairs to communicate at a certain time. They jointly optimize the transmit power level and the CCA threshold to improve throughput at a given node and overall in the network, given continuous traffic cumming from the end nodes.

Studies in [3]–[8] were exclusively done in a simulation environment. Moreover, study [8] does not include any coordination in device couples selection. In this study, we will present the first implementation of a C-SR mechanism in a real network and its performance against the normal WiFi operation. The presented algorithm optimizes the MCS index as well as transmit power.

III. Background to Coordinated Spatial Reuse (C-SR)

The probability of parallel transmissions in different OBSSs is increased in dense network deployment. Depending on the positions of the concurrent transmitters and their respective concurrent receivers such parallel transmissions can be all successful. However, based on the normal Wi-Fi channel access procedure used, many such parallel transmission opportunities can be missed in such scenarios. For example, even though multiple respective concurrent receivers are not interfered by the respective parallel transmissions, the parallel transmission can not start if any of the transmitters has detected the channel busy due to any other transmission.

Wi-Fi channel access mechanism has three indicators to classify a channel as busy [9]:

- **Energy detection**: whenever a device detects a signal with energy higher than -62 dBm, the channel is regarded as busy for the duration of signal transmission (no matter if the device could or could not decode the preamble of the signal)
- **Packet detection (PD)**: whenever a device detects a Wi-Fi packet preamble in the channel, the channel is regarded as busy for the duration specified in the preamble. The minimal PD threshold is set at - 82 dBm.
- **Virtual carrier sense**: is achieved by stopping any transmission based on the network allocation vector (NAV) length of any packet that could be decoded correctly. The channel is regarded as busy for the duration of the NAV (this usually includes also the inter-frame spacing and the acknowledgment air time).

In the IEEE 802.11ax standard, a new feature to distinguish between channel busy events by BSS and OBSS packet transmission is introduced. The so-called *BSS color* is a unique 6-bit ID that is added to the signal field of the physical header [10]. As such, each device can determine if the packet originated at its BSS or in another OBSS and can treat the channel's busy events differently. The device sets two different PD thresholds. An OBSS-PD threshold higher than the minimal PD threshold (-82 dBm) allows the device to ignore certain OBSS transmissions and continue its back-off procedure or start with the transmission. For all the BSS transmissions device maintains the default BSS-PD threshold at -82 dBm. In case the device decides to transmit during another OBSS parallel transmission, the transmit power should be decreased accordingly based on how much the OBSS-PD is increased. E.g. if the OBSS-PD was increased by 5 dB, the transmit power should be decreased by 5 dB to avoid any possible interference on the parallel OBSS transmission. In addition to this, the parallel transmission should continue with the same power transmission as it started until the end of the transmission opportunity. This might result in under-utilizing the network resources, as lower transit power means usage of lower modulation and coding scheme (MCS) index resulting in longer air time and reduced throughput.

The SR mechanism is a distributed mechanism and each device decides when and where to use it. During concurrent transmissions, one of the concurrent transmitters uses the full transmit power while others decrease their transmit power. Such an approach does not offer the best combination possible. During the initial standardization phase of IEEE 802.11be, there have been proposals to support the coordination of SR by exchanging data between the OBSS APs.

The description of the C-SR in this paragraph will be based on the proposals during the standardization phase of IEEE 802.11be. In [11] authors propose a C-SR procedure for communication in DL. An AP that has won the transmission opportunity (*sharing AP*), based on the measurements of the interference level on the receiving STA, can decide to share the transmission opportunity with another OBSS AP (*shared AP*). The *sharing AP* will determine the transmission power for the *shared AP* based on the RSSI known at the receiving STA. This information is shared between the *sharing AP* and *shared AP* with a C-SR trigger frame. Then based on the determined transmit power, the shared AP will choose to which client to communicate to.

In [12] authors propose a UL/DL C-SR procedure, where the *sharing AP* schedules transmission in UL from its STAs, while *shared AP* transmits in DL. Even in this case the transmit power of the *shared AP* is determined by the *sharing AP* and is informed using the C-SR trigger frame. For the UL-DL C-SR and UL-UL C-SR cases, measurements from all devices in the OBSS are required, which complicates the procedure of selection of the concurrent transmitters.

Since WiFi networks can be combined with legacy devices (devices that use older versions of WiFi standards), C-SR can be interfered by legacy Wi-Fi devices. However, legacy Wi-Fi devices from BSS of *sharing AP* will not transmit as the AP has won the transmission opportunity already. To protect from other legacy Wi-Fi devices that reside in the BSS(s) of *shared AP(s)* a null frame can be used and needs to be broadcasted by the *shared AP(s)*.

IV. Centralized DL C-SR

The centralized DL C-SR algorithm relies on RSSI measurement reports from clients to the central controller. Along with RSSI values from clients for each overheard AP, the central controller also knows the AP to which each client is connected. The algorithm's output consists of the attenuation for each concurrent OBSS AP transmission, with a specific client as the main receiver, and a given MCS index used for the main transmission. Using the calculated attenuation and measured interfered RSSI value, the signal to interference and noise ratio (SINR) is computed for each combination of the main client receiver and the concurrent client receiver. Based on the calculated SINR value, the algorithm determines the appropriate MCS index for the concurrent transmission.

A. Algorithm

The algorithm implemented in the centralized network controller is presented in Algorithm 1. Within lines 6 to 28, for each combination of clients and APs, we calculate the necessary attenuation at the interfering OBSS AP to avoid interference with the specific main receiver (line 9). Essentially, we ensure that the received power at the main receiving client from the interfering AP(s) remains below the packet detection threshold (-85 dBm). Simultaneously, we identify the highest MCS used to communicate with a particular client when there is no interference from any AP based on the measured RSSI levels (lines 13 to 25). If the client is not connected to a specific AP, the MCS is set as "NA" (line 10). The RSSI levels for each MCS are determined empirically based on measurements conducted on the openwifi platform [13] and can be adjusted for other platforms if needed.

Taking into account the determined attenuation for each AP, we proceed to calculate new RSSI values for all potential client combinations within lines 30 to 35. In this calculation, we consider scenarios where one client acts as the main receiver, and another client operates as the concurrent receiver. The RSSI value is obtained by summing the RSSI level received by the AP, *s*, to which the concurrent receiver, *k*, is connected, and the attenuation applied to the same AP, *s*, to prevent interference for the main receiving client, *l*.

The SINR value is determined for each pair of clients (lines 36 to 45). When $k = l$, it indicates that the client is the only main receiver, and the SINR practically represents the RSSI level above the packet detection threshold. Conversely, when $k \neq l$, the SINR is calculated as the difference between the calculated RSSI level at client *k* when the concurrent receiver is client *k* and the main receiver is client *l*, and the RSSI level at client *k* from AP *m*, to which client *l* is connected.

Once the SINR values are computed for each combination of concurrent receiver and main receiver client, we determine the appropriate MCS index for each possible combination of the concurrent link between lines 47 and 63. Note that the relation between SINR levels and the MCS index is determined based on empirical measurements conducted on the openwifi platform and can be adjusted for other platforms if required.

A detailed step-by-step analysis of the algorithm is given in Section VI together with the results from the given experiment. There we support the algorithm with real measured and calculated values for each step in a tabular way.

B. Implementation

The C-SR procedure follows two phases: the measurement phase and the concurrent transmission phase. During the measurement phase, each client collects the RSSI values of all the APs that overhear based on the reception of beacons. These RSSI values are then reported back to the central network controller where the presented algorithm determines the attenuation and MCS index for each concurrent link. The measurement phase and reporting are not complex as they utilize the in-band network telemetry for data sharing [14]. Practically the measurement information can be available at the end node at every beacon transmission interval and can be reported at any possible UL traffic.

Algorithm 1 DL C-SR algorithm network controller based on updated TX power

Input: $rssi[i][j] \quad i \leq clients_{all} \quad j \leq ap_{all}$, $mainAP[i] \quad i \leq clients_{all}$ ▷ Start from the RSSI table of each pair [client,AP]

Output:

$atten[i][j] \quad i \leq clients_{all} \quad j \leq ap_{all}$
$mcs_M[i][j] \quad i \leq clients_{all} \quad j \leq ap_{all}$
$rssi_S[i][j] \quad i,j \leq clients_{all}$
$SINR_S[i][j] \quad i,j \leq clients_{all}$
$mcs_S[i][j] \quad i,j \leq clients_{all}$
for $k \leq clients_{all}$ **do**
  for $l \leq ap_{all}$ **do**
    if $mainAP[k] \neq l$ **then**
      $atten[k][l] = -85 - rssi[k][l]$ ▷ -85 dBm is the PD threshold
      $mcs_S[k][l] = NA$ ▷ Client is not connected to this AP
    else if then
      $atten[k][l] = 0$ ▷ Client is connected to this AP, no need for attenuation
      if $rssi[k][l] \geq -45$ **then**
        $mcs_M[k][l] =' 5'$
      else if $-45 > rssi[k][l] \geq -55$ **then**
        $mcs_M[k][l] =' 4'$
      else if $-55 > rssi[k][l] \geq -65$ **then**
        $mcs_M[k][l] =' 3'$
      else if $-65 > rssi[k][l] \geq -68$ **then**
        $mcs_M[k][l] =' 2'$
      else if $-68 > rssi[k][l] \geq -72$ **then**
        $mcs_M[k][l] =' 1'$
      else if $-72 > rssi[k][l]$ **then**
        $mcs_M[k][l] =' 0'$
      end if
    end if
  end for
end for
▷ Find the RSSI value for each pair of clients once the Tx power is reduced for the ClientSlave
for $k \leq clients_{all}$ **do**
  for $l \leq clients_{all}$ **do**
    $s = mainAP[k]$
    $rssi_S[k][l] = rssi[k][s] + atten[l][s]$
  end for
end for
for $k \leq clients_{all}$ **do**
  for $l \leq clients_{all}$ **do**
    if $k == l$ **then**
      $SINR_S[k][l] = rssi_S[k][l] + 85$
    else
      $m = mainAP[l]$
      $SINR_S[k][l] = rssi_S[k][l] - rssi[k][m]$
    end if
  end for
end for
▷ Based on the SINR values of the clientSlave we determine the MCS value for concurrent transmission for each pair of clients: [clientMain,clientSlave]
for $k \leq clients_{all}$ **do**
  for $l \leq clients_{all}$ **do**
    if $SINR_S[k][l] \geq 40$ **then**
      $mcs_S[k][l] =' 5'$
    else if $40 > SINR_S[k][l] \geq 30$ **then**
      $mcs_S[k][l] =' 4'$
    else if $30 > SINR_S[k][l] \geq 20$ **then**
      $mcs_S[k][l] =' 3'$
    else if $20 > SINR_S[k][l] \geq 17$ **then**
      $mcs_S[k][l] =' 2'$
    else if $17 > SINR_S[k][l] \geq 12$ **then**
      $mcs_S[k][l] =' 1'$
    else if $12 > SINR_S[k][l]$ **then**
      $mcs_S[k][l] =' 0'$
    end if
  end for
end for

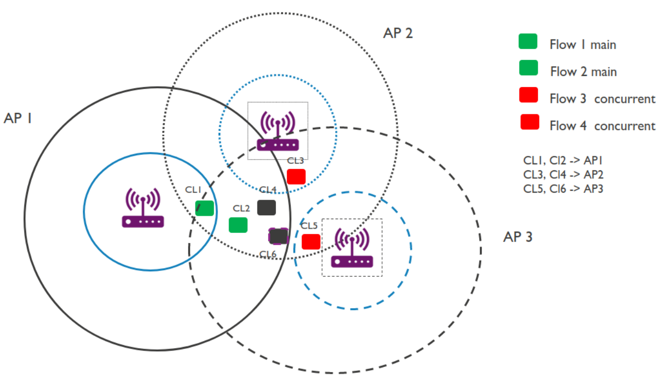


Fig. 1: Network topology used during measurements

openwifi platform supports accurate time synchronization [15] and scheduling [16] for wireless links. To facilitate C-SR measurement in our test-bed setup, the DL concurrent links are scheduled within the same time slot. In addition, specific mechanisms were added to openwifi to cater to C-SR requirements, including transmit power reduction, packet detection threshold adjustments, and MCS updates on a per-time-slot basis. These enhancements enable the AP to update the transmit power and MCS index for C-SR time slots, optimizing concurrent transmissions. For implementation convenience, we have defined distinct regions for each AP, as depicted in Figure 1. This regional approach allows for scheduling based on AP regions, and depending on the region of the main receiver, concurrent receivers are selected from regions that enhance the overall system throughput.

V. Measurement Setup

A measurement setup consisting of three APs, two clients per AP, and one wired client was set up in the IDLab Industrial

IoT lab. Each AP had one client in its nearby zone and one in its far-away zone located in the middle zone between all APs, as shown in Figure 1. It is expected that clients in the in-between zone will be highly interfered by the OBSS APs in case maximal transmit power is used.

To perform tests we chose AP 1 to be the main transmitter, respectively its two clients as main receivers. The two other APs are the concurrent transmitters, with their clients as concurrent receivers, respectively. During the measurement phase, the algorithm determined that there is no possibility for client 4 and client 6 to be used as concurrent receivers where AP 1 is the main transmitter due to a high level of interference. Thus, the client receivers left to be used in this setup were client 3 and client 5 connected to AP 2 and AP 3, respectively.

The schedule applied in all APs is shown in Figure 2. Queue 0 is used for PTP traffic that supports time synchronization between all the wireless nodes. Q1 and Q2 are used to send traffic flows, while Q4 is used for control traffic between different controlling agents in each of the wireless nodes. The communication cycle is set at 16.384 ms. Half of the air time is scheduled for Q1 and Q2 in AP1, respectively. In AP1, Q1 is used to serve client 1 (flow 1), and Q2 is used to serve client 2 (flow 2), respectively. In AP2 and AP3 both Q1 and Q2 are used to serve client 3 (flow 3) and client 5 (flow 4), respectively.

Iperf 3 was utilized to conduct a test involving four UDP traffic flows in the DL direction, transmitting from the wired station to wireless clients. The primary objective was to identify the maximum amount of UDP traffic that Iperf could independently send on each link. To achieve this, we sent each of the four flows individually, without any interference. This step aimed to determine the traffic load generated by each flow, enabling subsequent C-SR measurements to be conducted under stress test conditions, where each flow operates with its maximum achievable goodput. As such, for flow 1 and flow 2, we requested data rates of 3 Mbps and 2.5 Mbps, respectively. Flow 3 and flow 4 were allocated twice as much airtime, leading to data rate requests of 7 Mbps and 2.5 Mbps, respectively. These data rate requests align well with the MCS index used for each flow and the assigned time slot lengths. Specifically, flow 1 was sent with MCS 4, flow 2 with MCS 2, flow 3 with MCS 4 (split across two different time slots), and flow 4 with MCS 0.

For benchmarking, we conducted the same experiment where both the main and concurrent receivers were positioned at the same location. We carried out four distinct benchmarking scenarios. Throughout all these scenarios, the transmit power from all APs remained unchanged, utilizing the highest possible transmission power. In the first case, we set the MCS index to the highest value used for the link when no interference was present. In the second case, we allowed the MCS to be dynamically selected using the Minstrel algorithm. In the third case, we fixed the MCS to the lowest value, while in the final case, we utilized the dynamic MCS selection approach but employed TCP traffic instead of UDP traffic.

TABLE I: Measured RSSI level [dBm] for each pair AP - Client.

	AP1	**AP2**	**AP3**
CL1	**-47**	Na	-78
CL2	**-67**	-84	-74
CL3	-83	**-49**	-81
CL5	-77	Na	**-48**

VI. RESULTS

Table I presents the measured RSSI values from each client based on the overheard beacons from its main AP and the OBSS APs. RSSI values in bold indicate the value from the main AP for that client. Table II shows the calculated attenuation required to eliminate interference from the interfering OBSS AP for each client in the network. Such calculations are performed using formulas as shown in algorithm 1 in lines 8 to 12. For example, when AP1 is the concurrent transmitter and CL5 is the main receiver, then the signal level at CL3 will be -77 dBm. To decrease this signal level below the default packet detection threshold of -85 dBm, the transmit power of AP1 should be decreased by 8 dB ($-85 + 77 = -8dB$). As openwifi supports only three levels of attenuation (-6 dB, -12 dB, -18 dB), the calculated attenuation is rounded to one of these levels.

During the tests, the clients of AP1 acted as the main receivers. The algorithm calculated the expected RSSI levels at the concurrent receivers (CL3 and CL5) from their respective APs while considering the applied attenuation. Table III shows the anticipated RSSI levels at the concurrent receivers after applying the attenuation. These RSSI values are calculated utilizing formulas in algorithm 1, lines 30 to 35. For instance, for CL5, the new RSSI level is -60 dBm, as the attenuation at AP3 (its main AP) is set to -12 dB (see Table II) when CL1 is the main receiver, e.g ($-48dBm - 12dB = -60dBm$).

As a next step, the algorithm calculates the SINR level for the concurrent receivers. This is done as the difference between the RSSI level received from the main AP and the RSSI level received from the interfering OBSS AP as specified in algorithm 1 between lines 36 to 45. For example, when CL5 is the concurrent receiver and CL1 is the main receiver, we find the SINR as a difference between the RSSI level of AP3 in CL5, -60 dBm (Table III), and the RSSI value of AP1 in CL3, -77 dBm (Table III). Thus the SINR in CL5 is 17 dB.

Table IV shows the SINR levels for the concurrent receiver links given the main receiver. On the other hand, Table V displays the selected MCS for the concurrent receiver links based on their respective SINR levels, given main receivers.

Figure 3 shows the achieved end-to-end latency for each of the four concurrent traffic flows. In Figure 3a, when the C-SR is enabled, contention between flows is avoided and the end-to-end latency is maintained under 16 ms for all the flows, determined by the communication cycle of 16.384 ms. When C-SR is disabled then the contention for certain flows is increased making the end-to-end latency increase for flows

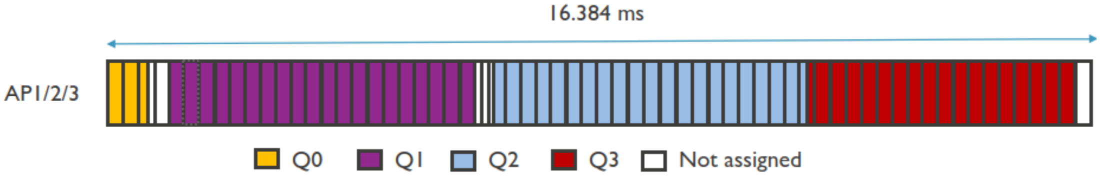
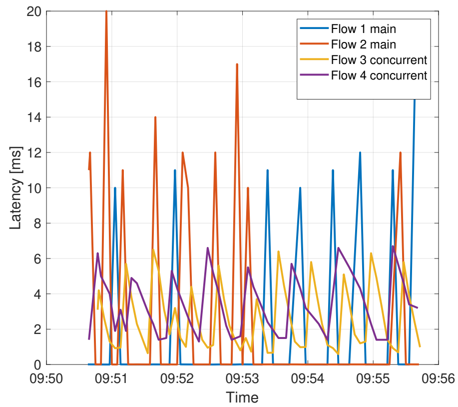
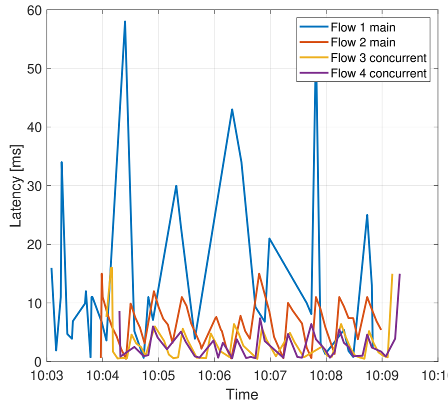


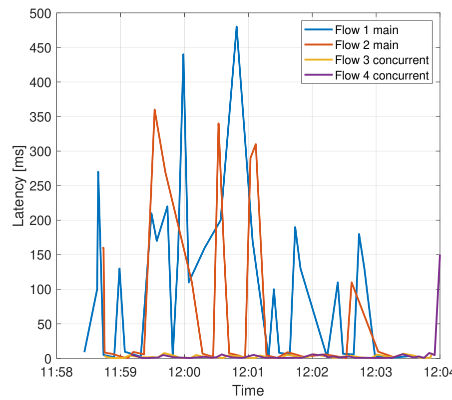
Fig. 2: Schedule applied in AP1 to AP3 (one box is 256 us)



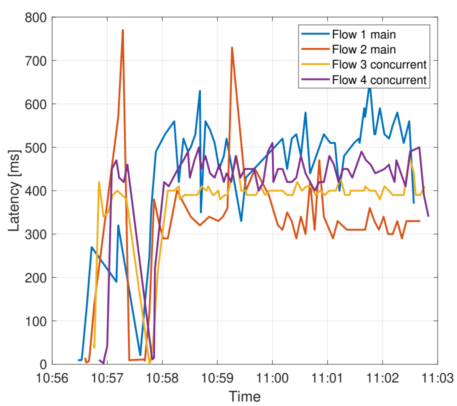
(a) C-SR feature enabled



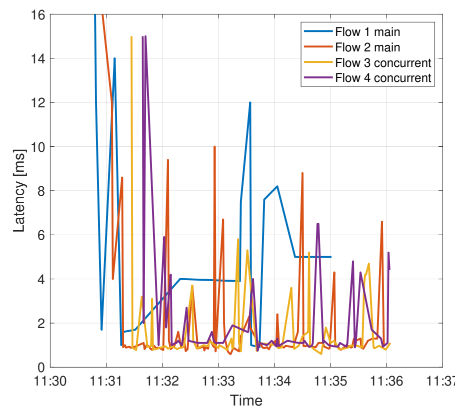
(b) C-SR feature disabled, dynamic MCS index



(c) C-SR feature disabled, fixed high MCS index



(d) C-SR feature disabled, fixed MCS = 0



(e) C-SR feature disabled, dynamic MCS with TCP traffic

Fig. 3: End-to-end latency for each benchmarking scenario.

TABLE II: Calculated attenuation actual/rounded to [-6, -12, -18] dB for each combination pair AP - Client

	AP1	**AP2**	**AP3**
CL1	0/0	Na/Na	-7/-12
CL2	0/0	-1/-6	-11/-18
CL3	-2/-6	0/0	-4/-6
CL5	-8/-12	Na/Na	0/0

that have to wait longer to access the channel, as is the case e.g. flow 1 in Figure 3b and 3c. The delay comes also due to longer buffer fills caused by the delayed channel access. When the MCS index is fixed at MCS 0, the air-time of the packets

TABLE III: Calculated RSSI level [dBm] for concurrent receiver links (column) given main receiver (row)

	CL1	**CL2**
AP2 $\rightarrow$ CL3	-49	-55
AP3 $\rightarrow$ CL5	-60	-66

TABLE IV: Calculated SINR level [dB] for concurrent receiver links (column) given main receiver (row)

	CL1	**CL2**
AP2 $\rightarrow$ CL3	34	28
AP3 $\rightarrow$ CL5	17	11

TABLE V: Calculated MCS index for concurrent receivers

	CL1	**CL2**
CL3	MCS4	MCS3
CL5	MCS2	MCS0

gets increased as well, keeping the channel busy for a longer time, which results in a longer time to access the channel for all the flows as shown in Figure 3d. On the other hand, when TCP traffic flows are used in Figure 3e, due to the congestion mechanism of TCP the amount of traffic going into the air is reduced significantly, thus the latency is maintained as well.

Figure 4 shows the achieved goodput and packet losses for each of the concurrent flows when C-SR is used. In Figure 4a, the goodput for each flow is near to the requested data rate (as shown in section V): 2.5 Mbps for flow 1, 2.37 Mbps for flow 2, 6.99 for flow 3, and 2.5 Mbps for flow 4. Also, the losses are relatively low ranging between 0.08 to 0.24%, as shown in Figure 4b.

In Figure 5 we show the overall network goodput achieved and average packet losses per flow for the C-SR case as well as for benchmarking cases. In terms of overall system goodput (Figure 5a), it is noticeable that C-SR outperforms all the other cases, being 20% higher than the case when fixed highest MCS is used and 33% higher than the case when dynamic MCS is employed. Also in terms of losses (Figure 5b), in all of the benchmarking cases, the average packet loss per traffic flow is between 15% and 32%. Only in the case of TCP packet losses were 0%. This comes from the fact that TCP does retransmission at the transport level, as well as the amount of data sent, was much lower than in other cases due to the congestion control mechanism.

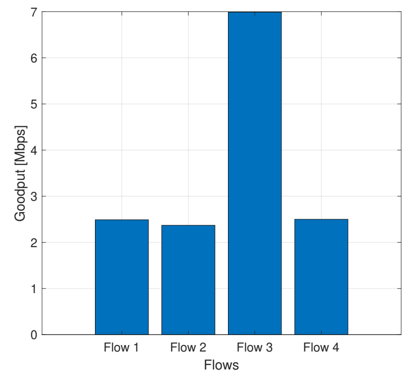
We see the benefit of C-SR in dense networks in two folds. The overall network throughput is increased, by decreasing losses due to interference, as well as the communication latency is maintained low due to lower contention and faster channel access.

VII. Conclusion and Future Work

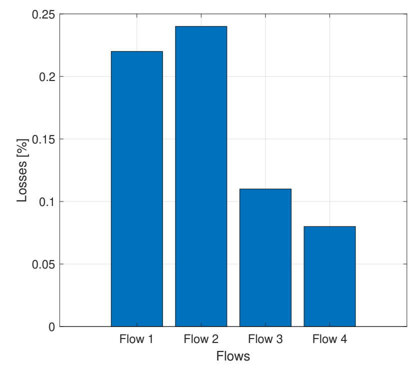
Coordinated spatial reuse (C-SR) is a key enhancement planned for inclusion in the upcoming IEEE 802.11be standard, aiming to optimize resource utilization in dense deployment scenarios. In this paper, we have presented a centralized C-SR algorithm that leverages RSSI data from clients and determines appropriate transmit powers and MCS indexes for each concurrent transmission. The algorithm focuses on maximizing the overall system goodput by optimizing combinations of main receivers and concurrent receivers. Our findings demonstrate that employing C-SR resulted in a significant improvement in overall goodput. Specifically, the overall goodput increased by 20% compared to using fixed MCS without enabling C-SR, and by 33% compared to when dynamic MCS was utilized. It is worth noting that clients were positioned in the inner zone between APs, representing one of the most challenging scenarios. We anticipate that future studies involving different network topologies will exhibit even higher increases in the overall system goodput. Regarding the communication latencies, in the case when the C-SR feature was activated they remained lower than the applied communication cycle. Due to lower interference levels, channel access delays were reduced, helping to maintain communication latency low. Contrary, the communication latencies for cases without C-SR, could go up to several hundreds of milliseconds due to longer waiting times to access the channel.

In the presented toy test-bed scenario in this paper, centralized C-SR algorithm scalability could not be verified. Future works on how algorithm scalability can be improved can be researched. One possibility is to separate the algorithm only for groups of OBSS to speed up calculations.

Another challenge is the environment's dynamicity and node mobility. The presented algorithm works well with static nodes, however, when dynamic nodes will be employed in the network the measurements report periodicity should be adapted to the mobility speed.



(a) Goodput



(b) Packet loss percentage

Fig. 4: Achieved goodput and losses for individual flows when C-SR was used.

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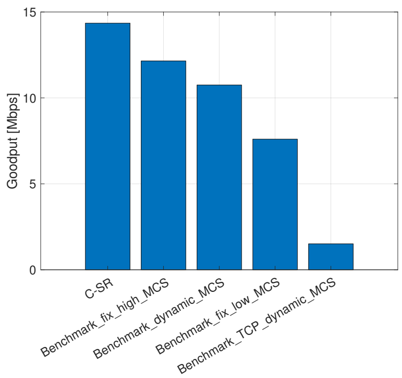
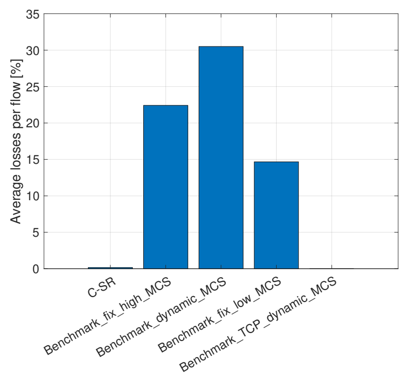


(a) Goodput



(b) Packet loss percentage

Fig. 5: Comparison of achieved goodput and losses for each benchmark case.

infrastructures for private professional environments) project and the Flemish Government under the "Onderzoeksprogramma Artificiële Intelligentie (AI) Vlaanderen" program.

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