A Supplementary Document for the Paper: Deep Reinforcement Learning Based Scheduling for NR-U/WiGig Coexistence in Unlicensed mmWave Bands

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I. Introduction

This is a supplementary document for our paper: Deep Reinforcement Learning Based Scheduling for NR-U/WiGig Coexistence in Unlicensed mmWave Bands. In this document, we provide various network topologies for the coexistence of NR-U and WiGig in Section V of our paper. In general, as shown in Fig. 1, we consider an unlicensed mmWave HetNet, in which the NR-U network and the WiGig network share a common wireless channel to transmit data packets. To be specific, M multi-antenna APs and multiple single-antenna STAs are deployed in the WiGig network, and the NR-U network is composed of a multi-antenna gNB and N single-antenna UEs deployed around the WiGig STAs. Furthermore, the gNB in the NR-U network is equipped with K independent panels; and each panel $k \in \mathcal{K} = \{1, 2, \cdots, K\}$ is responsible for serving one specific UE group k containing N_k UEs located in a fixed region without interfering with other panels, wherein $\sum_{k=1}^{K} N_k = N$. In the following, we will introduce the detailed network topologies for the coexistence of NR-U and WiGig in Section V of our paper.

A. Data Rate Evaluation

The network topology corresponding to the coexistence scenario in Section V-B of our paper is presented in Fig. 2, where UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. The gNB in the NR-U network is equipped with four panels which serve 2, 3, 3, and 4 UEs, respectively. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. Among all the distances from UEs to gNB, the shortest is 5 m, and the farthest is 20 m. The distance from each WiGig AP to the gNB is 15 m.

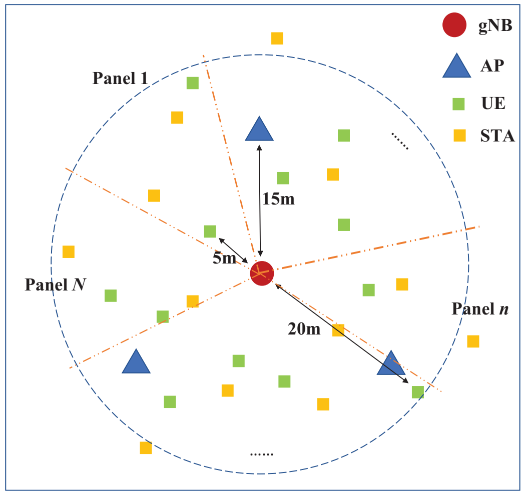


Fig. 1. The general NR-U/WiGig coexistence system.

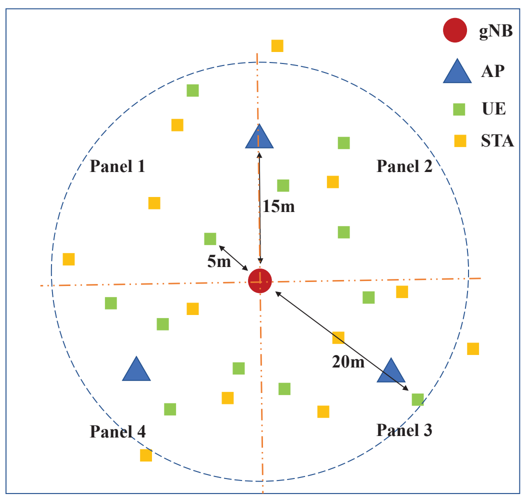


Fig. 2. The network topology for the coexistence scenario in Section V-B of our paper.

B. Robustness to Different Data Rate Requirements

As shown in Fig. 3, in the network topology corresponding to the coexistence scenario in Section V-C1 of our paper, UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. In the NR-U network, the gNB possesses three panels and each panel serves three UEs. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. Among all the distances from UEs to gNB, the shortest is 5 m, and the farthest is 20 m. The distance from each WiGig AP to the gNB is 15 m.

C. Robustness to Different Numbers of UEs

In Section V-C2 of our paper, we evaluate the robustness of various scheduling mechanisms by changing the number of UEs served by each panel. Therefore, there are multiple network topologies for this coexistence scenario,

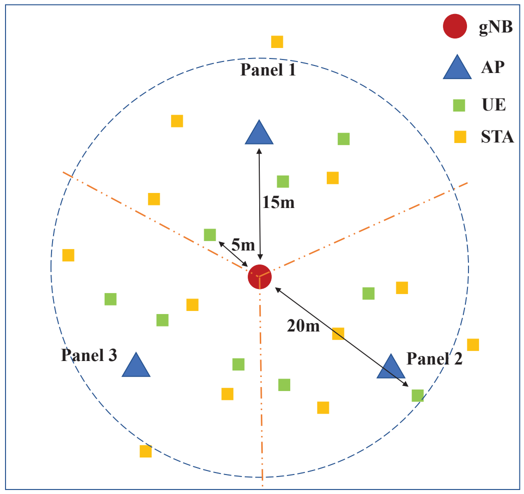
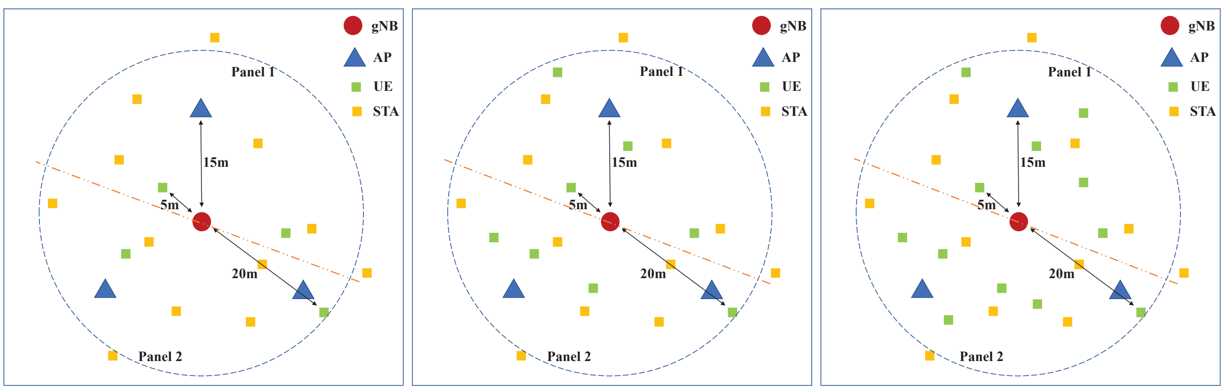


Fig. 3. The network topology for the coexistence scenario in Section V-C1 of our paper.



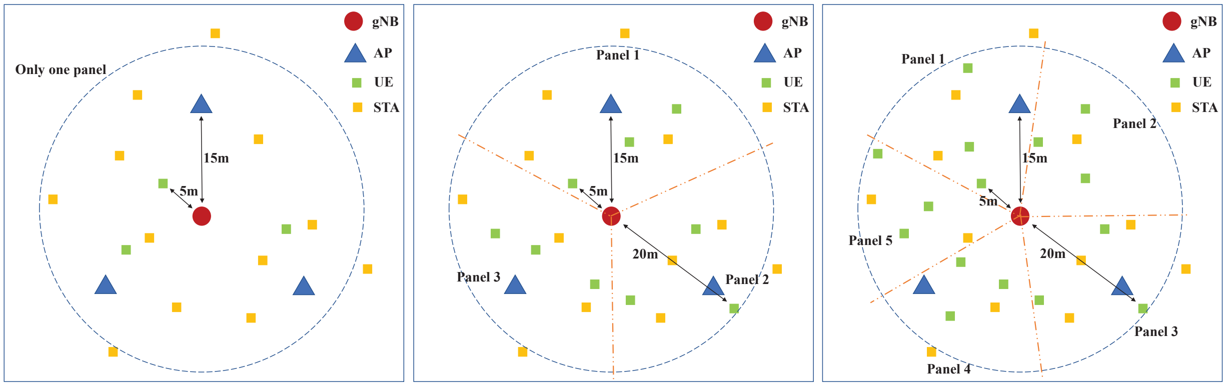
(a) Each panel serves 2 UEs. (b) Each panel serves 4 UEs. (c) Each panel serves 6 UEs.

Fig. 4. The network topologies for the coexistence scenario in Section V-C2 of our paper.

which are depicted in Fig. 4. In all network topologies, UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. The distance from each WiGig AP to the gNB is 15 m. In the NR-U network, the gNB adopts two panels to serve all UEs, where the number of UEs in each panel is varied from 2 to 6 with a step size of 2. Specifically, Fig. 4a, Fig. 4b, and Fig. 4c show the scenarios where each panel serves 2, 4, and 6 UEs, respectively. Among all the distances from UEs to gNB, the shortest is 5 m, and the farthest is 20 m.

D. Complexity Evaluation of DeepDS and DeepCS

In Section V-D of our paper, we evaluate the complexity of DeepDS and DeepCS by changing the number of panels at gNB. Therefore, there are multiple network topologies for this coexistence scenario, which are presented in Fig. 5. In all network topologies, UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. The distance



(a) The gNB is equipped with 2 panels. (b) The gNB is equipped with 3 panels. (c) The gNB is equipped with 5 panels.

Fig. 5. The network topologies for the coexistence scenario in Section V-D of our paper.

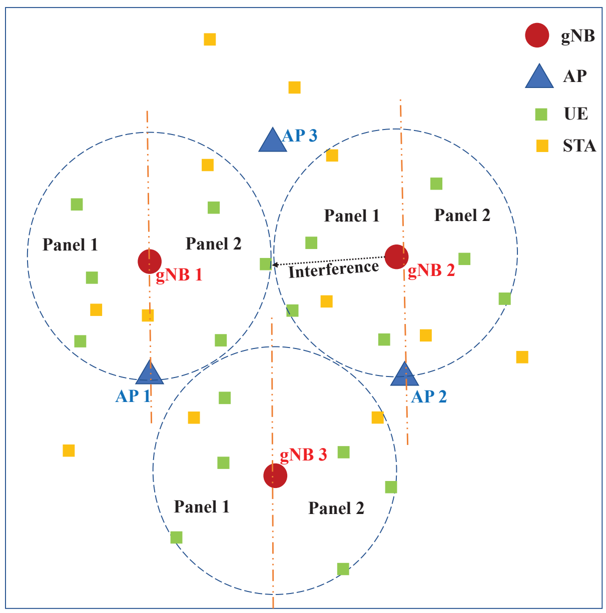


Fig. 6. The network topology for the coexistence scenario in Section V-E of our paper.

from each WiGig AP to the gNB is 15 m. In the NR-U network, the gNB is equipped with K panels each serving three UEs, where the value of K from 1 to 5 with a step size of 2. Specifically, Fig. 5a, Fig. 5b, and Fig. 5c show the scenarios where the number of panels are 1, 3, and 5, respectively. Among all the distances from UEs to gNB, the shortest is 5 m, and the farthest is 20 m.

E. Performance Evaluation in Multi-gNB Scenarios

As shown in Fig. 6, in the network topology corresponding to the coexistence scenario in Section V-E of our paper, UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. In NR-U systems, there are three NR-U networks

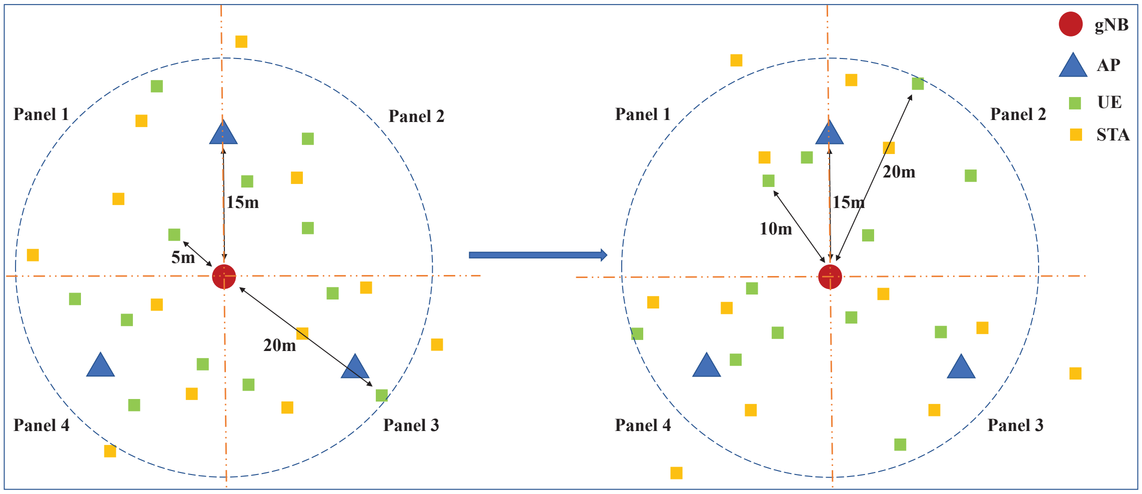


Fig. 7. The network topology for the coexistence scenario to evaluate the adaptiveness of the proposed algorithms.

each consisting of one gNB and six UEs. In each NR-U network, the gNB possesses two panels and each panel serves three UEs. Furthermore, different gNBs will interfere with each other, as presented in Fig. 6.

We provide the detailed distance descriptions among gNBs, APs, UEs, and STAs as follows. Specifically, among all the distances from gNB1 to its UEs, the shortest is 7 m, and the farthest is 15 m; among all the distances from gNB2 to its UEs, the shortest is 11 m, and the farthest is 15 m; and among all the distances from gNB3 to its UEs, the shortest is 7 m, and the farthest is 15 m. The distances from WiGig AP 1 to gNB 1, gNB2, and gNB3 are 20, 35, and 22 m, respectively; the distances from WiGig AP 2 to gNB 1, gNB2, and gNB3 are 35, 20, and 22 m, respectively; and the distances from WiGig AP 3 to gNB 1, gNB2, and gNB3 are 22, 22, and 38 m, respectively.

F. Adaptiveness to Environmental Changes

In this section, we evaluate the adaptiveness of the proposed algorithms to the environmental change. Due to the limited page length, we omit this part in our paper. As provided in Fig. 7, we consider the network topology where UEs and STAs are randomly deployed within 20 meters from gNB and corresponding APs, respectively. The gNB in the NR-U network is equipped with four panels which serve 2, 3, 3, and 4 UEs, respectively. In the WiGig network, there are 3 WiGig APs each serving 4 STAs. The distance from each WiGig AP to the gNB is 15 m.

The detailed distance descriptions between gNB and its UEs are given as follows. In the beginning (i.e., the left figure in Fig. 7), among all the distances from UEs to gNB, the shortest is 5 m, and the farthest is 20 m. The data rate requirements of these 12 UEs are randomly chosen from the set $\{0.5, 1, 1.5\}$ Gbps. At the 50000-th time slot, the locations of all UEs and STAs along with their data rate requirements in the system all change, as shown in the right figure in Fig. 7. In this scenario, among all the distances from UEs to gNB, the shortest is 10 m, and the farthest is 20 m. The data rate requirements of all UEs are re-selected from the set $\{0.5, 1, 1.5\}$ Gbps in random.

Fig. 8 presents the total data rate of the overall HetNet over time slots. As can be seen, at the beginning, DeepDS and DeepCS can quickly learn an efficient scheduling strategy, and achieve much better performance than omniLBT

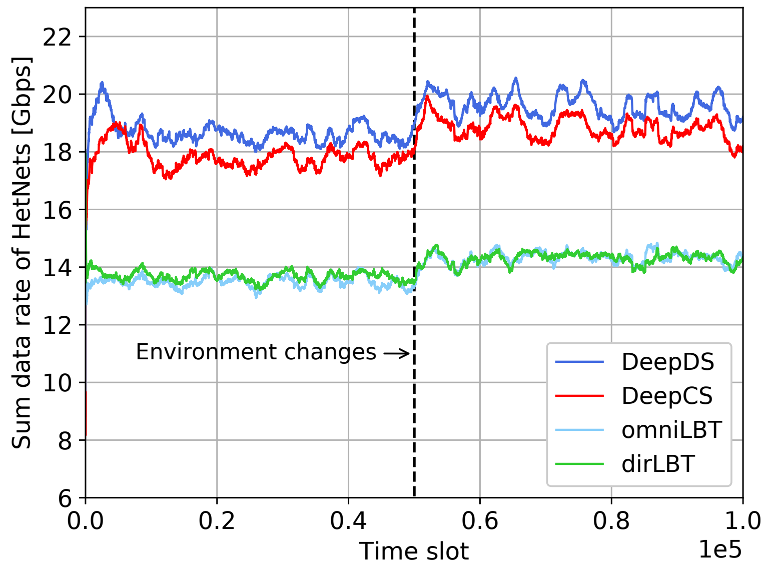


Fig. 8. Adaptiveness of various algorithms in dynamic environments.

and dirLBT. After the environment changes, with powerful online learning capabilities, DeepDS and DeepCS can follow this change and quickly learn a new efficient scheduling policy. This result demonstrates that DeepDS and DeepCS can adapt well to the environmental change.