Shared Spectrum Coordination in an heterogeneous IoT network

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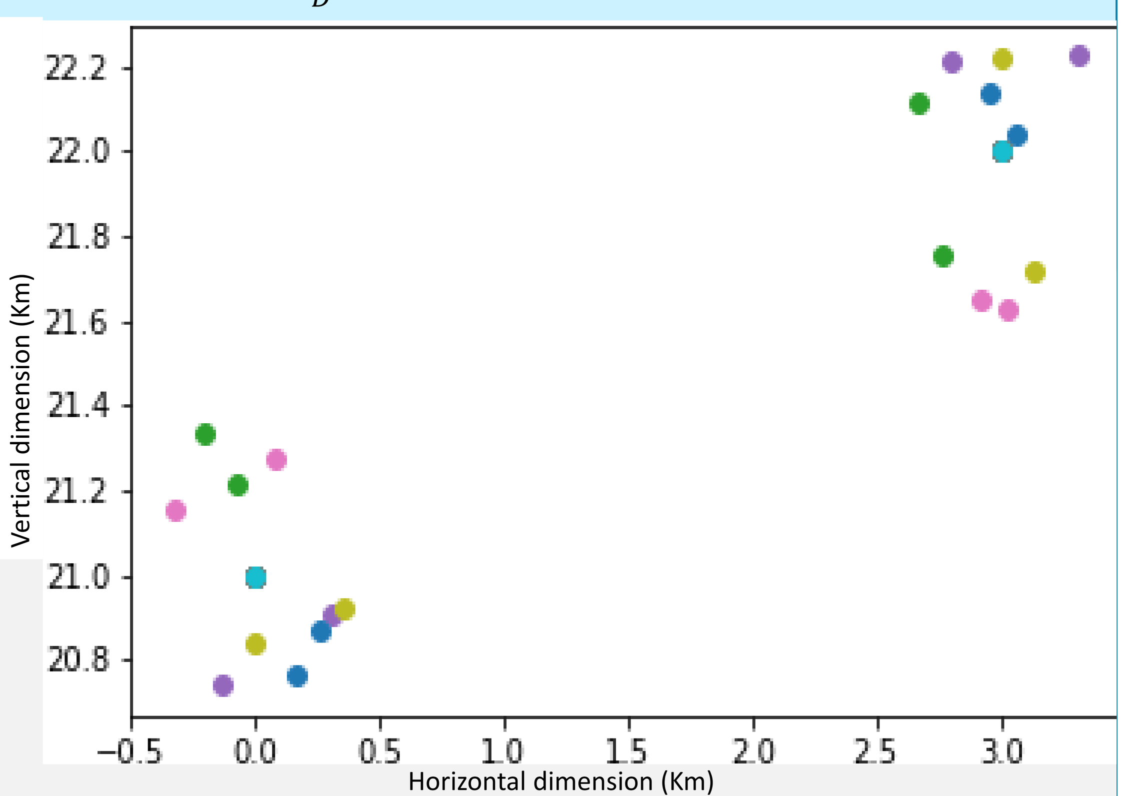
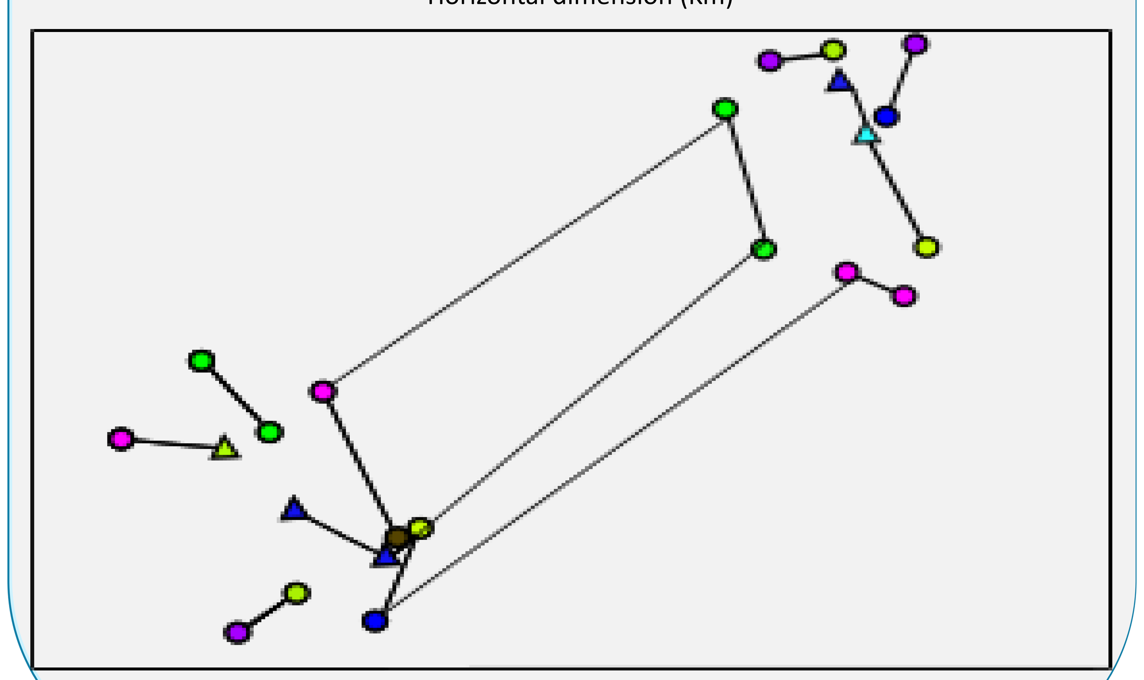
Introduction

- Internet of Things (IoT) is applied in manufacturing, health care, and our daily lives.
- Shared spectrum's affordable connectivity for these devices, facilitates universal deployment.
- Shared spectrum technologies are made affordable as resources are shared between licensed/Primary users (PUs) and unlicensed/Secondary users (SUs).
- Dynamic Spectrum technologies such as Television White Space (TVWS) or Citizen Broadband Radio Service (CBRS) allow shared resources between PUs and SUs.
- Other shared spectrum use cases are shared 5G bands offered by regulators, 5G in network slicing, and resource sharing among MNOs.
- PUs are usually protected and SU's protection can be problematic. Unlike PUs, SUs can change location and spectral demand.
- Hence, to maximize the shared experience of SUs, the following questions are examined:
  - How can SUs reuse spectrum more efficiently?
  - How effectively do coexistent managers in TVWS and CBRS architectures mitigate interference among SUs?

Method

- A network experimental space of 10 x 25 km was assumed.
- Two major networks supported 802.22 and 802.11af heterogeneous devices
- Four channel slots were assumed to be available to all SUs.
- The dynamic nature of IoT devices was represented by the changing locations and different number of SUs.
- The coexistent manager allocated channels to SUs either randomly (TVWS) or used CBRS's recursive cluster method.
- The size of the experimental space kept the two base stations interfering with each other. Thus, cluster size was 2.
- The interference levels between random pairs of devices, reusing channels were computed and shown in Figures 1 and 2.
- Interference levels were computed using the Longley Rice propagation model and link budget.
- A Q-learning algorithm trained a coexistent manager to observe the location of devices and allocate channels to devices with the highest separation distance.
  - Reward = $-\frac{1}{D^{-2}}$ where D = distance between a pair of devices.





Interfering pairs in experimental area

Results

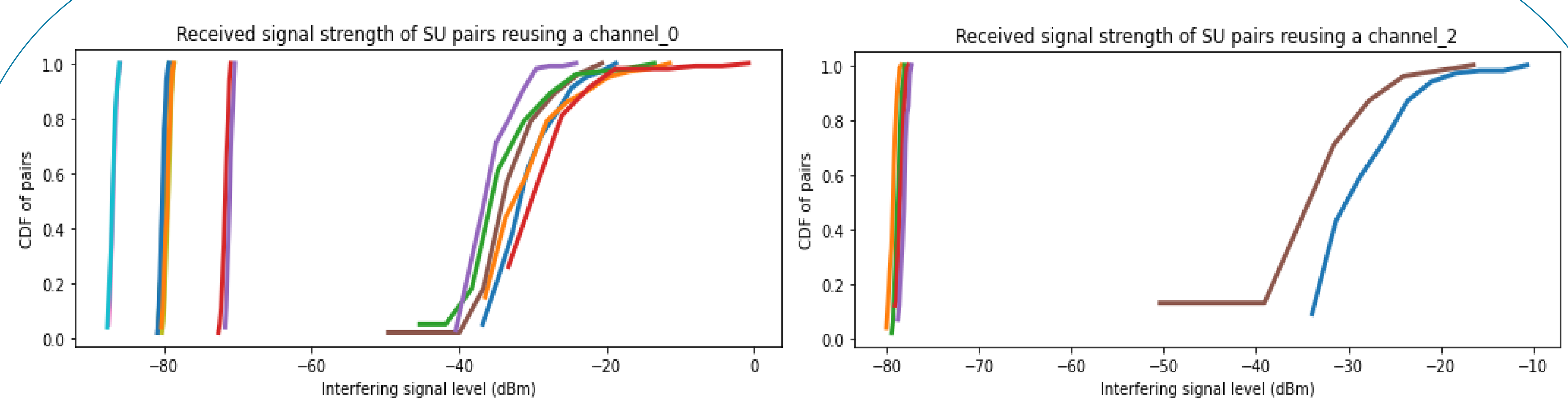


Figure 1: Random reuse of channels amongst 20 devices. An uneven use of channels with most devices experiencing -80 to -25dBm levels of interference.

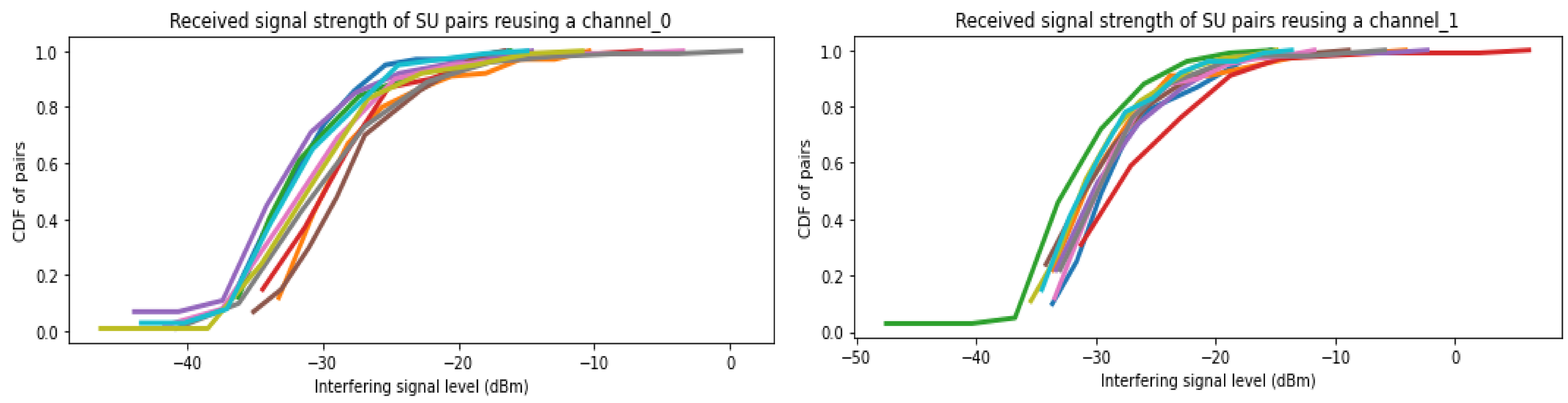


Figure 2: Recursive cluster method used to allocate 4 channels to 20 devices. It improved channel distribution and eliminated inter-network. In the absence of a management scheme within a sub-network, SUs reusing channels suffered very interference level of -25 dBm or less.

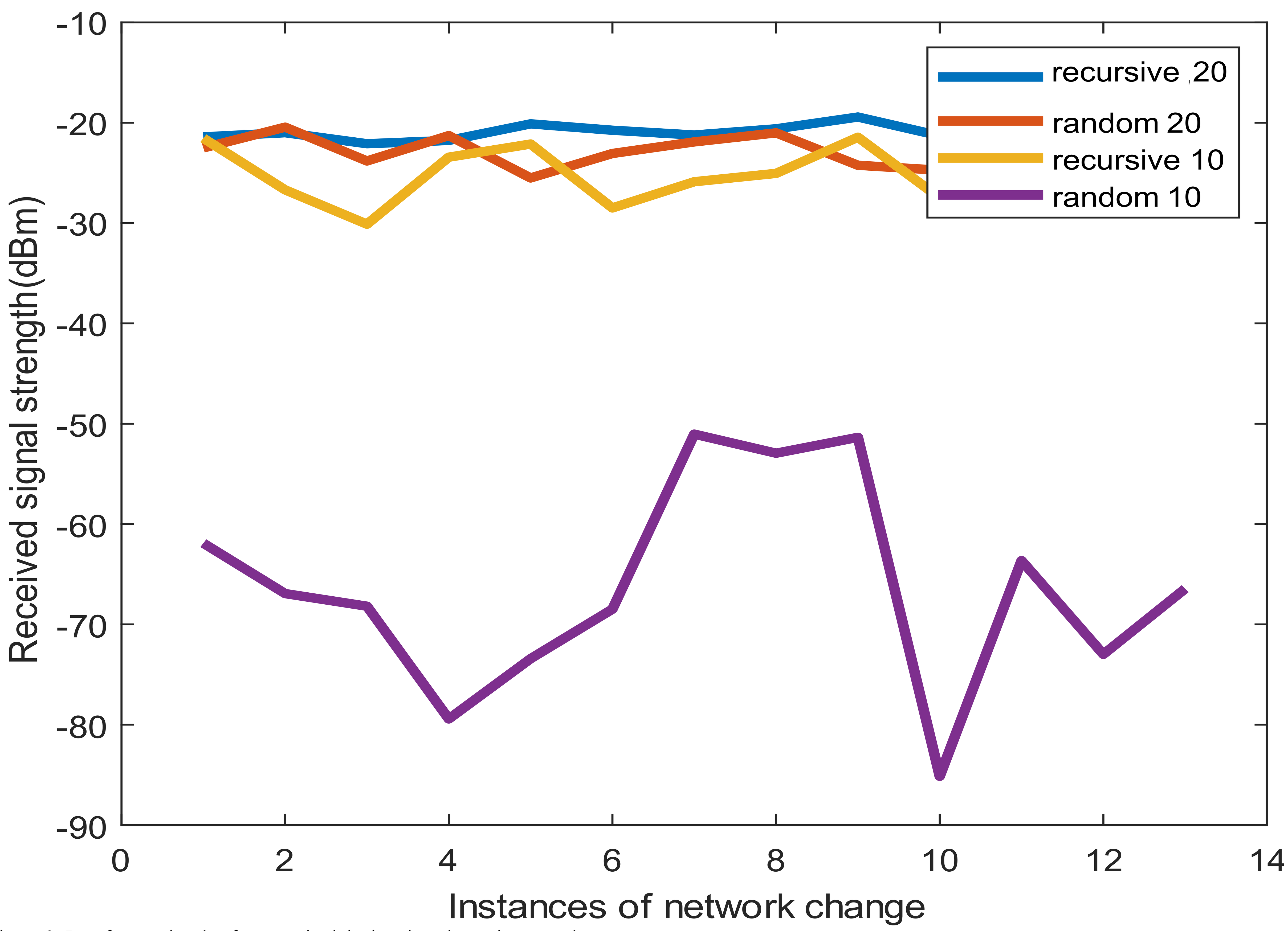


Figure 3: Interference levels of most paired devices in a dynamic network.

Intelligent allocation of resources can improve channel reuse, thus enabling spectral efficiency.

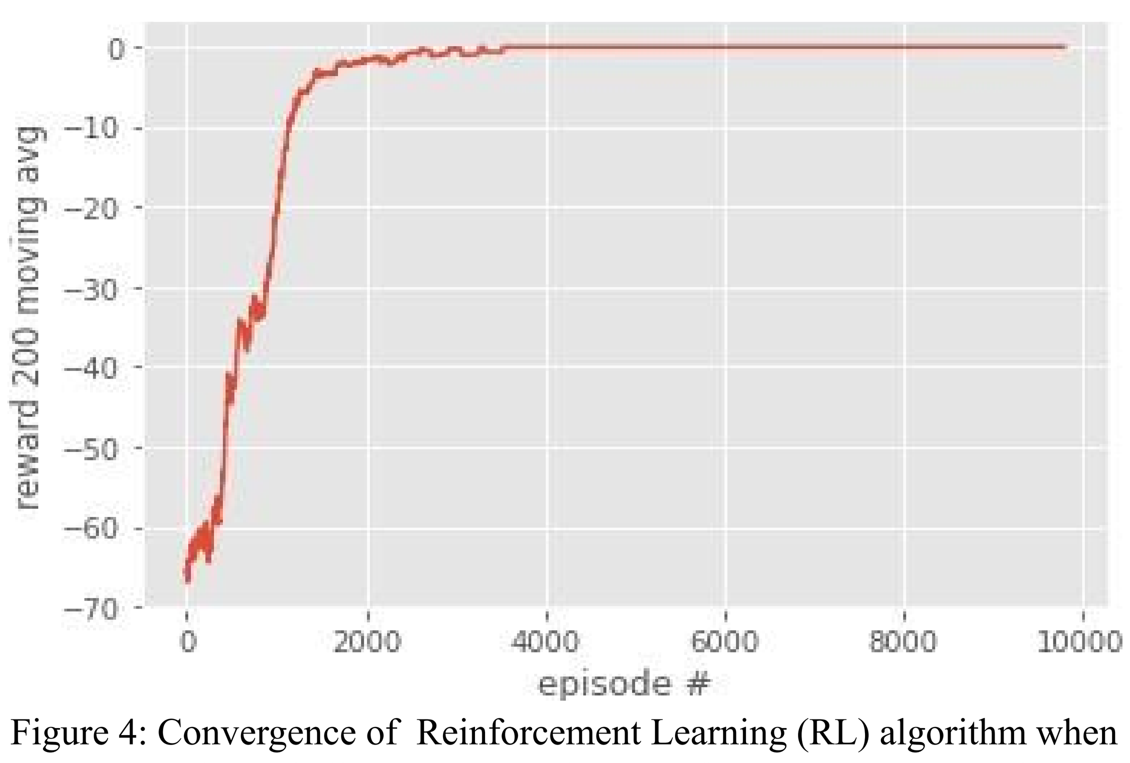


Figure 4: Convergence of Reinforcement Learning (RL) algorithm when optimizing channel allocation to 10 devices after 200 iterations and 10000 episodes.

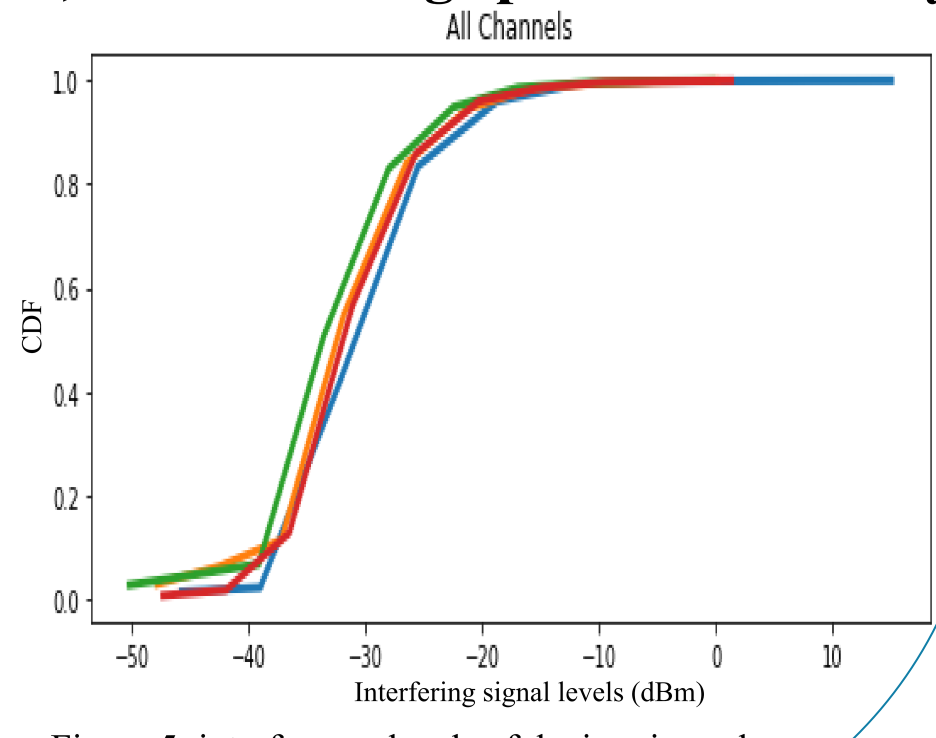


Figure 5: interference levels of devices in each channel.

Conclusion

- Affordable internet provided by shared spectrum networks need intelligent schemes to prevent high interference levels among SUs.
- High interference levels were at unacceptable values when four channels were reused randomly by 10 and 20 heterogeneous devices, in a dynamic network figures 1, 3 & 5.
- Recursive clustering method resulted in no interference between networks $[s_1, s_2] \cap [s_3, s_4] = 0$. However, coexistent managers need to prevent high intra-network interference, figures 2 & 3.
- A coexistent manager learned to share channels to devices that were farthest apart using a Reinforcement Learning algorithm, figure 4.

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Reference:
1. CBRS WInnForum Standards, 2019
2. IEEE 802.19, 2018