Leveraging Link Adaptation for Fully Autonomous and Distributed Underlay Dynamic Spectrum Access Based on Neural Network Cognitive Engine

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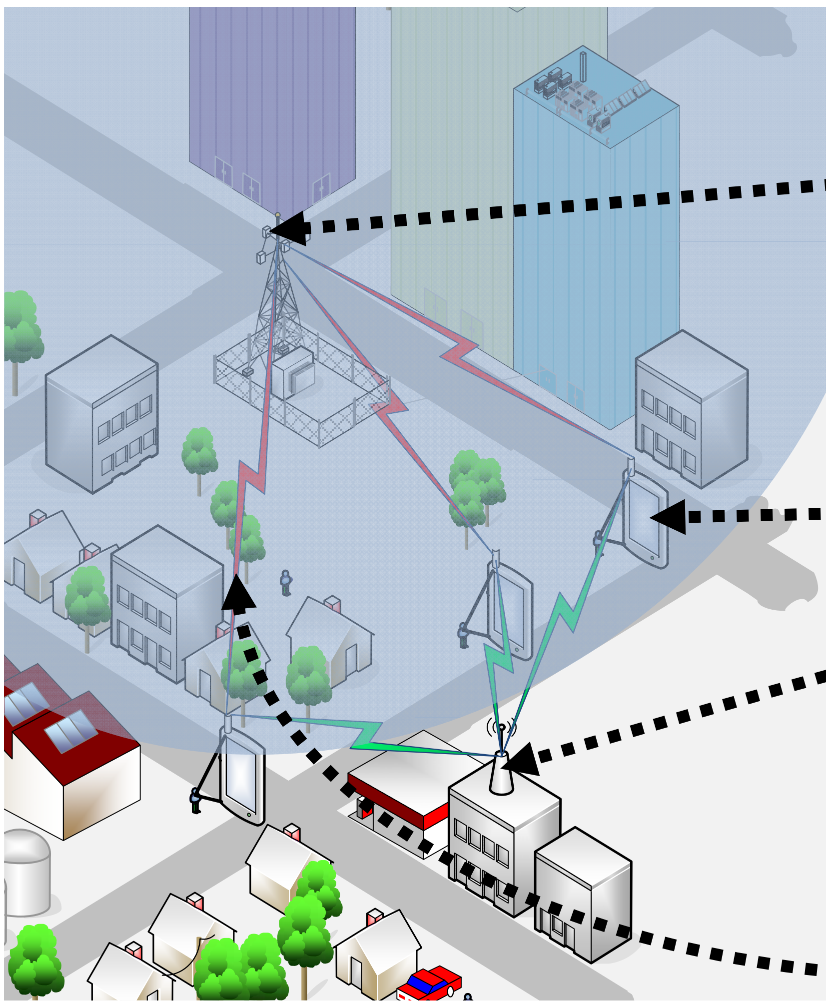
Outline

- Main challenges with Underlay Dynamic Spectrum Access.
- Role of Adaptive Modulation and Coding (AMC) in addressing challenges.
- A Neural Network Cognitive Engine for Autonomous and Distributed Underlay Dynamic Spectrum Access:
  - » Secondary nodes infer the effect that different settings in a secondary network transmission would have on the primary network.
  - » Very fine control over effects on the primary network.

System Setup:
Underlay Dynamic Spectrum Access



» A primary network (PN) owns a portion of the spectrum.

Primary network access point.

» A secondary network (SN) transmits over the same portion of the spectrum.

Secondary network terminal (secondary user – SU) – These are cognitive radios.

Secondary network access point.

» Interference created by secondary network on primary network needs to be below a tolerable threshold.

Interference from secondary network to primary network.

Underlay DSA

Key challenges:

- How can SUs become aware of the interference they create on the primary network?
  - *Depends on many factors, e.g.: distance between secondary transmitter and primary receiver*

$$\gamma_i^{(p)} = \frac{G_{ii}^{(pp)} P_i^{(p)}}{\sum_{j \neq i}^{N_P} G_{ij}^{(pp)} P_j^{(p)} + \sum_{j=1}^{N_S} G_{ij}^{(ps)} P_j^{(s)} + \sigma^2}$$

- How to set transmit power levels in secondary transmitters that result in interference to primary links below a limit? How to set this limit?
- **All done without any exchange of information between primary and secondary networks.**

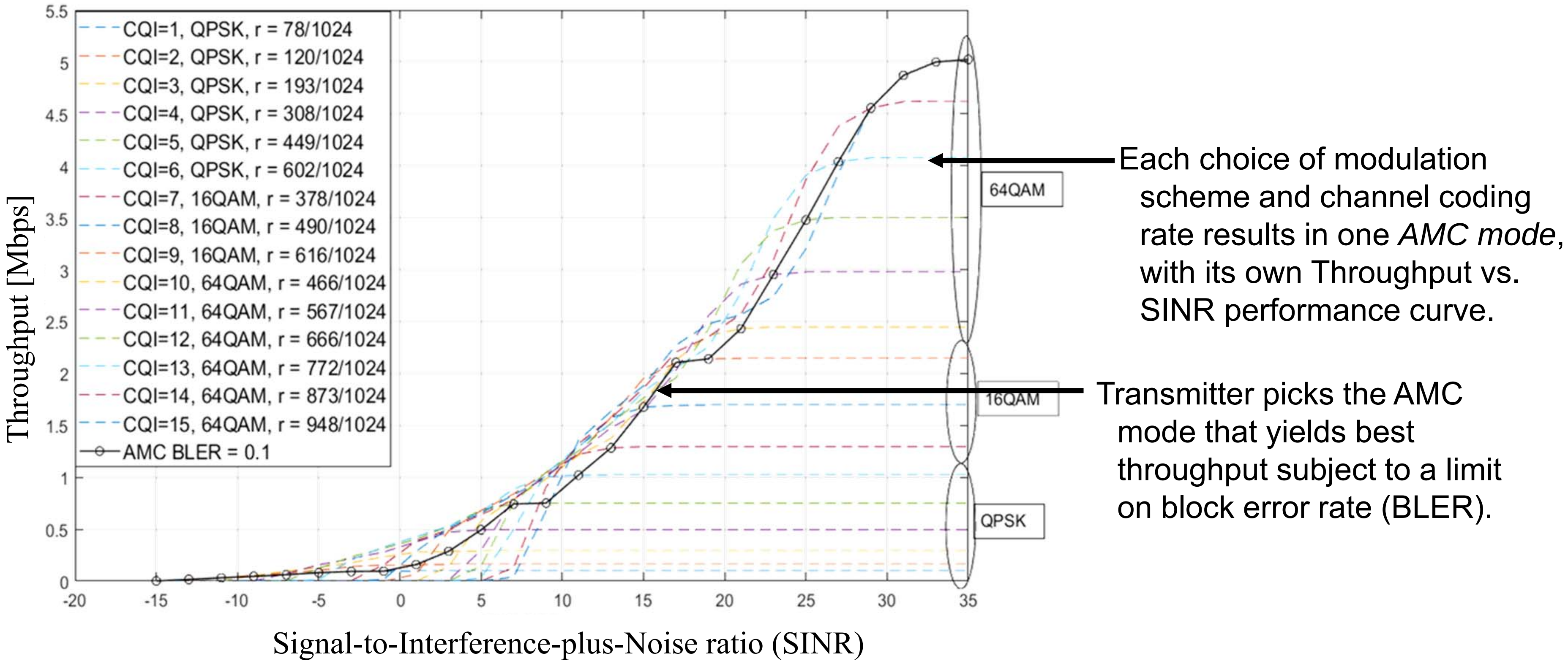
Solution:

- Take advantage of Adaptive Modulation and Coding (AMC) used in primary network (part of practically all high-performing wireless communications standards for more than two decades).

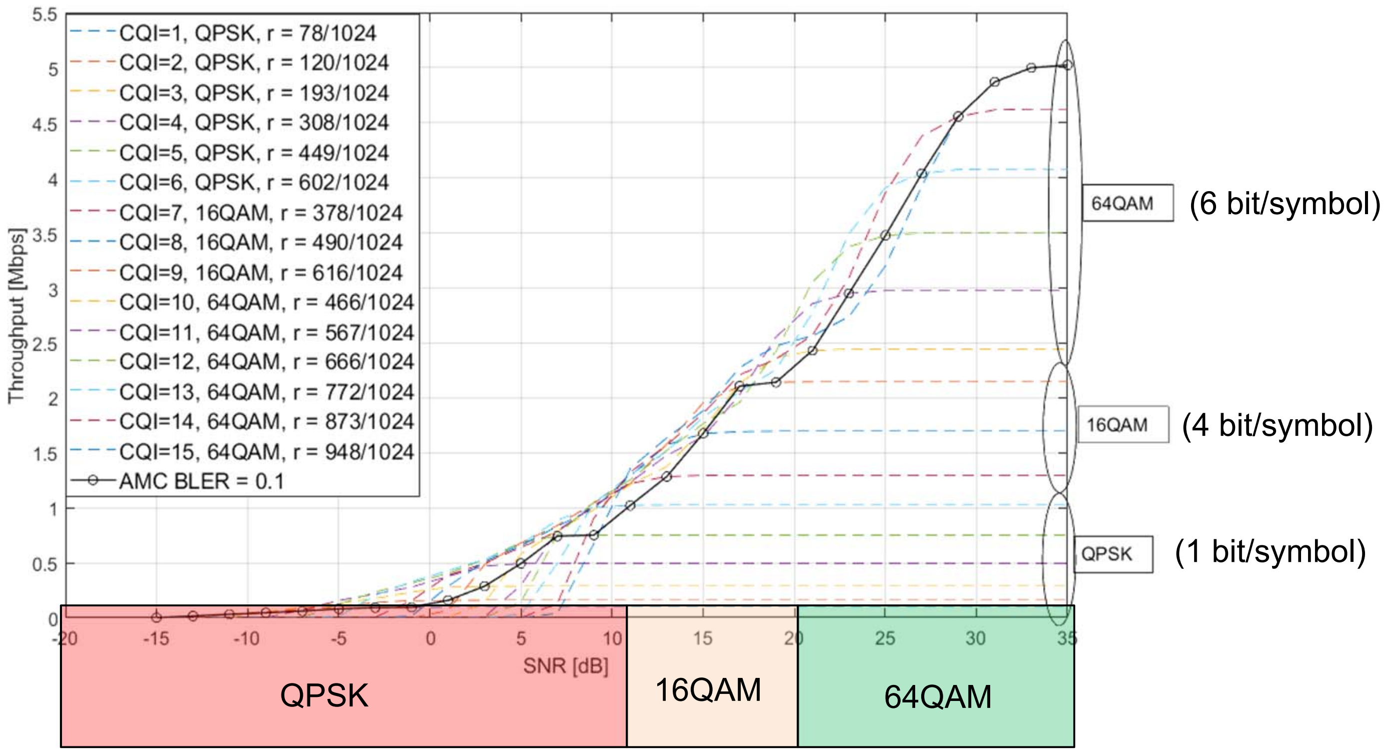
Adaptive Modulation and Coding

- Based on the channel SINR transmitter adapts modulation scheme and channel coding rate.

Typical case for an LTE resource block

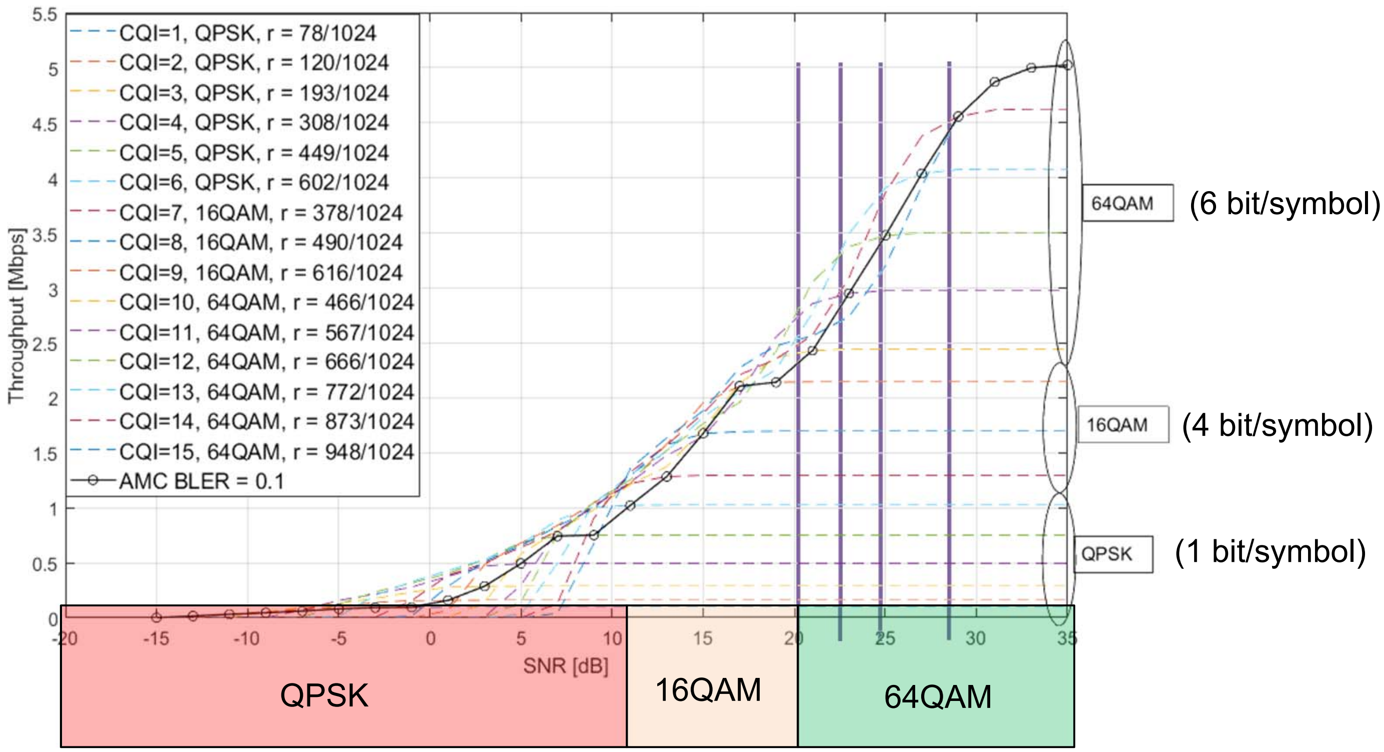


Adaptive Modulation and Coding



- By analyzing the radio signals, it is possible through signal processing algorithms to estimate the modulation scheme being used (modulation classification).
- Knowing the modulation scheme provides a broad indication of the SINR in a primary link.

Adaptive Modulation and Coding



- By analyzing the radio signals, it is possible through signal processing algorithms to estimate the modulation scheme being used (modulation classification).
- Knowing the modulation scheme provides a broad indication of the SINR in a primary link.
  - » **Knowing the full AMC mode provides a finer resolution indication**.

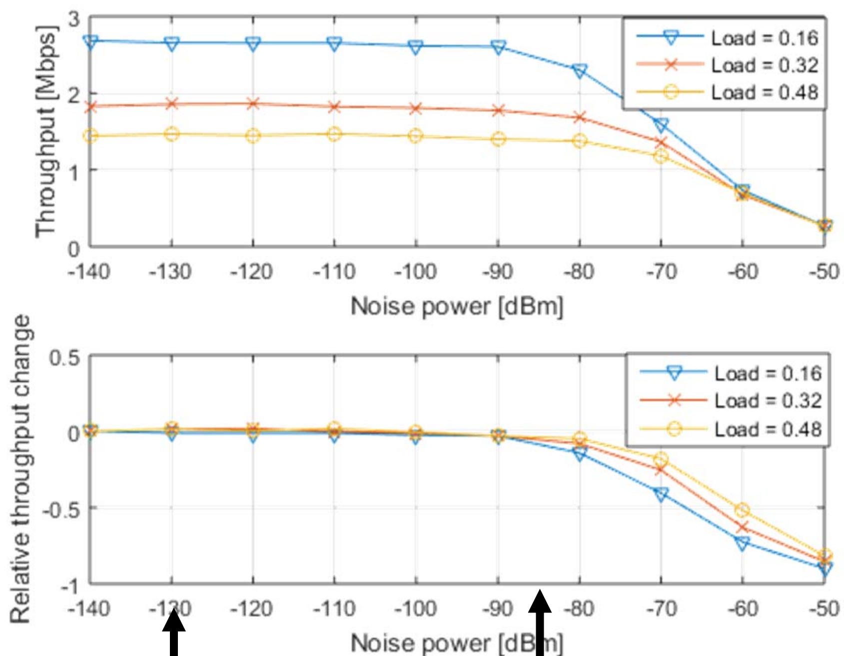
Adaptive Modulation and Coding

- Important property for adaptive modulation:

  When using adaptive modulation, average throughput is maintained at its maximum value as the background noise power increases to a limit value.

- In underlay DSA, the secondary network's interference can be thought of as added background noise

$$\gamma_i^{(p)} = \frac{G_{ii}^{(pp)} P_i^{(p)}}{\sum_{j \neq i}^{N_P} G_{ij}^{(pp)} P_j^{(p)} + \sum_{j=1}^{N_S} G_{ij}^{(ps)} P_j^{(s)} + \sigma^2}$$



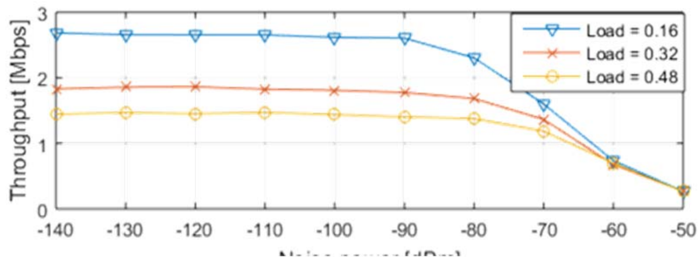
Noise power

Secondary network could add interference to primary network up to this value

Underlay DSA – Revisiting Challenges

- How can SUs become aware of the interference they create on the primary network?
  - » Solution: by perceiving changes in the AMC mode used at nearest primary link.

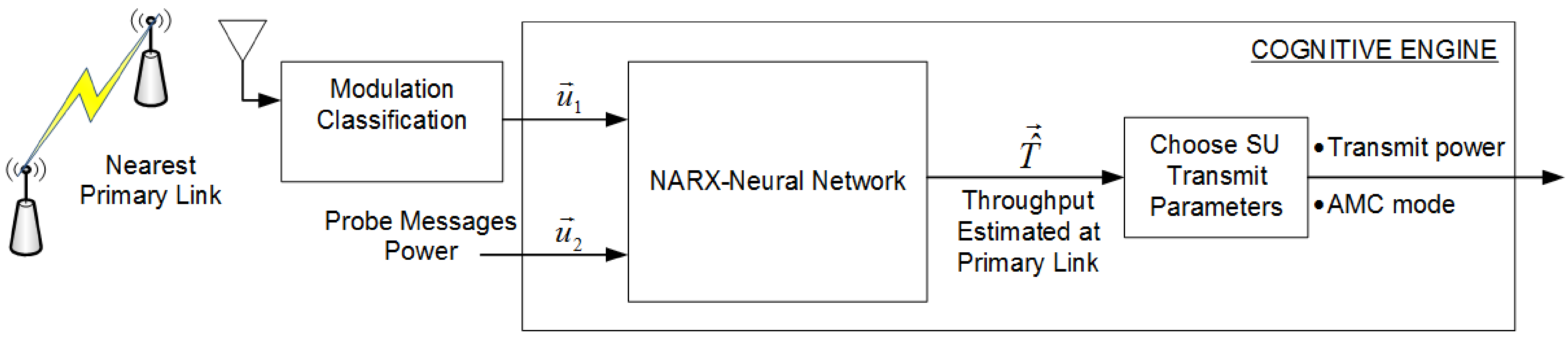
- How to set transmit power levels in secondary transmitters that result in interference to primary links below a limit? How to set this limit?
  - » Solution: Leverage properties of AMC.



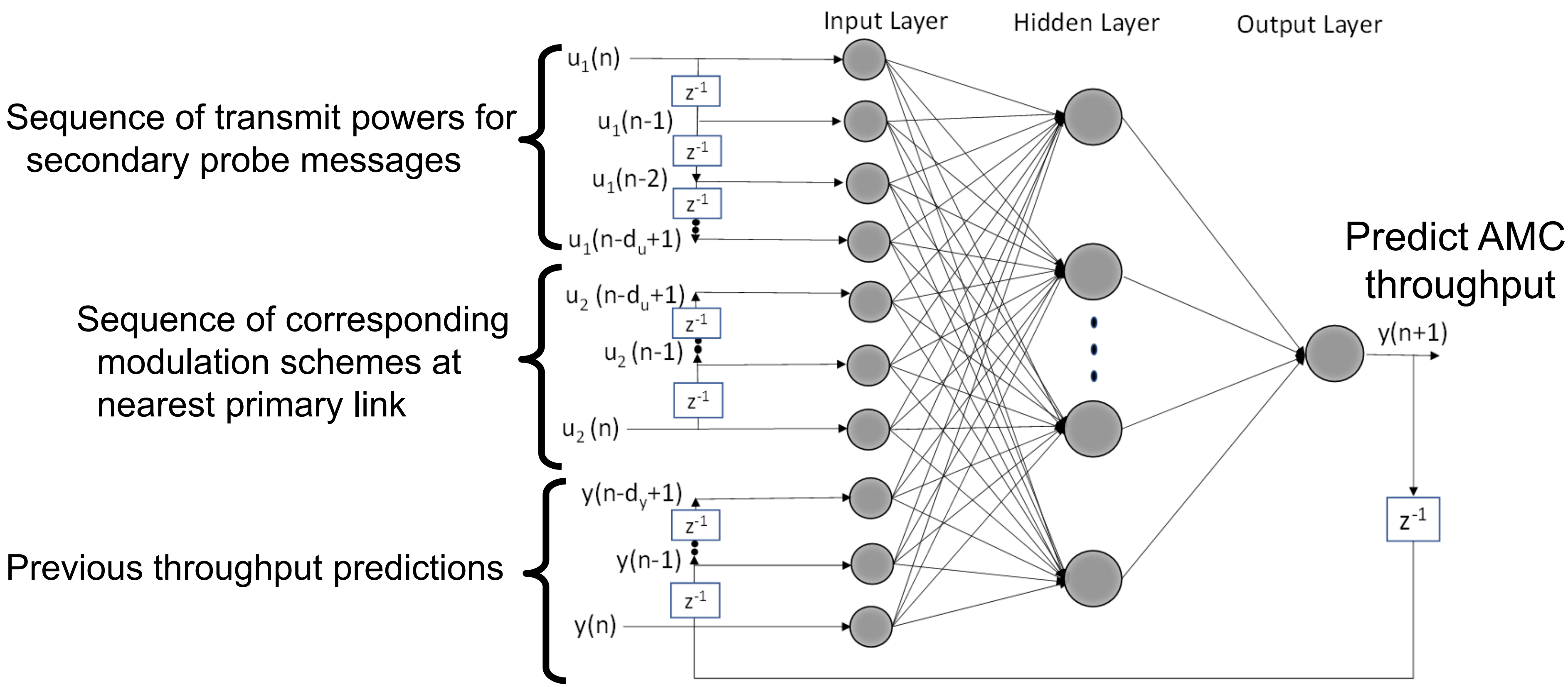
- All done without any exchange of information between primary and secondary networks.
  - » Solution 1: Listen to nearest primary link transmission and use signal processing to infer modulation scheme
  - » Solution 2 (better): Listen to nearest primary link transmission and infer full AMC mode (finer resolution). Realized through a cognitive engine based on a Non-linear Autoregressive Exogenous Neural Network (NARX-NN).

Cognitive Engine

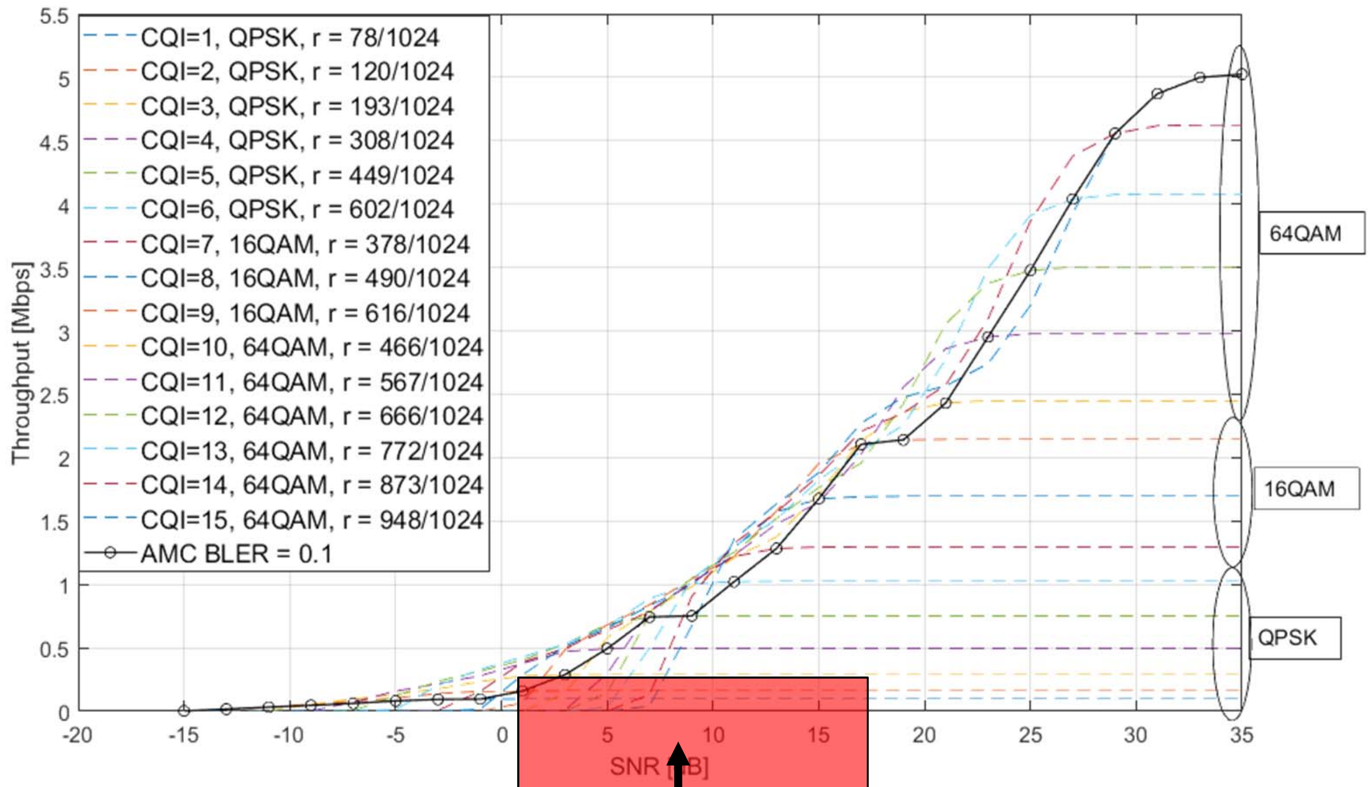
- Main component to implement underlay DSA.
- Underlay DSA mechanism:
  - Sense modulation scheme of nearest primary link without transmitting. Estimate throughput and convert it to AMC mode.
  - Send a sequence of short probe messages.
  - Listen to modulation scheme used in the nearest primary link.
  - Pairs of probe message power and primary link modulation scheme are inputs to NARX-NN.
  - Output from NARX-NN are throughput estimates at nearest primary link.
  - Choose transmit settings that meet a maximum allowed reduction in throughput at the nearest primary link.

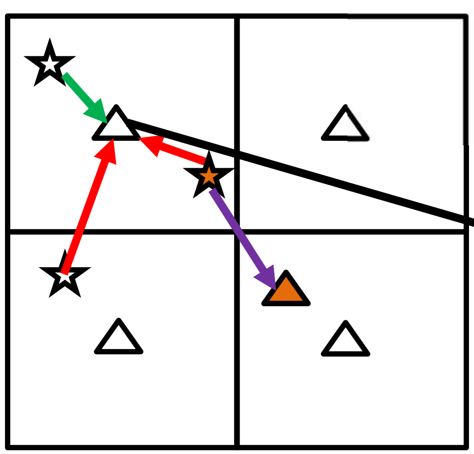


NARX Neural Network



Training the NARX-NN





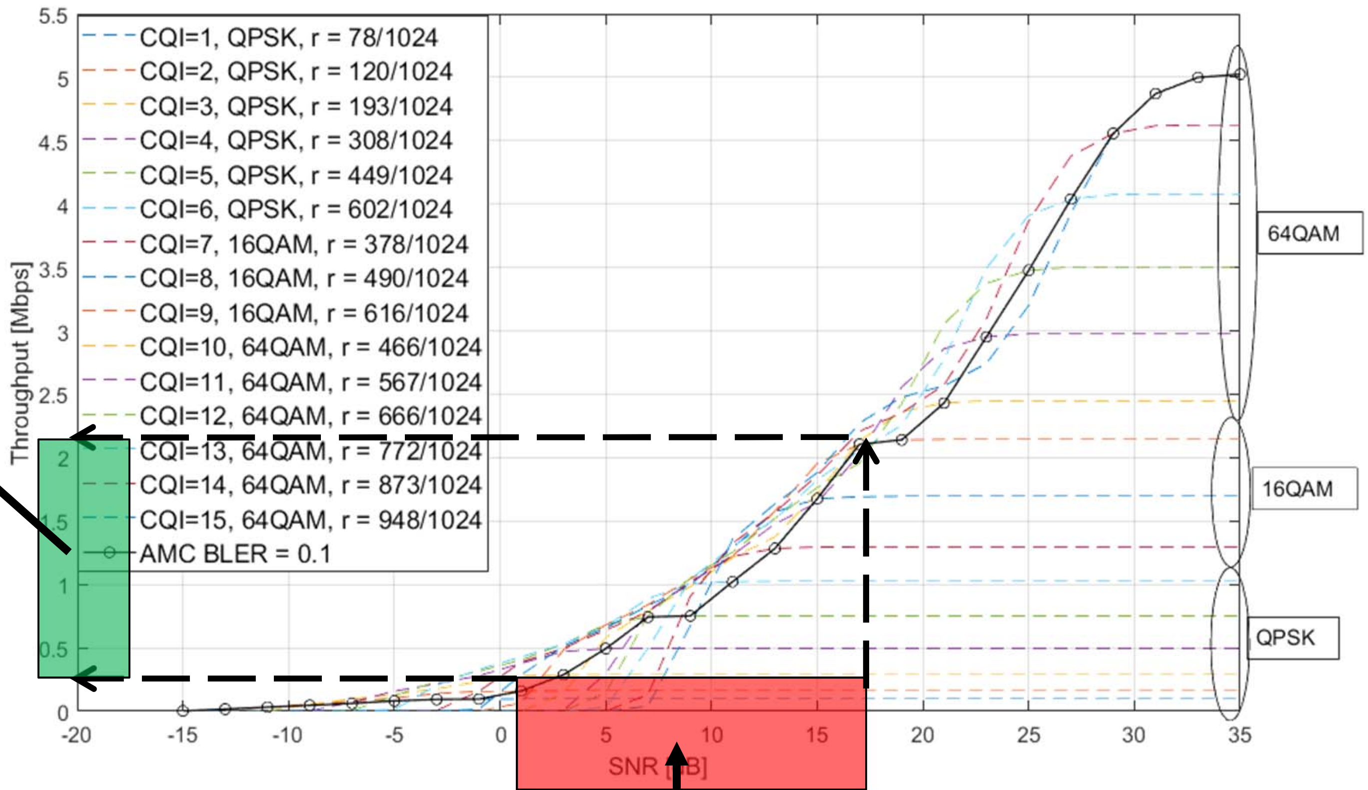
For a network setup, a sequence of secondary transmit powers yields a range of SINR values

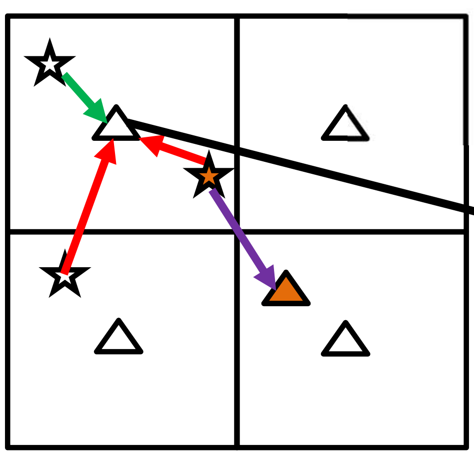
$$\gamma_i^{(p)} = \frac{G_{ii}^{(pp)} P_i^{(p)}}{\sum_{j \neq i}^{N_P} G_{ij}^{(pp)} P_j^{(p)} + \sum_{j=1}^{N_S} G_{ij}^{(ps)} P_j^{(s)} + \sigma^2}$$

NARX-NN learns the approximate location of the SINR band through the input of modulation schemes.

Training the NARX-NN

MARX-NN learns to predict throughput (equivalently the modulation scheme and channel coding rate)





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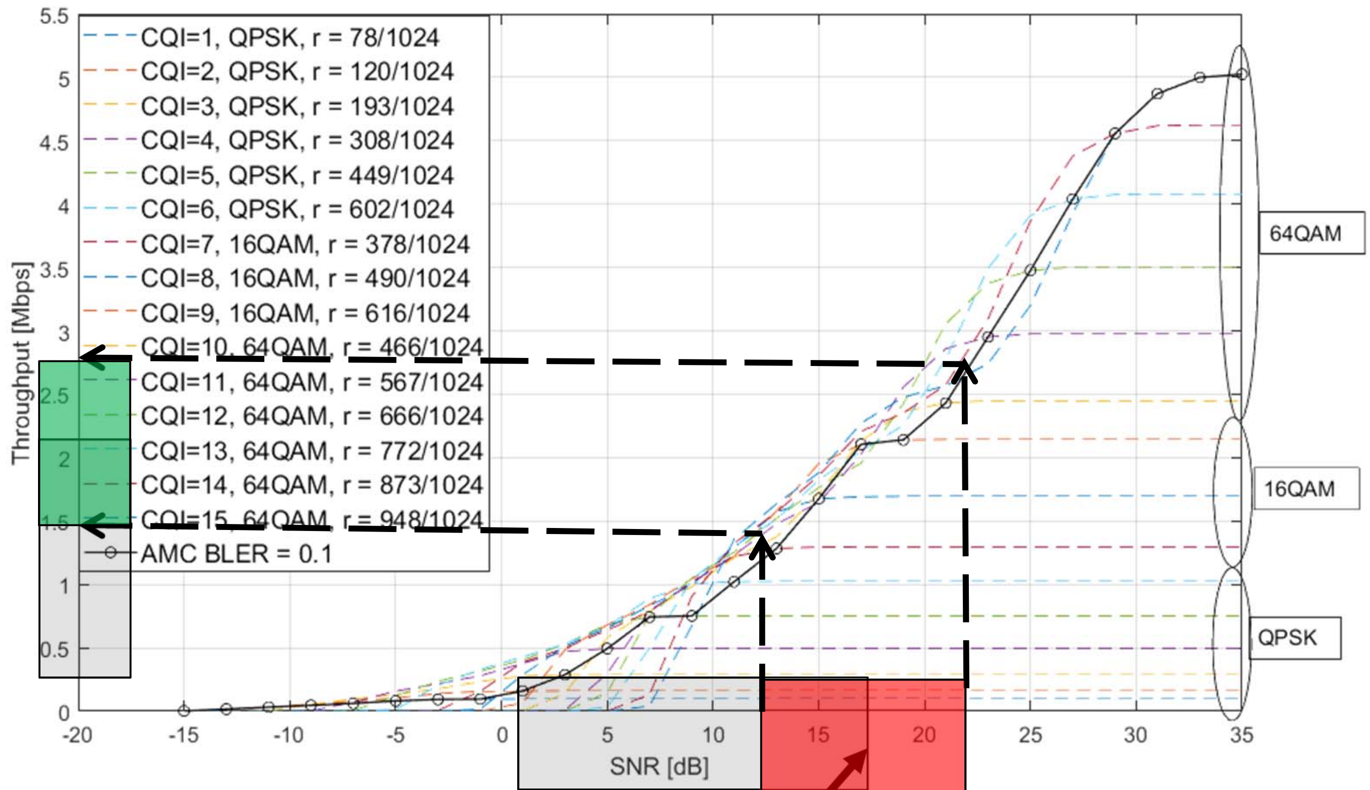
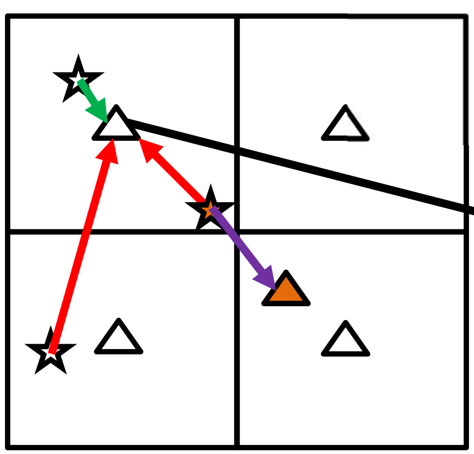
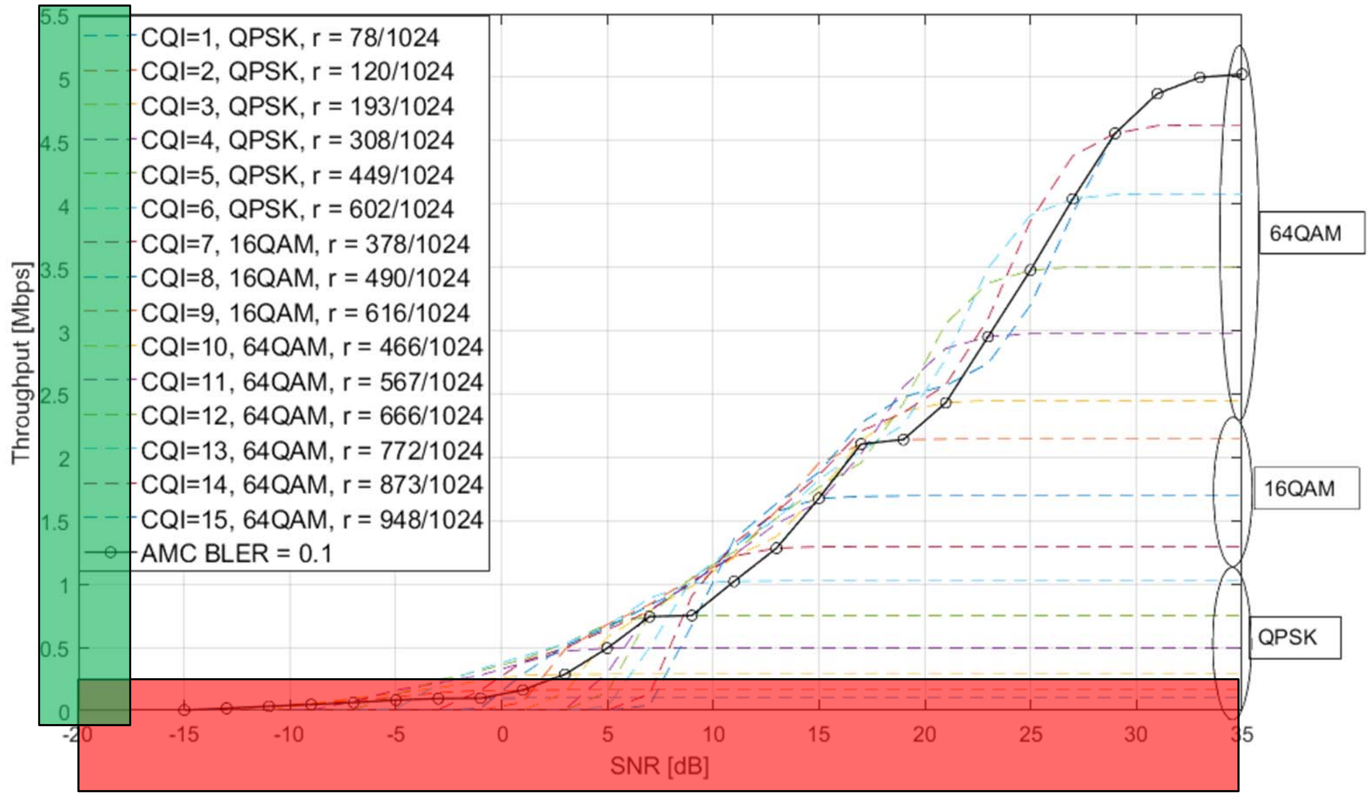




A different network setup, yields a different range of SINR values with new range of throughput predictions

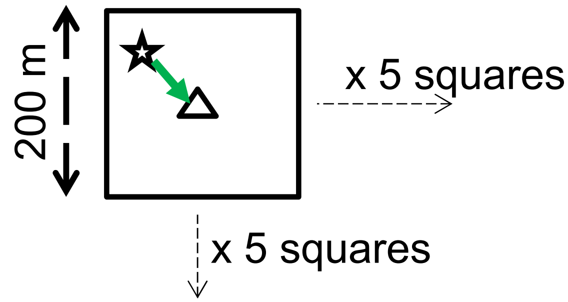
Training the NARX-NN



Eventually, after training with many different network scenarios, the NARX-NN cognitive engine learns the throughput vs SINR AMC performance curve and the corresponding modulation schemes used.

Results

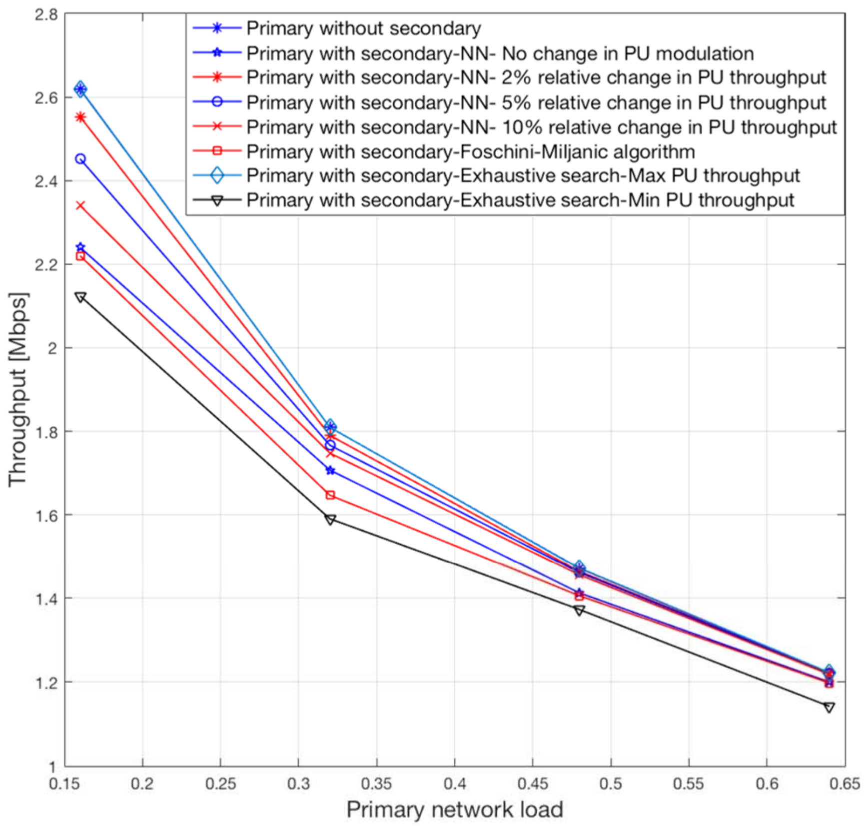
- Primary network has 25 access points located in a 5x5 square grid that wraps around the edges.
  - Access points are at the center of a square 200x200 m. coverage area.
  - Each access point is connected to one primary transmitter located at random within the square coverage area.

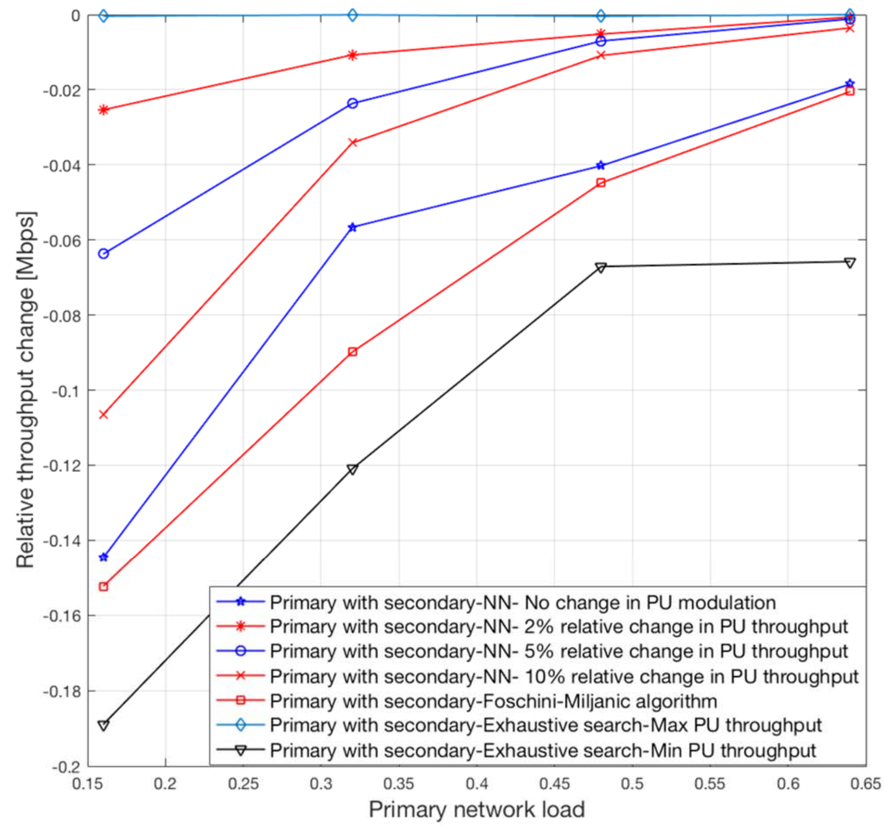


- Not all 25 primary transmitters are active in a transmission. The ratio of number of active transmitters to total number of transmitters is the **network load**.
- Four secondary receivers placed at random within the primary network coverage area.
- Each secondary transmitter placed at random within no more than 50 m. of its assigned receiver.
- Primary transmit power between -20 and 40 dBm. Secondary transmit power between -20 and 30 dBm.

Results

Average throughput and relative throughput change in primary network





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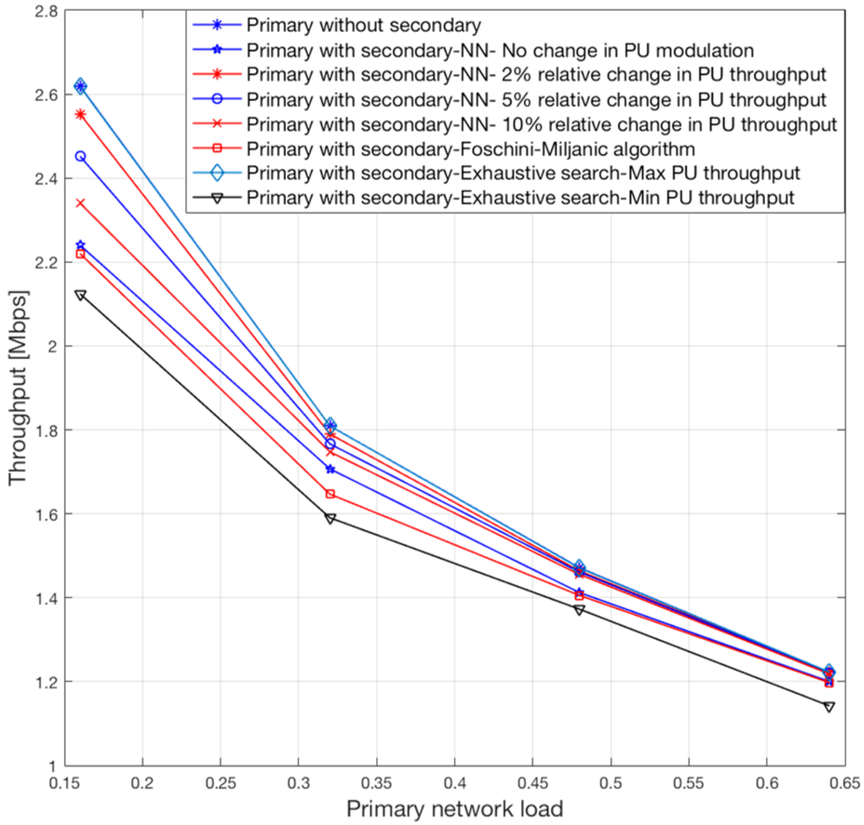
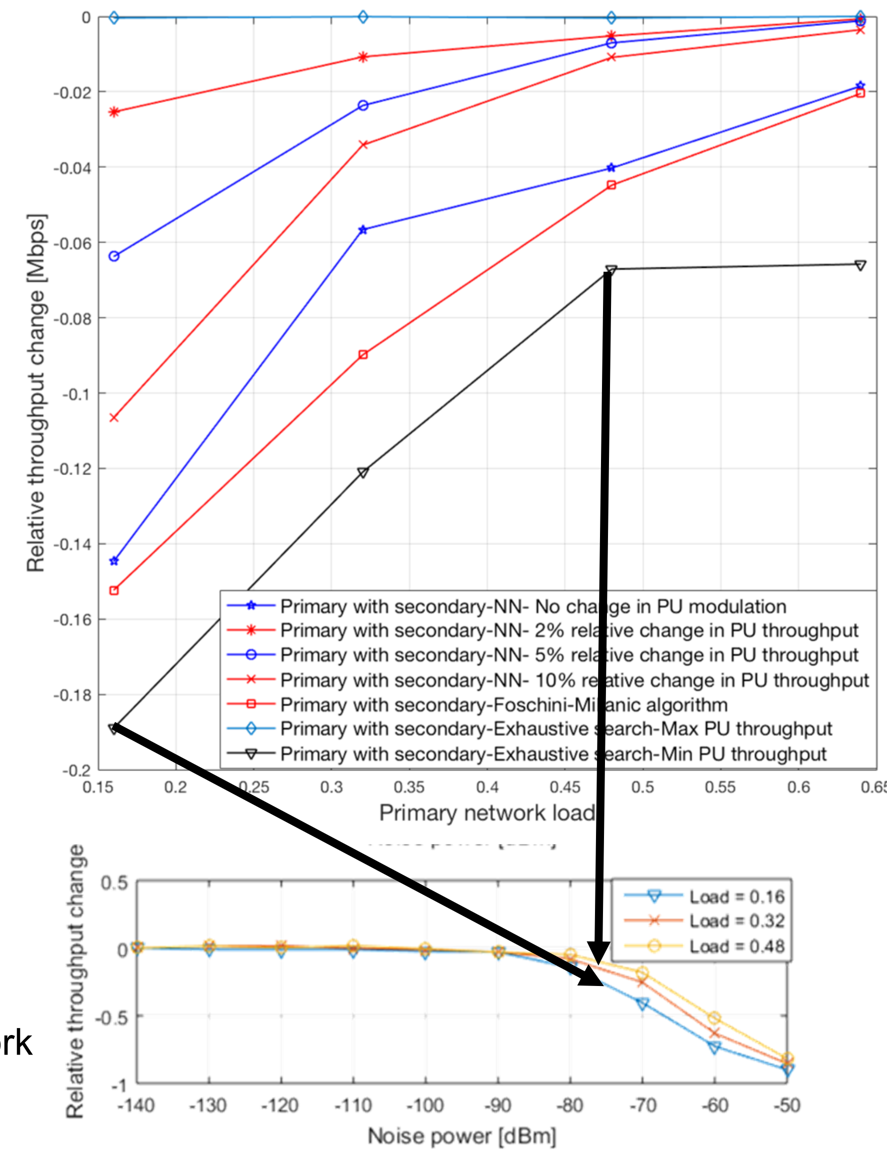
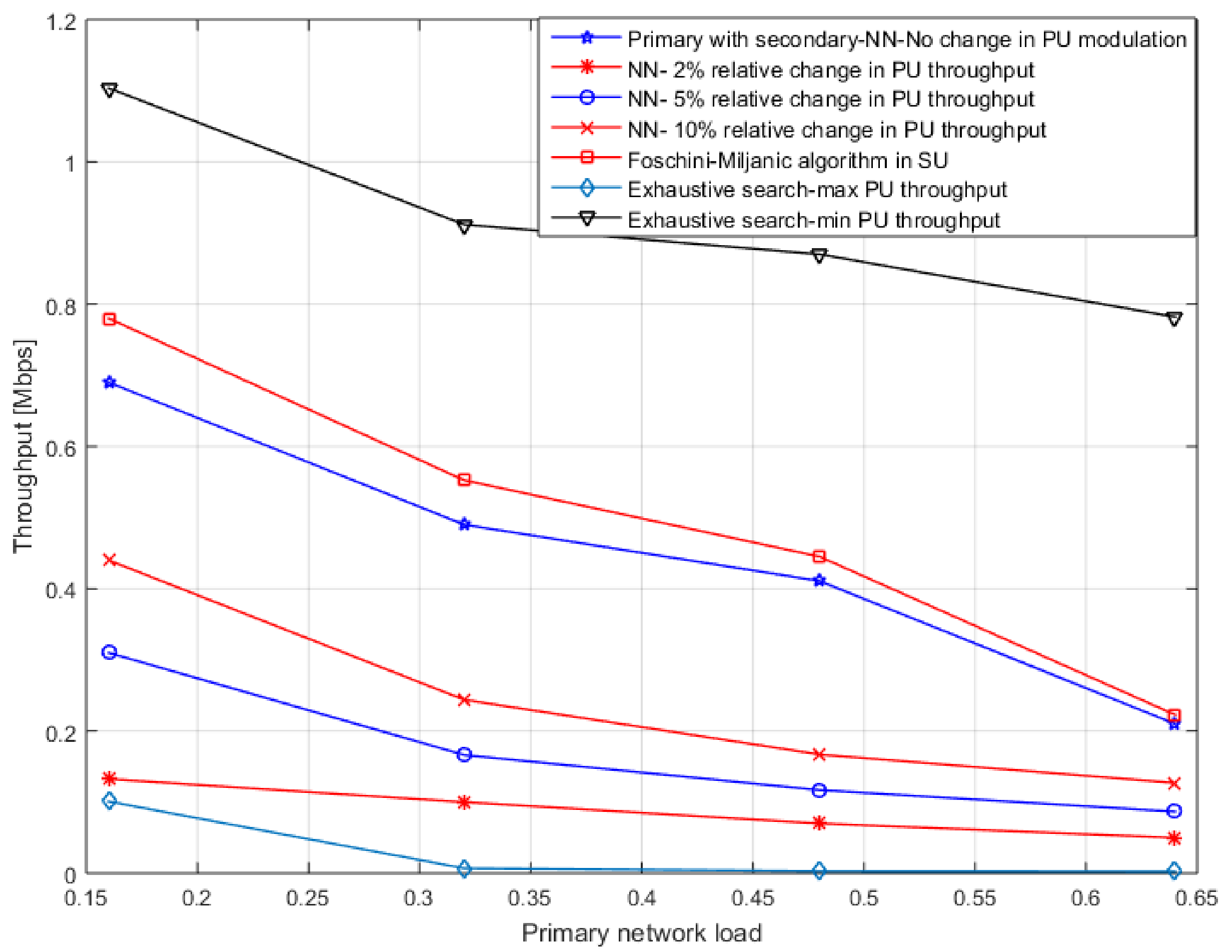




Relative throughput change in primary network as a function of background noise power

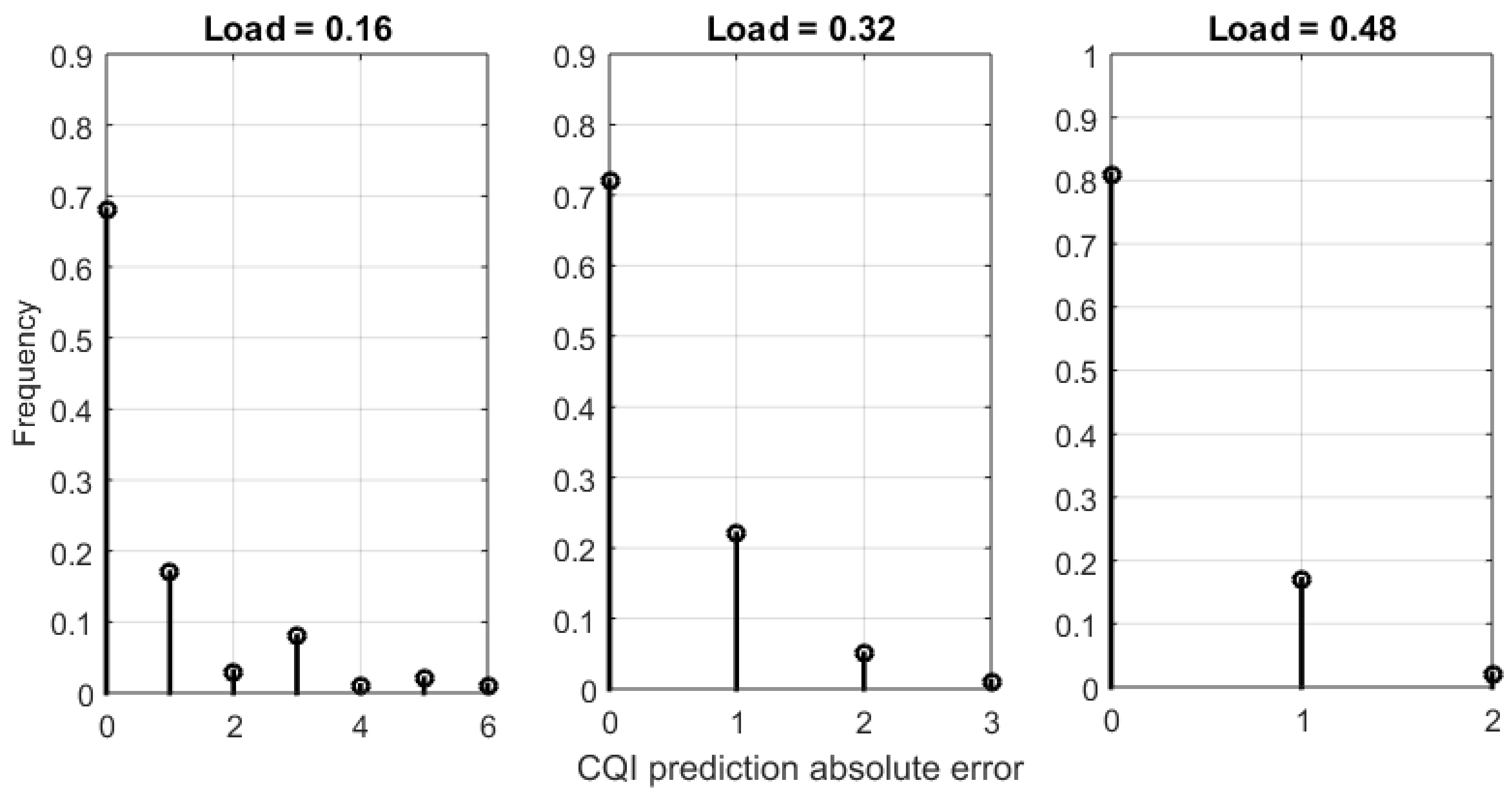
Results

Average throughput in secondary network



Results

AMC mode prediction accuracy (in terms of Channel Quality Indicator – CQI)



Conclusions

- Presented a neural network cognitive engine for autonomous and distributed underlay dynamic spectrum access:
  - » A cognitive engine based on a NARX neural network leverages the use of adaptive modulation and coding (AMC) in the primary network to infer the effect that different settings in a secondary network transmission would have on the primary network.
  - » No exchange of information between primary and secondary network.
  - » The technique is able to accurately predict the full AMC mode used in a primary link.
  - » Very fine control over effects on the primary network:
    - » The cognitive engine is able to find transmit settings for the cognitive radio so that average throughput at the primary network is not reduced by more than a chosen limit.