The GOODPUT System: A Machine Learning-Driven Optimization Framework for Dynamic Spectrum Control in Heterogeneous WLANs

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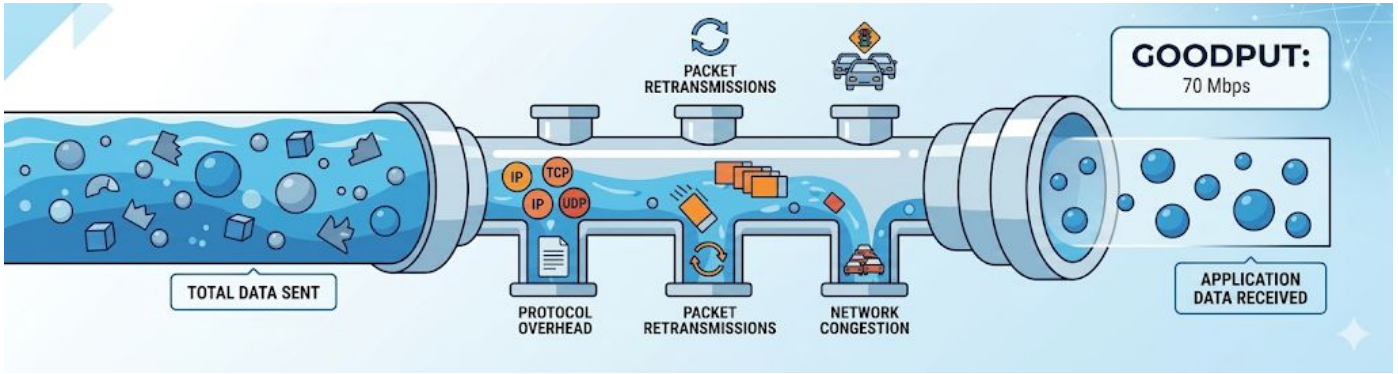
Goal

To optimize **goodput** (useful communication throughput) in spectrum-constrained scenarios via:

- *Access point (AP) channel assignment.*
- *Channel bonding decision.*
- *Wireless device (station) to AP mappings.*



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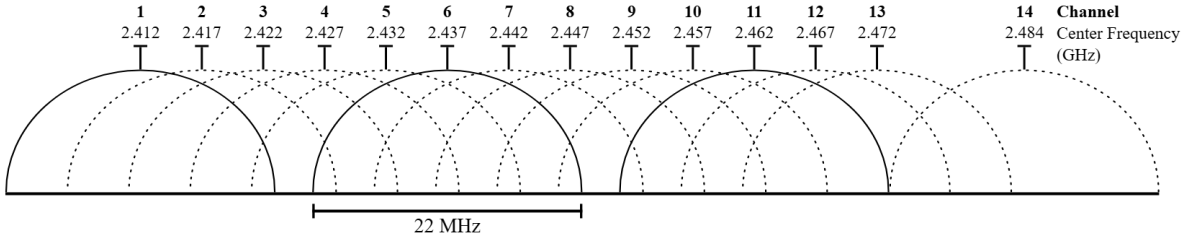

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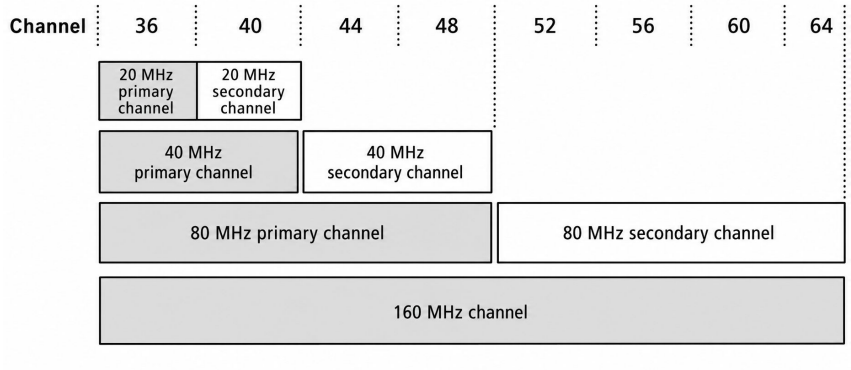

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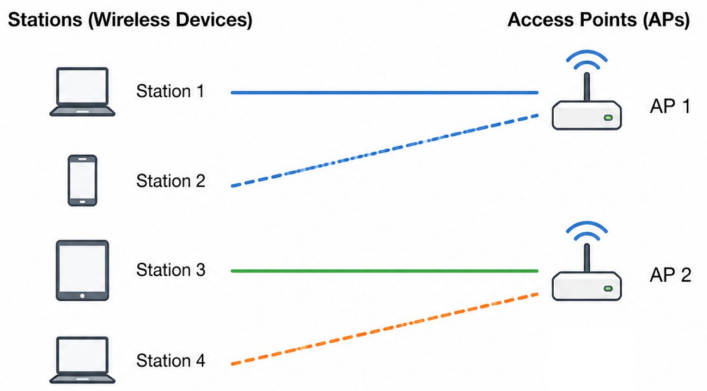
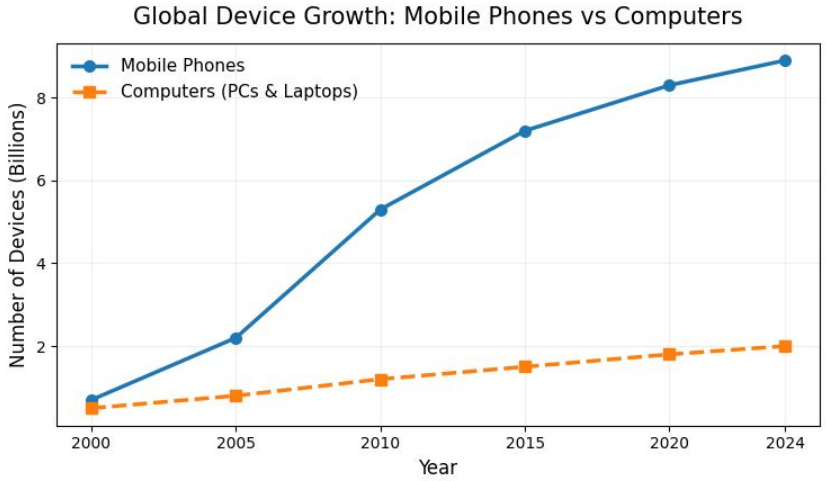


Background - Huge Amount of Devices

Mobile phones dominate device growth and are the primary driver of network load

- Mobile Phones: ~ 9 B
- Computers: ~2 B

(More than 75% of the connected devices use 2.4 GHz and 5 GHz bands)



Background - Suboptimal Solutions

Access Point-Centric Solutions:

- AP load-balancing.
- Heuristic based channel selection.
- Dynamic channel bonding.

Station-Centric Solutions:

- AP selection.
- Intelligent application traffic control.

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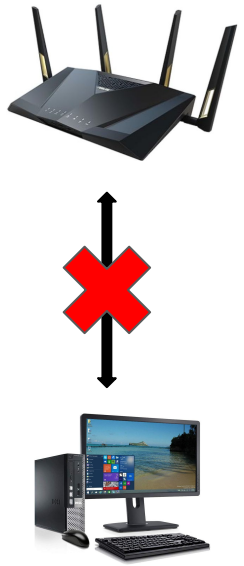

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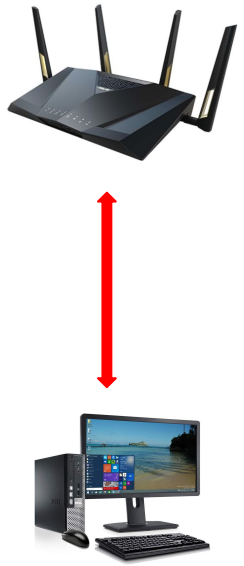
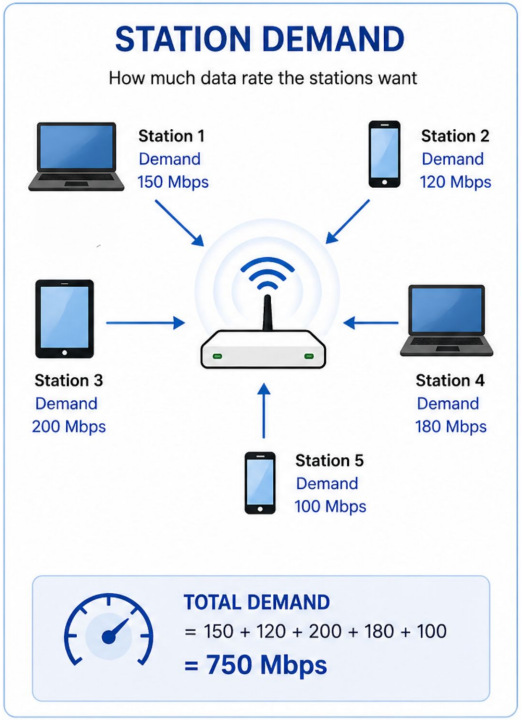


Supply and Demand Relationship

By analyzing

- device communication trace.
- AP channel information.



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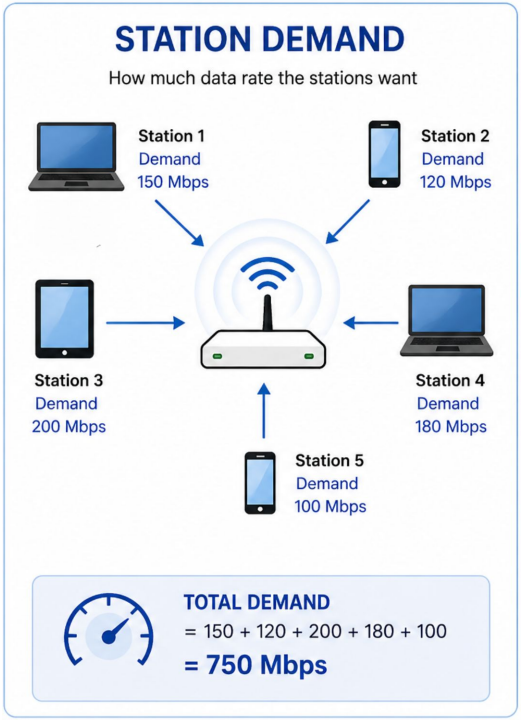
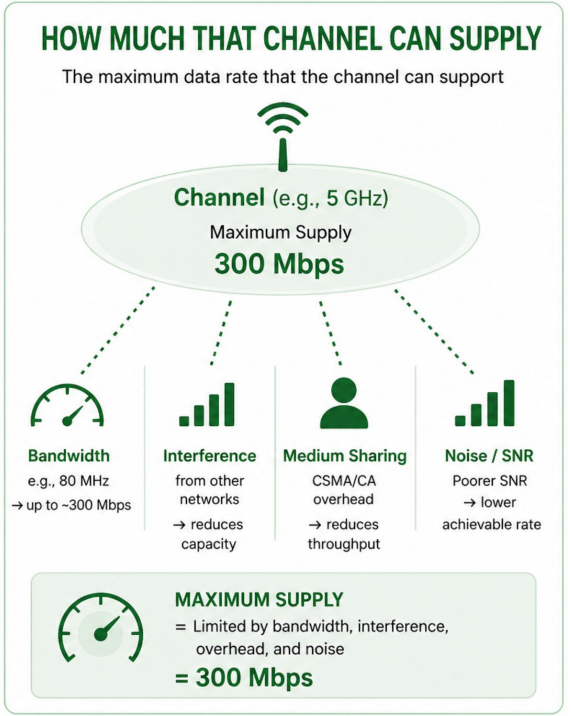
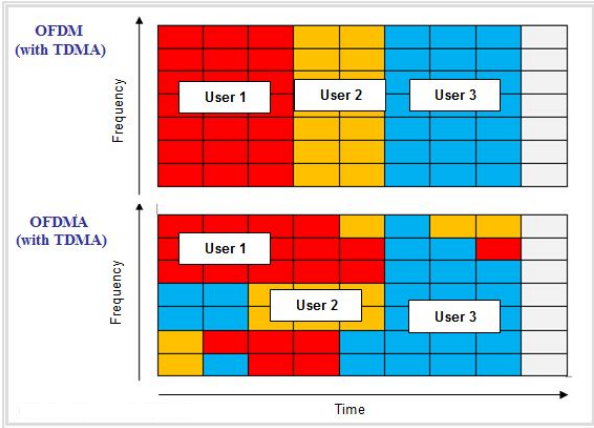




OFDMA

Orthogonal Frequency-Division Multiple Access (OFDMA):

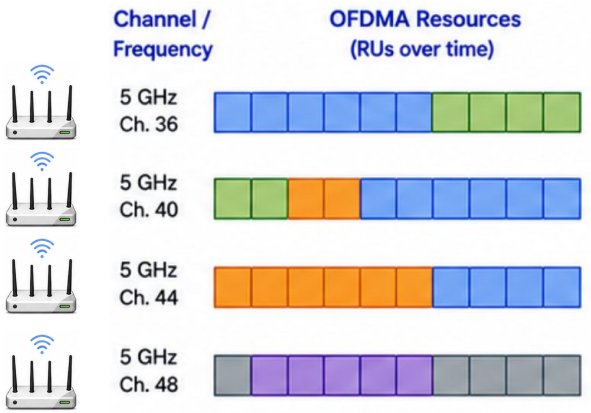
- Introduced in Wi-Fi 6 (802.11ax).
- Dividing wireless channels into smaller sub-carriers called Resource Units.
- Serve multiple users simultaneously within a single transmission window.

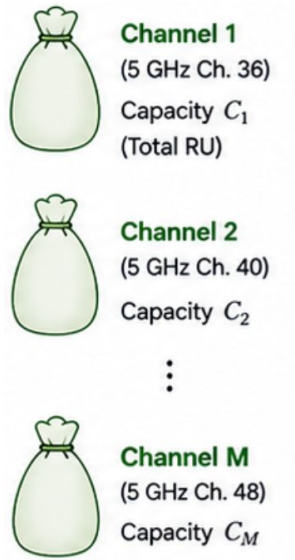


OFDMA to Multiple Knapsack Problem

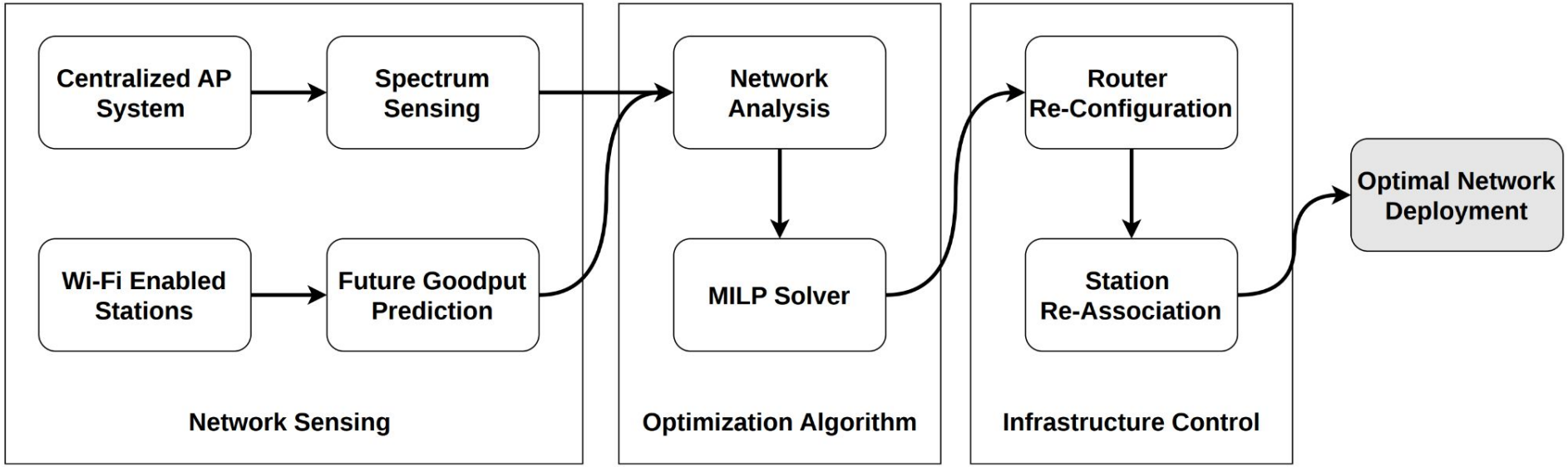
Formulated as Multiple Knapsack Problem (MKP):

- Captures multi-channel nature of OFDMA.
- Handles heterogeneous station demands.





GOODPUT System Overview



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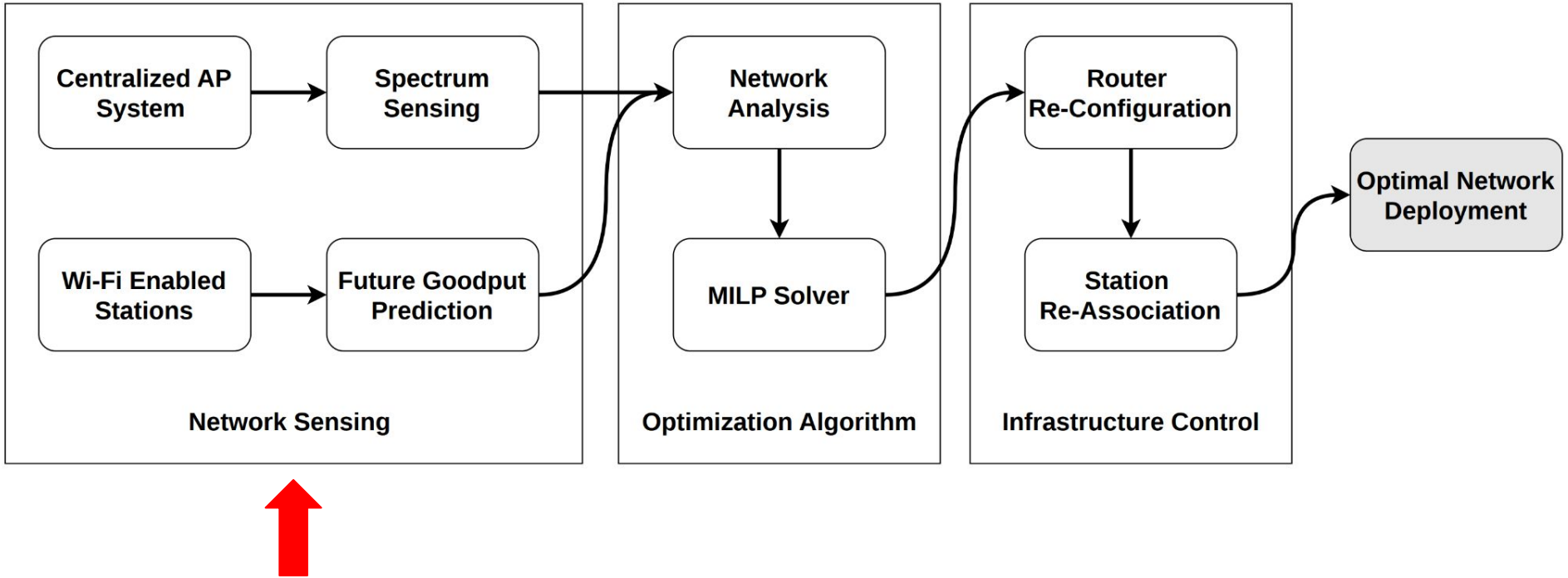
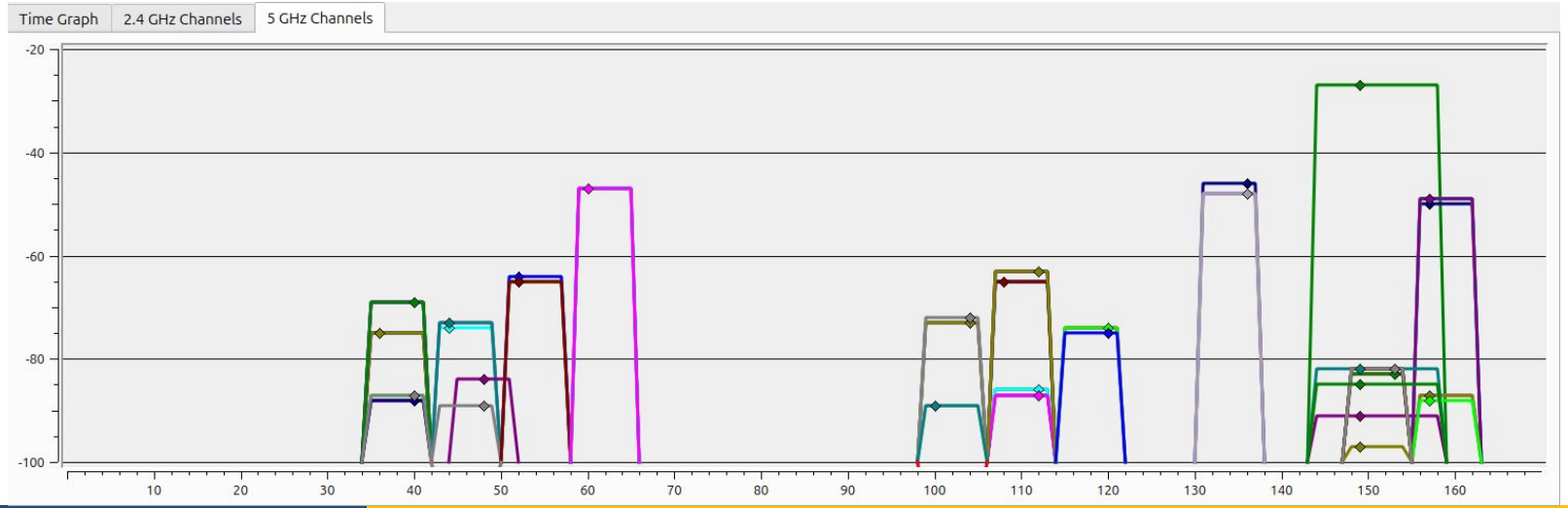


Network Sensing

The system sense

- Channel distribution.
- Station demand.



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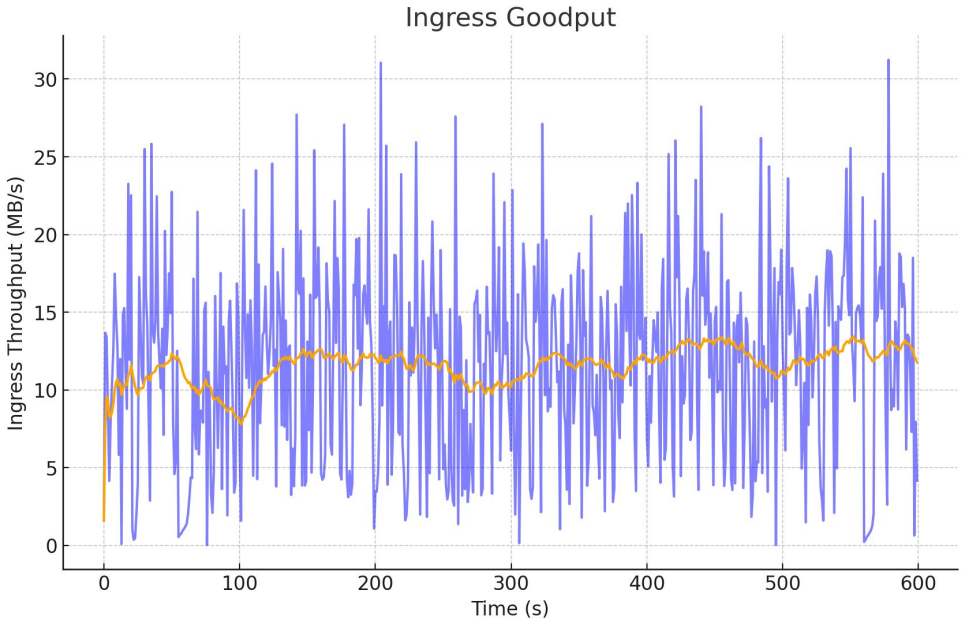
- Station demand (LSTM model is used for future demand prediction).



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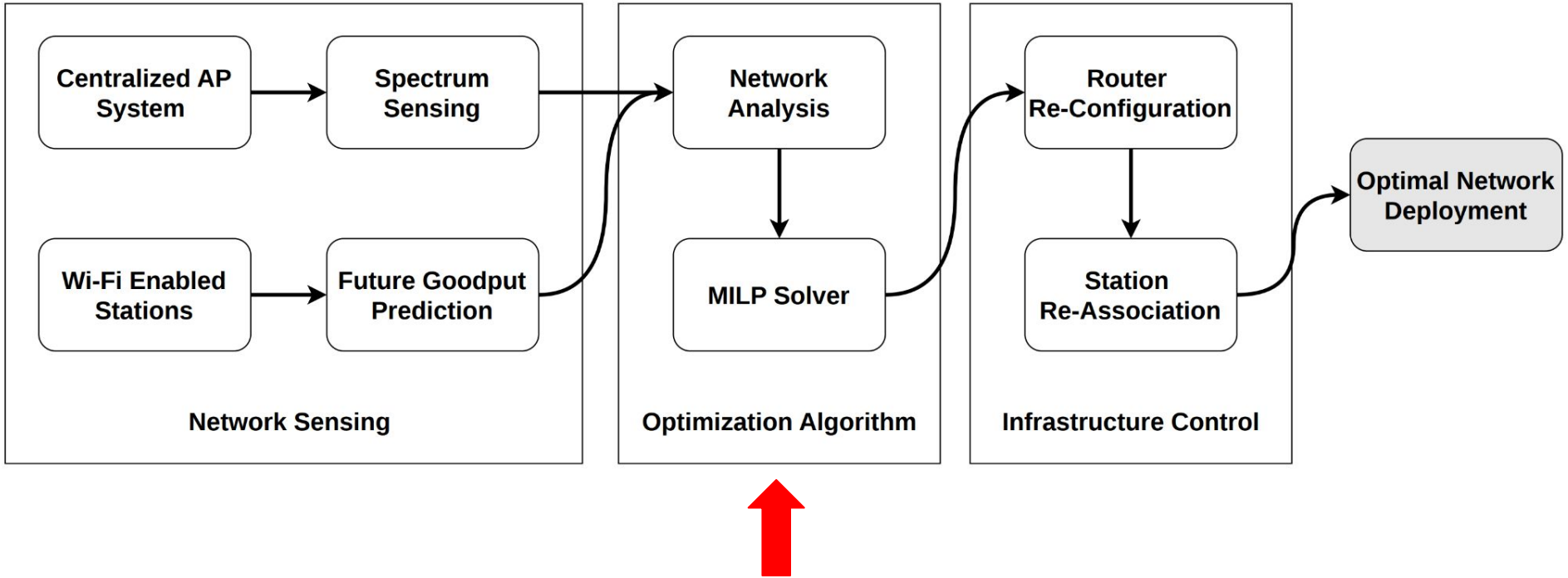


Optimization Algorithm

1) Objective Function

We aim to maximize the total delivered data (goodput) across all stations, APs, and time slots.

$$\max \sum_{t=1}^{T} \sum_{i=1}^{n} \sum_{j=1}^{m} x_{i,j,t}\, z_{i,t}\, d_i(t)\, \Delta t$$

- T : total number of time slots
- n : total number of STAs
- m : total number of APs
- $d_i(t)$: achievable data rate of STA i in slot t (bps)
- Δt : duration of one slot (s)

2) Constraints

a) Each AP uses exactly one configuration in each time slot

$$\sum_{c=1}^{K} y_{j,c,t} = 1,\ \forall j, t$$

b) Each STA is associated with at most one AP in each time slot

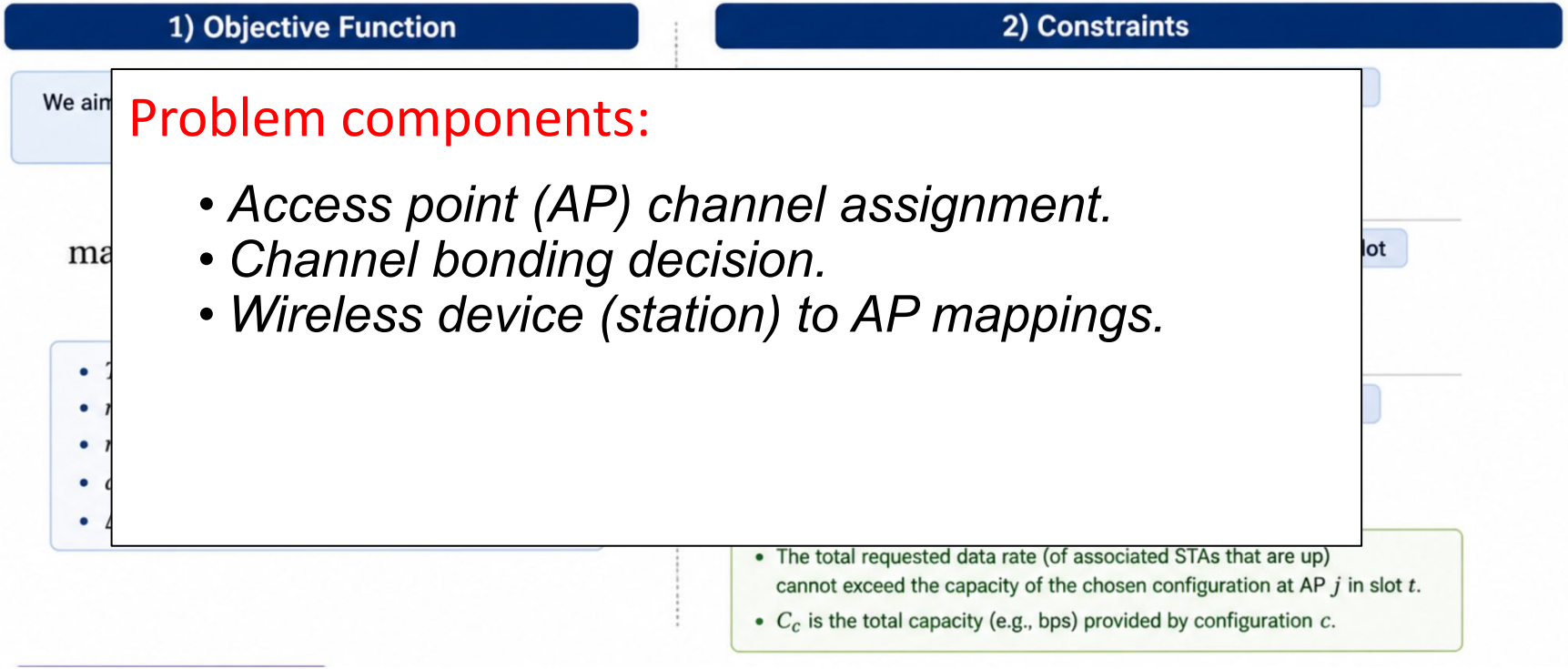
$$\sum_{j=1}^{m} x_{i,j,t} = 1,\ \forall i, t$$

c) Resource (capacity) constraint for each AP and time slot

$$\sum_{i=1}^{n} x_{i,j,t}\, z_{i,t}\, d_i(t) \le \sum_{c=1}^{K} y_{j,c,t}\, C_c,\ \forall j, t$$

- The total requested data rate (of associated STAs that are up) cannot exceed the capacity of the chosen configuration at AP j in slot t.
- C_c is the total capacity (e.g., bps) provided by configuration c.

Optimization Algorithm



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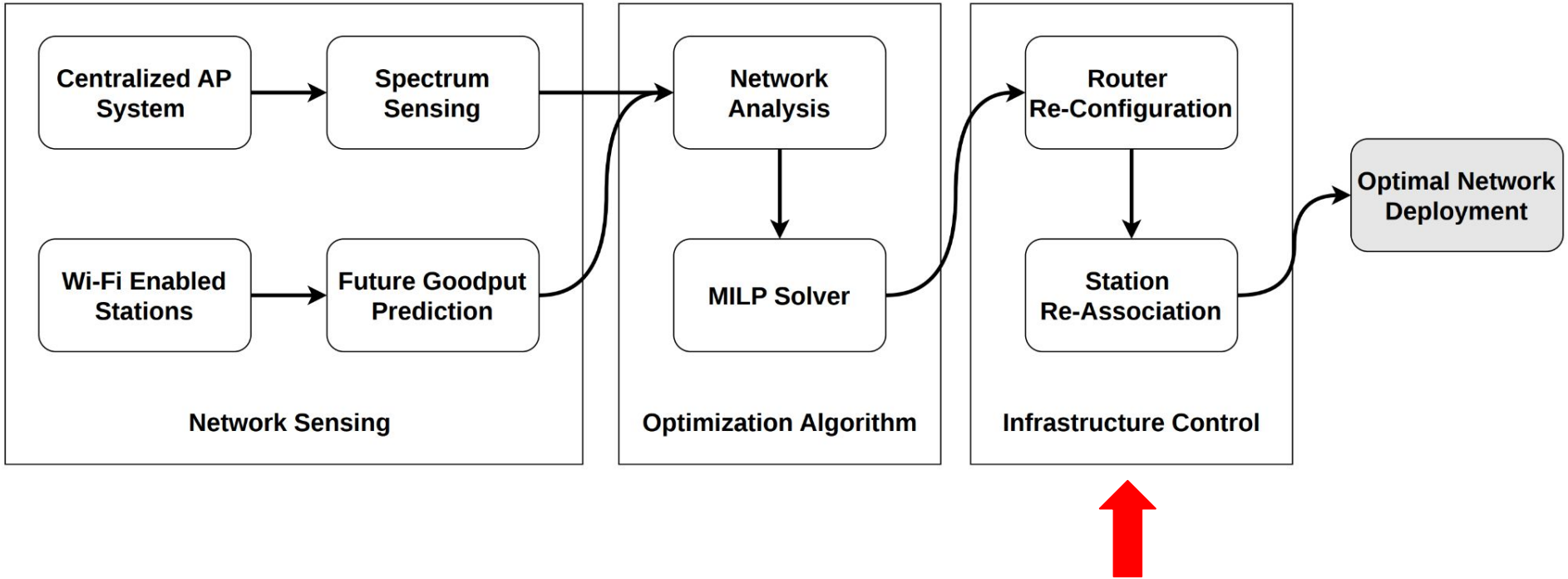
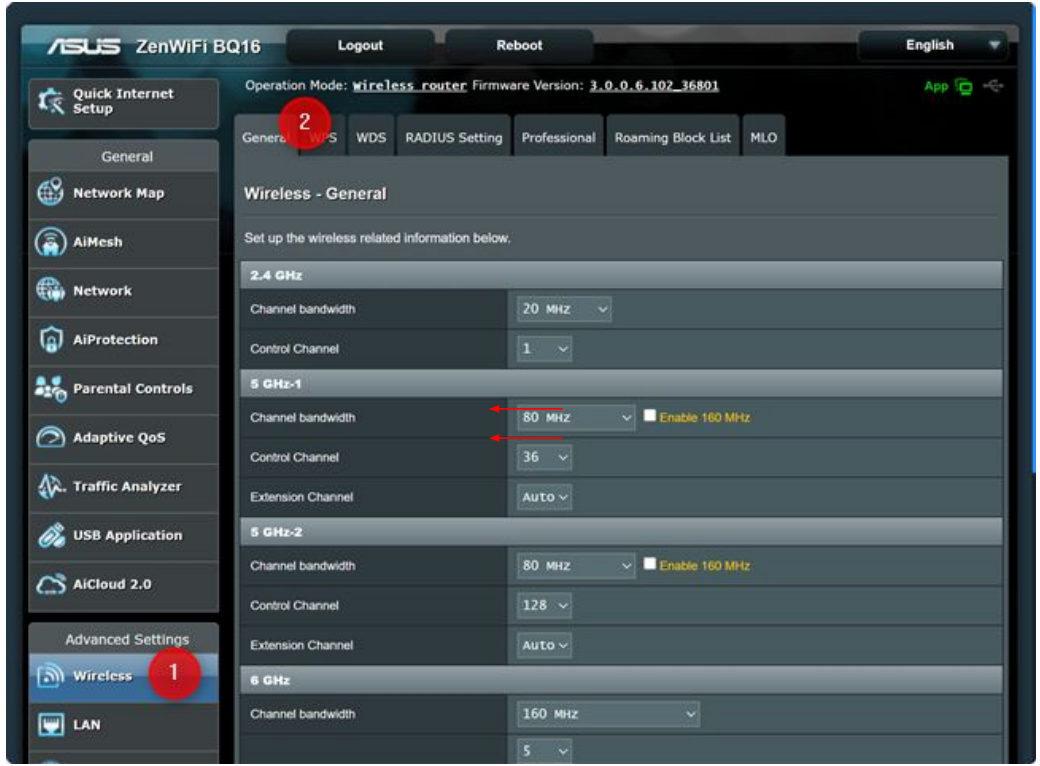


Infrastructure Control

Access Point:

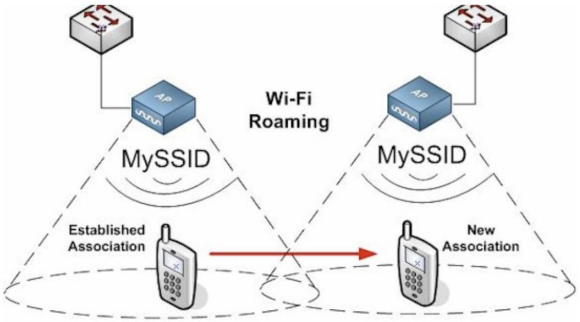
- Selenium WebDriver.
- Web-based AP control interface



Infrastructure Control

Wireless device (station):

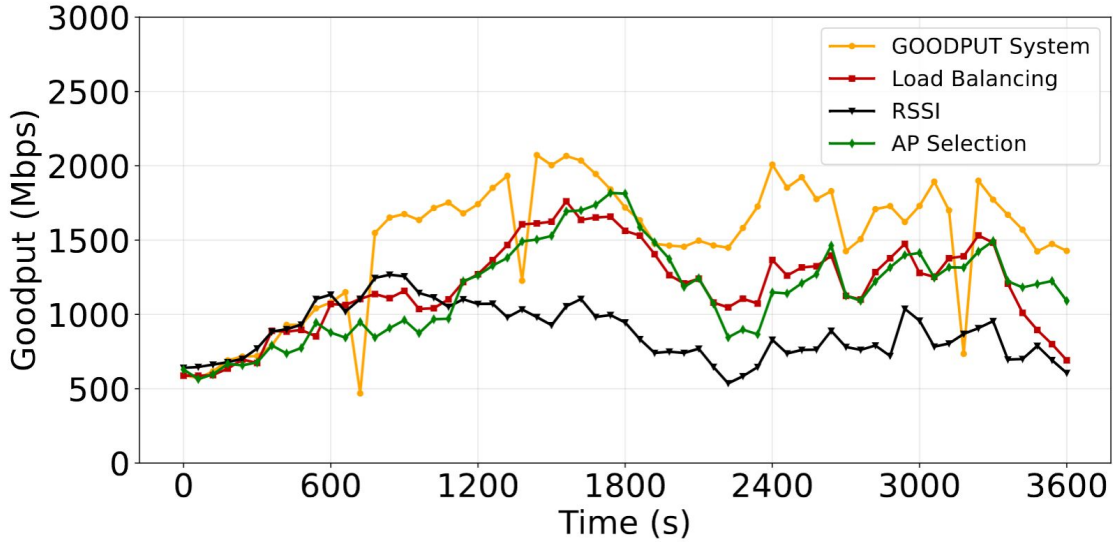
- Wpa_cli: a command-line tool used to interact with wpa_supplicant, a program that handles wireless network connections on Linux systems.



Results

Hardware deployment:

- 3 access points. 15 hardware hosts. 100 virtualized stations.
- 3 baseline comparisons: RSSI association, dynamic load balancing, DNN based access point selection.



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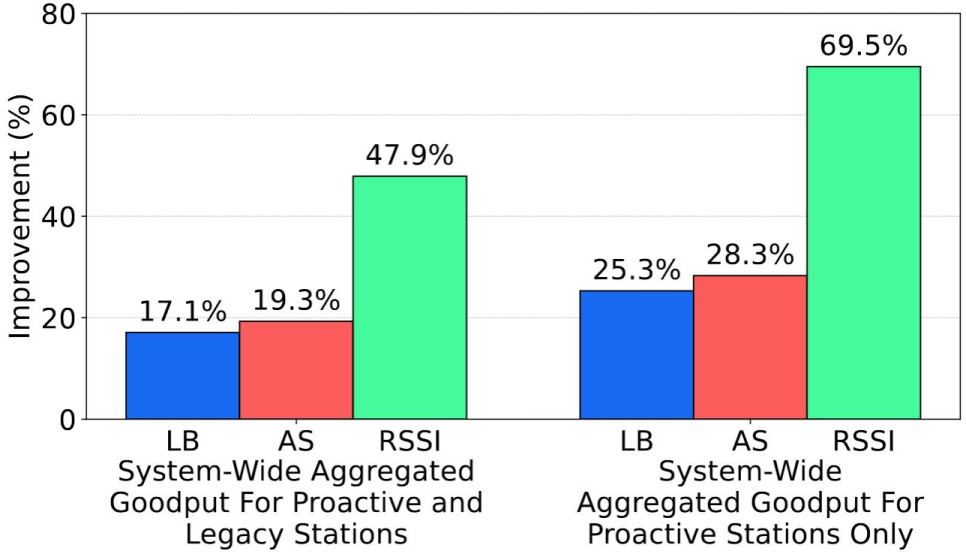

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- Baselines: fixed at 240 MHz channel.
- GOODPUT: dynamically reduces to 200 MHz (after 482 s).
- Effect: lowers interference in congested environments.
- Efficiency: typically uses 207 MHz.
- Savings: 14% less spectrum than static baselines.