Building Network Digital Twins for Next-Generation WLANs using Graph Neural Networks

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Agenda

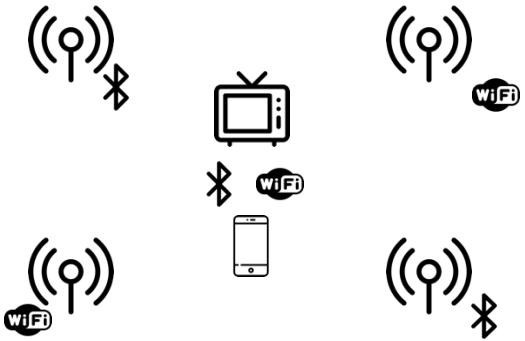
- Part 0 – Network Digital Twins – 6G-TWIN vision
  - Motivation
  - Technology enablers
  - Architectural concept
- **Part I - Introduction to Wireless Networking Management**
  - Background in Wi-Fi and its medium access mechanisms.
  - Background in Channel Bonding
  - Challenges in Channel Bonding
  - Necessity for digital twins
- Part II – Hands-on: Building an NDT for Next-Generation WLANs with traditional AI/ML/DL
  - Introduction to dataset
  - Introduction to AI/ML/DL techniques
  - Hands-on: Building an NDT with traditional AI/ML/DL
- Part III – Hands-on: Building an NDT for Next-Generation WLANs using Graph Neural Networks
  - Motivation for using Graph Neural Networks (GNNs) in topology-based problems
  - Introduction to GNNs
  - Hands-on: Building an NDT for Next-Generation WLANs using GNNs
- Part IV – What is next?

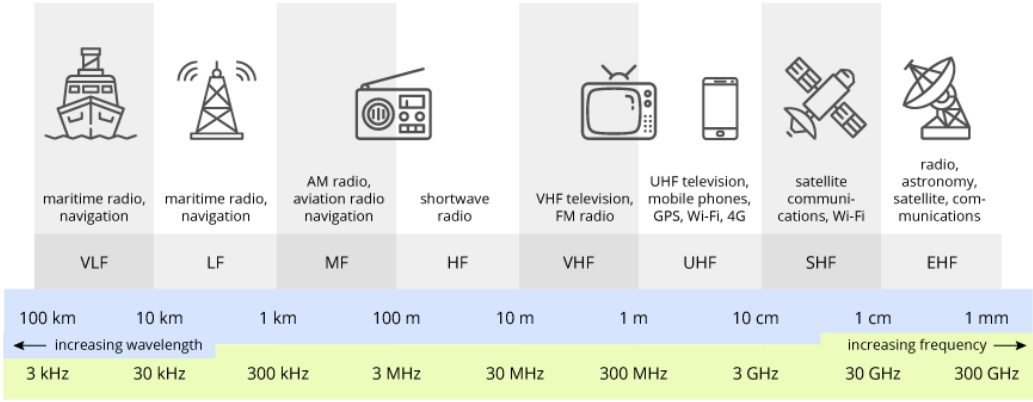
Introduction to Wi – Fi

Wi-Fi Background

Introduction

- Technically known as IEEE802.11 (back in 1999).
- Mainly uses the 2.4GHz and the 5GHz radio spectrum bands (a.k.a. unlicensed spectrum).
- The spectrum is shared with other technologies.
  - Listen before talk mechanisms – spectrum sensing





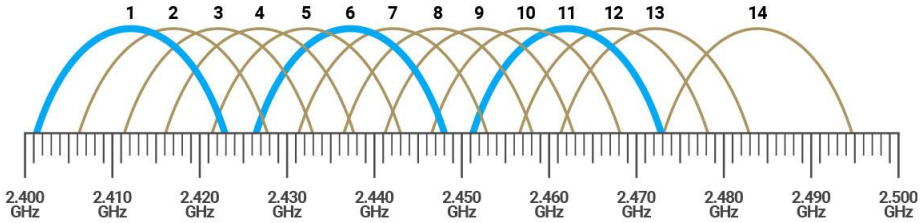
Source: https://terasense.com/terahertz-technology/radio-frequency-bands/

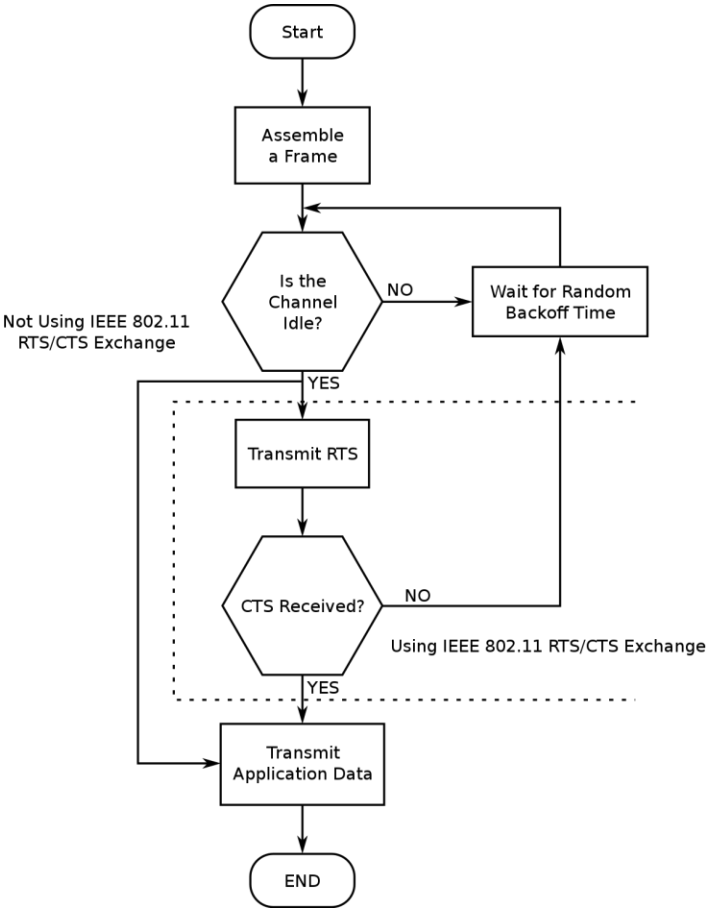
Wi-Fi Background

Spectrum Sharing in Wi-Fi

- Through protocols Wi-Fi shares the spectrum with same/other technologies.
- Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)

Source: https://www.engeniustech.com/go-guide-channel-transmit-power-wi-fi-networks-2/





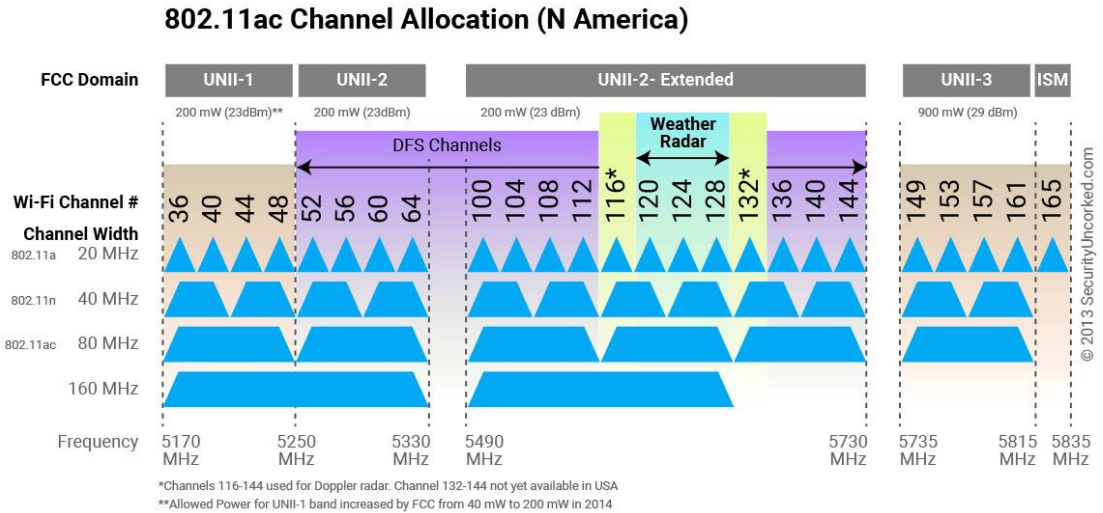
Source: https://en.wikipedia.org/wiki/Carrier-sense_multiple_access_with_collision_avoidance

Introduction to Channel Bonding

Channel Bonding

Increase available bandwidth

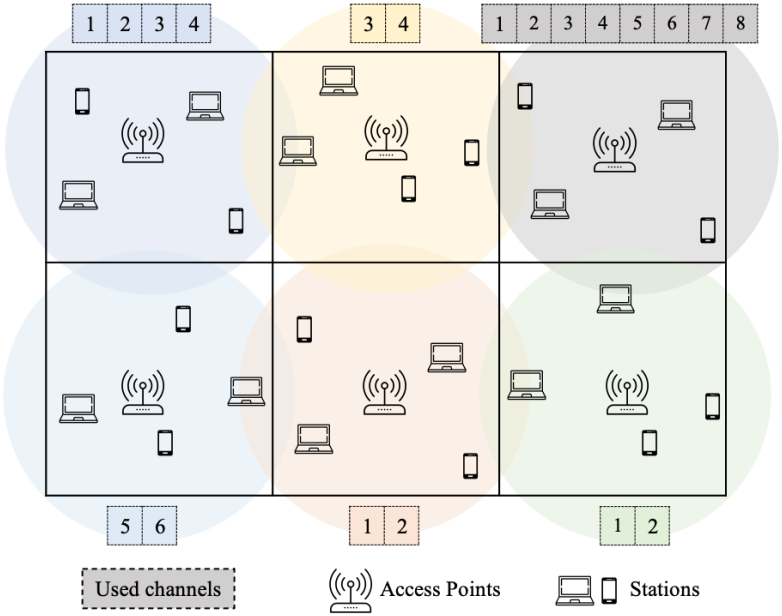
- Typical bandwidth in Wi-Fi is 20MHz
- Key Idea: Improve capacity by bonding frequency channels
- CSMA/CA is still valid.
- Can have different channel access policies

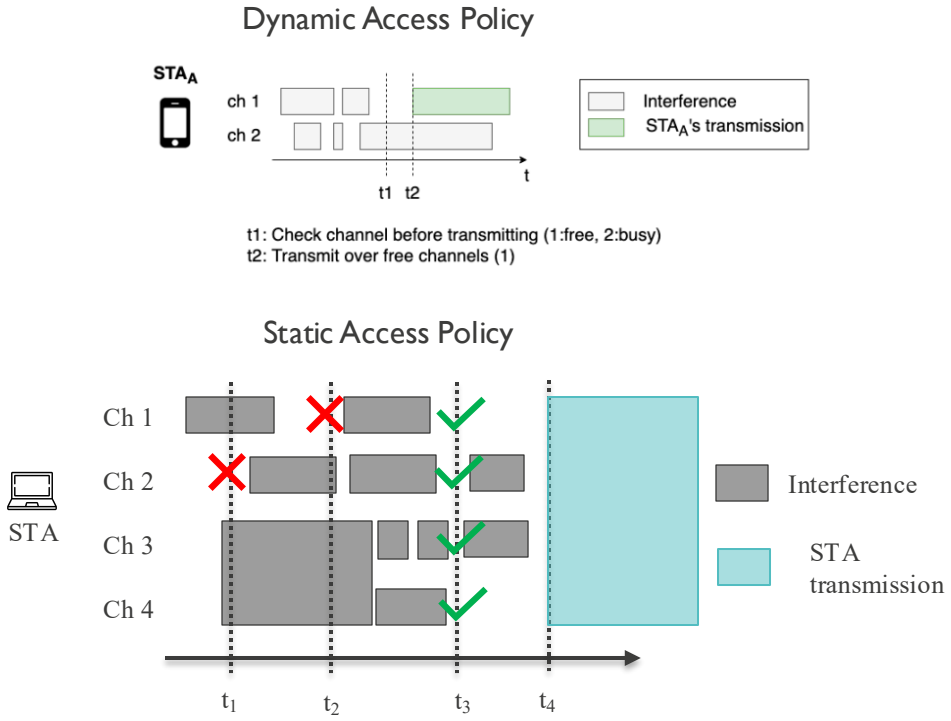


Source: https://www.engeniustech.com/go-guide-channel-transmit-power-wi-fi-networks-2/

Channel Bonding

Increase available bandwidth

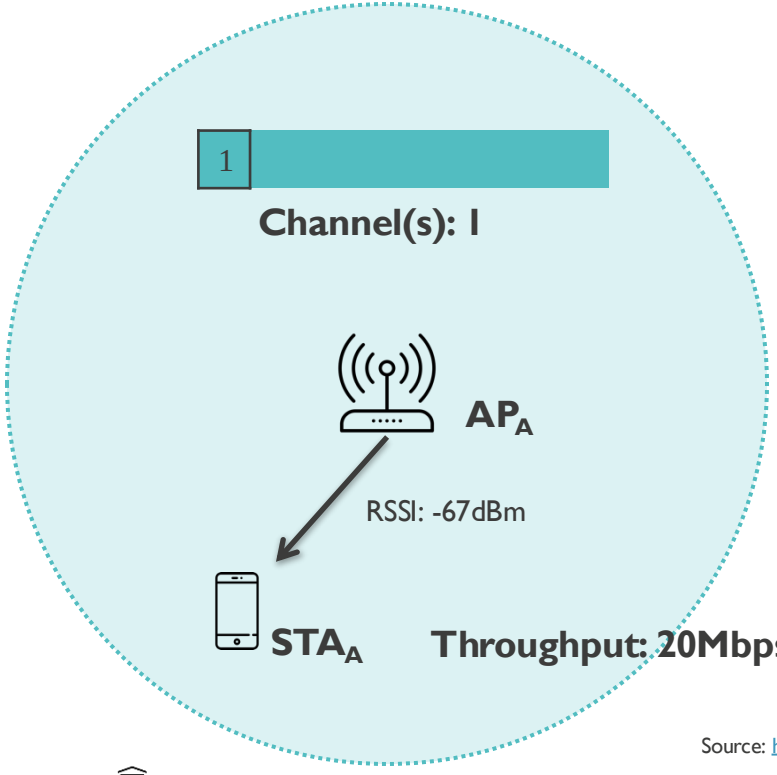




I. F. Wilhelmi, D. Goez, P. Soto, et al, "Machine learning for performance prediction of channel bonding in next-generation IEEE 802.11 WLANs", ITU Journal on Future and Evolving Technologies, Volume 2 (2021), Issue 4 - AI and machine learning solutions in 5G and future networks, Pages 67-79.

Channel Bonding

Challenges



The quality of the transmission (e.g., throughput, delay) depends on the Tx power & Channel effects

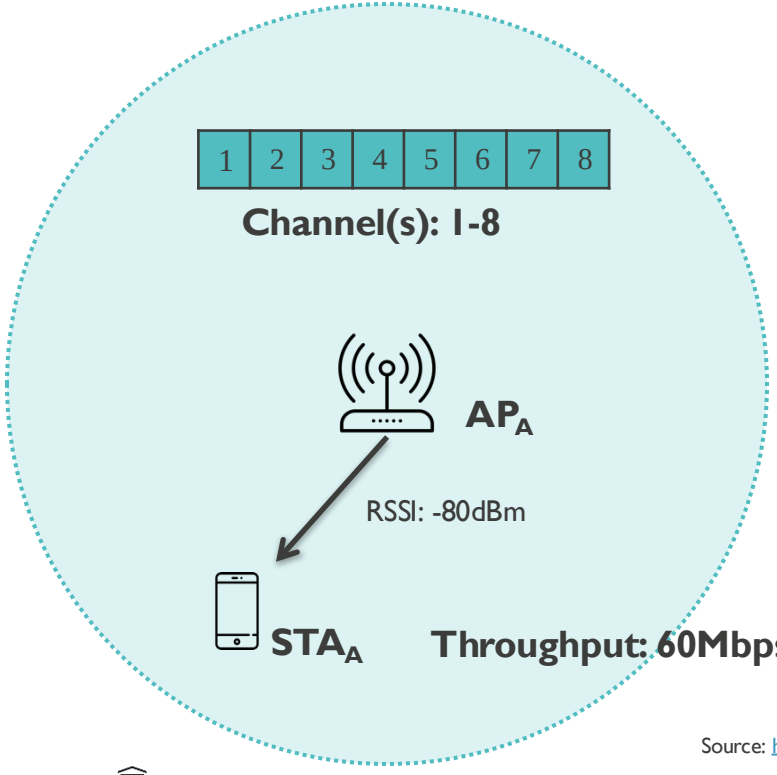
$$C = B \cdot log_2(1 + SINR)$$

C: Channel capacity
B: Channel bandwith
SINR: signal to interference plus noise ratio

Source: https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20AI_ML%20Challenge%20-%20UPF.pdf

Channel Bonding

Challenges



The throughput is not x8 since the transmission power is spread over the spectrum

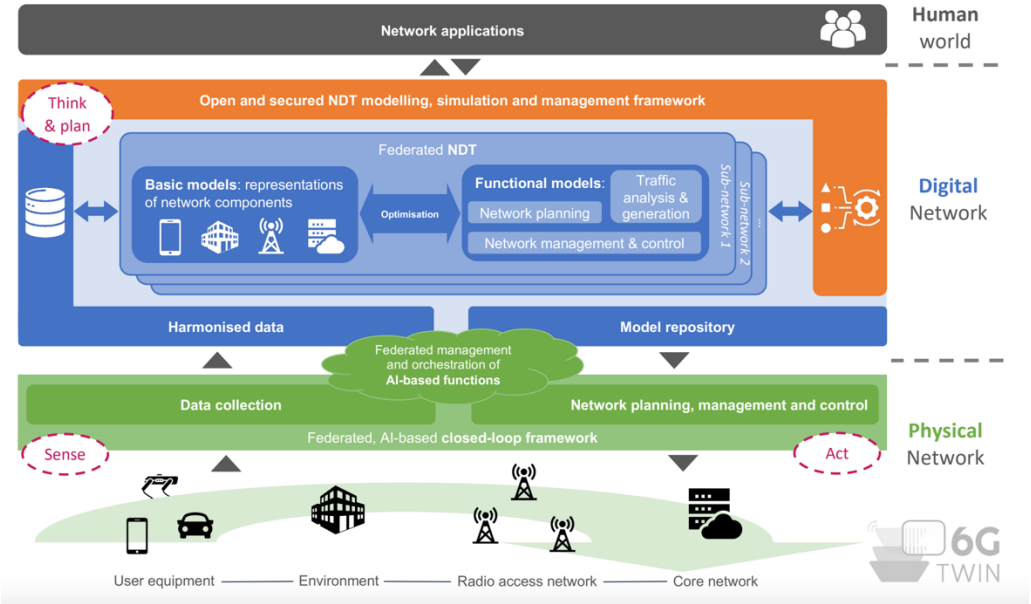
Source: https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20AI_ML%20Challenge%20-%20UPF.pdf

Network Digital Twins

Digital Twins

Introduction

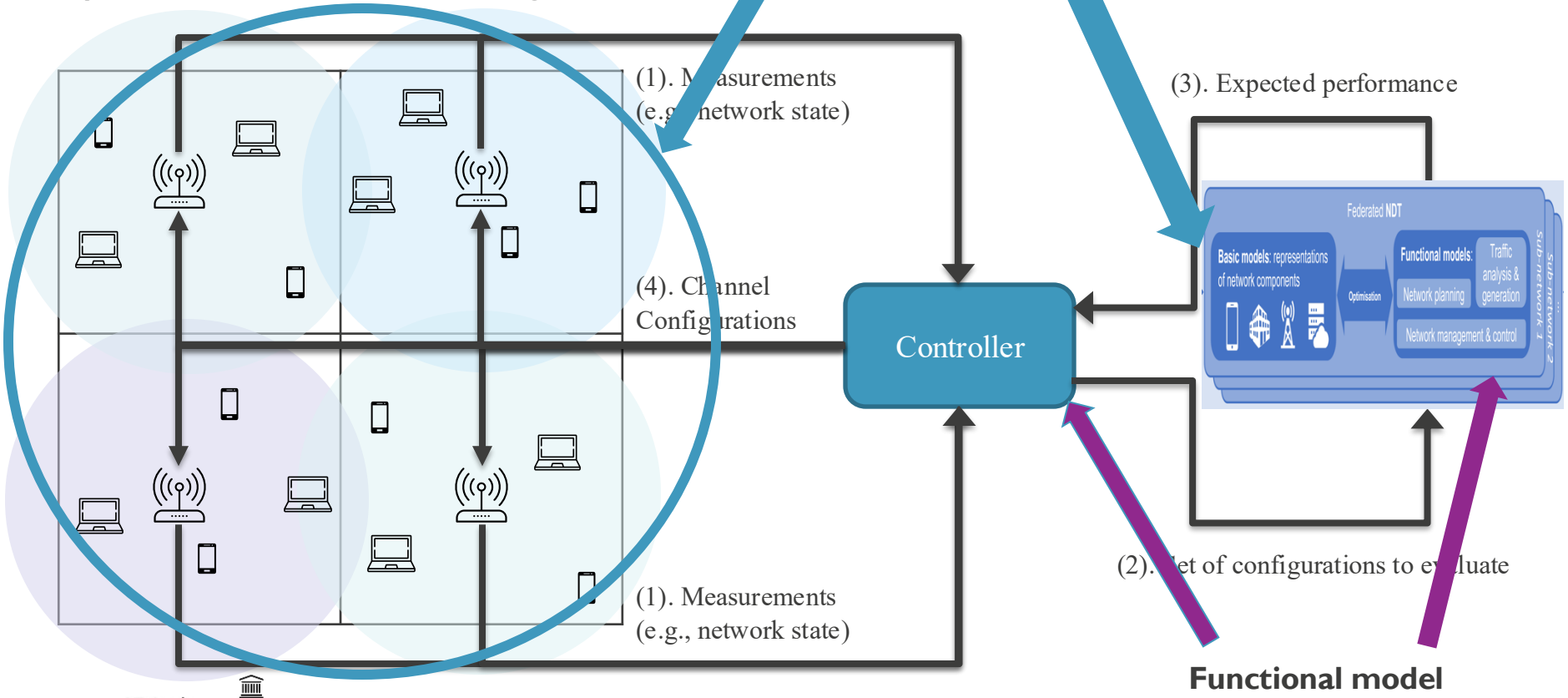
- Digital representation of a physical element.
- Monitored data to enhance the operational view of the physical system.
- Applied to networks, a Digital Twin it's a network model.
  - What-if analysis → What is the obtained throughput under this configuration?
  - Network planning and optimization → Can the network support another demand?



S. Faye *et al.*, "Integrating Network Digital Twinning into Future AI-based 6G Systems: The 6G-TWIN Vision," *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, Antwerp, Belgium, 2024, pp. 883-888, doi: 10.1109/EuCNC/6GSummit60053.2024.10597058.

Digital Twins

Why a NDT is needed in next generation WLANs?



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