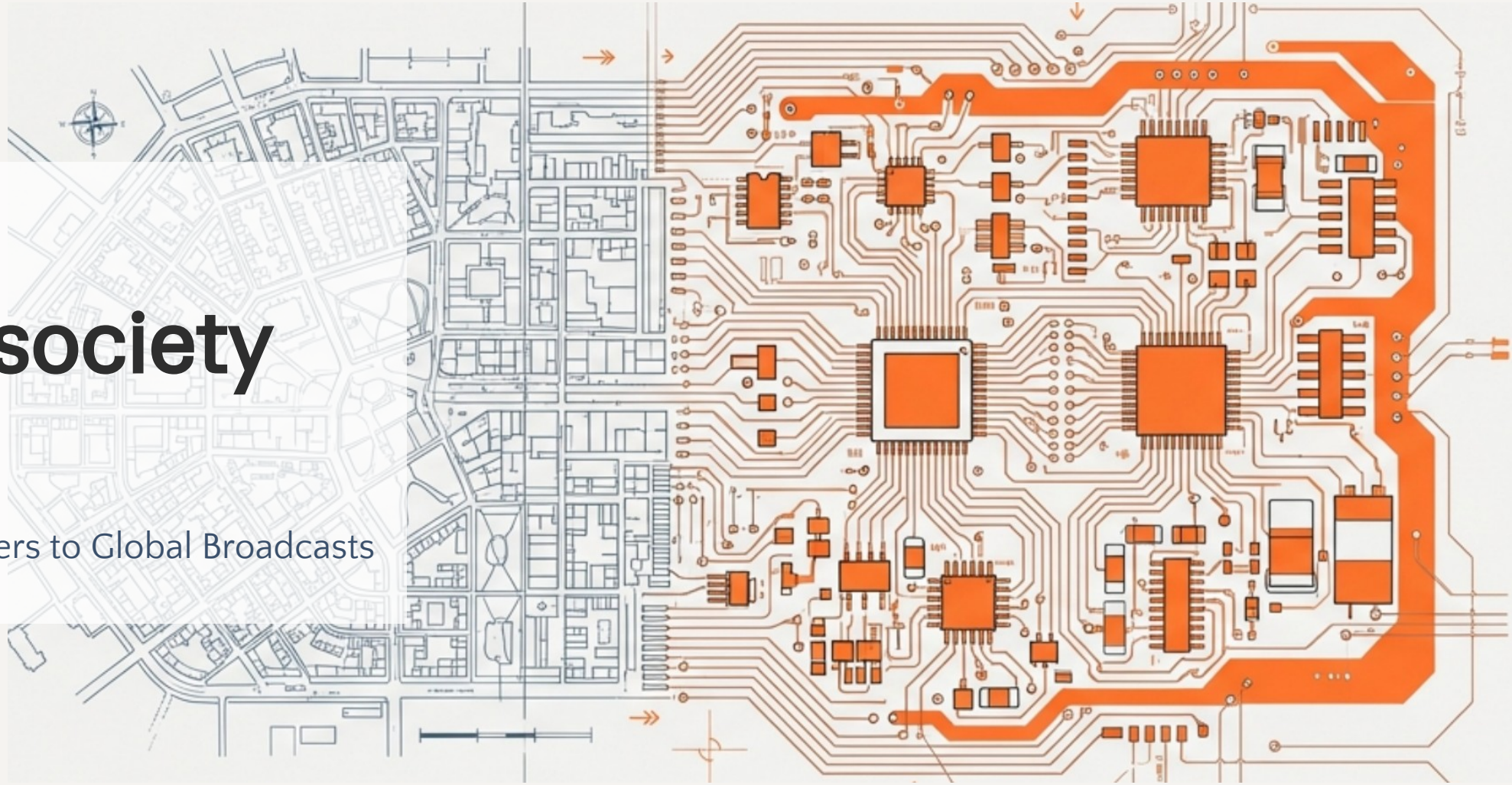
FAB ACADEMY 2026

Building a network/ society of things

From Chip-Scale Whispers to Global Broadcasts



Course Context:

- Interiors: Chip-to-Chip
- Infrastructure: Device-to-Device
- The Horizon: Networked Systems

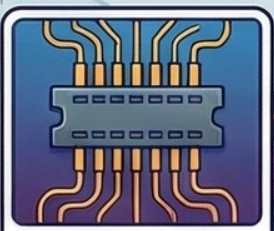
By Eric Pan, Henk Buursen,
Luc Hanneuse, Saheen Palayi
& NotebookLM

Navigation

THE BEGINNER'S ROADMAP TO HARDWARE COMMUNICATION

From Internal Chip-to-Chip Talk to Global Decentralized Systems

THE INNER CIRCLE
(Computers inside a Computer)



UART, I2C, and SPI
The most common wired protocols for connecting sensors and displays to an Arduino.

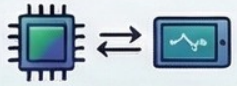
COMPARISON CHEATSHEET
(Inner Circle)

Internal | I2C / SPI
Connecting a screen or acceletometer to an Arduino.

Advanced Wired Buses
Complex industrial standards like CRN, LIN, and R5-405 for robust, long-distance wiring.

USB
(Universal Serial Bus)
Standard high-speed interface for connecting microcontrollers to computers and advanced peripherels.

COMPARISON CHEATSHEET
(Inner Circle)



Internal | I2C / SPI
Connecting a screen or accelerometer to an Arduino.

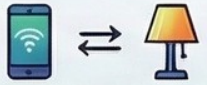
THE SOCIAL NETWORK
(Computers to Computers)

WIFI vs. BLUETOOTH
(LAN A PAN)
WiFi provides internet access: Bluetooth (BLE) is best for low-power, short-range device pairing.

LORA AND LONG-RANGE WIRELESS
Low-power wide-area networks (NAN) capable of kilomolers-long commanication for remote sensors.

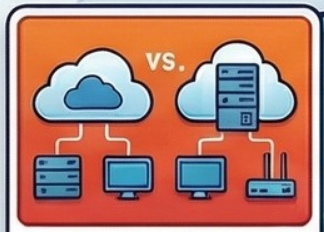
MESHTASTIC AND SATELLITES
Advanced decentralized device to-device messaging that functions without traditional cellular or internet infrastructure.

COMPARISON CHEATSHEET
(Local Network)

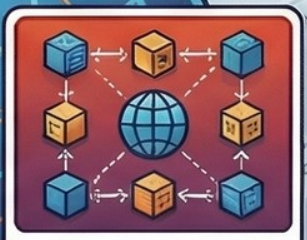


Local | WiFi / BLE
Controlling a smart lamp from a mobile phone.

THE DIGITAL SOCIETY
(Computers as a Computer)

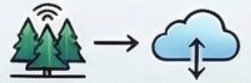


CLOUD vs. EDGE COMPUTING
Moving processing from centralized remote servore (Cloud) to local, real-time device intelligence (Edge).



BLOCKCHAIN AND DECENTRALIZATION
Cultural and technical choices shifting data ovnaerahip from central authorities to distributed networks.

COMPARISON CHEATSHEET
(Global Network)



Global | LoRa / Cloud
Tracking environmental data in a remote forest.

THE BLUEPRINT

Stratigraphy of the Network

The OSI Model as Digital Geology

7 — Application Layer
The Conversation · HTTP / MQTT

6 — Presentation Layer
Data Translation & Encryption

5 — Session Layer
Connection Management

4 — Transport Layer
Delivery · TCP (Reliable) / UDP (Fast)

3 — Network Layer
Routing · IP Addresses (192.168.1.1)

2 — Data Link Layer
Local Rules · MAC Addresses

1 — Physical Layer
The Raw Material · Voltage & Frequency

Producer Note

FabAcademy works primarily between Layer 1 (The Board) and Layer 3 (The Local Network).

This practical focus grounds abstract networking concepts in hands-on hardware implementation, bridging theory and practice.

Key Insight

Each layer serves the one above it, creating a modular architecture where changes at one level don't affect others.

Metaphor: Like a building's architecture, each floor has its function, yet they all work together.

THE INFRASTRUCTURE

Asynchronous Serial Streams

Communication Without a Shared Clock

NO CLOCK LINE

Timing is agreed upon in advance

Unlike synchronous protocols (I2C/SPI), asynchronous communication relies on **pre-configured baud rates** at both ends. Both devices must agree on timing before communication begins—like two musicians using metronomes set to the same tempo.

UART

Universal Asynchronous Receiver-Transmitter

Topology: Point-to-Point

Connection: TX → RX

Use: Debugging, PC connection

RS-232

Legacy Standard

Voltage: +/- 12V

Converter: FTDI required

Use: Legacy hardware

RS-485

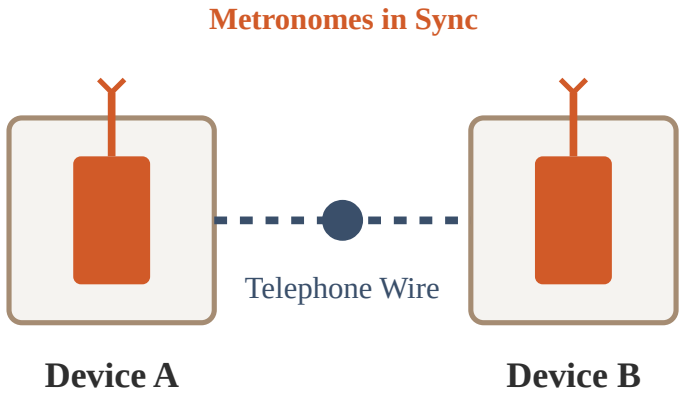
Industrial Standard

Signaling: Differential

Advantage: Noise immunity

Use: Long distances

Visual Metaphor



Both devices must use the **same baud rate** (e.g., 9600, 115200) for successful communication.

THE INTERIORS

Synchronous Chip Dialogue

Comparing I2C and SPI Protocols

I2C

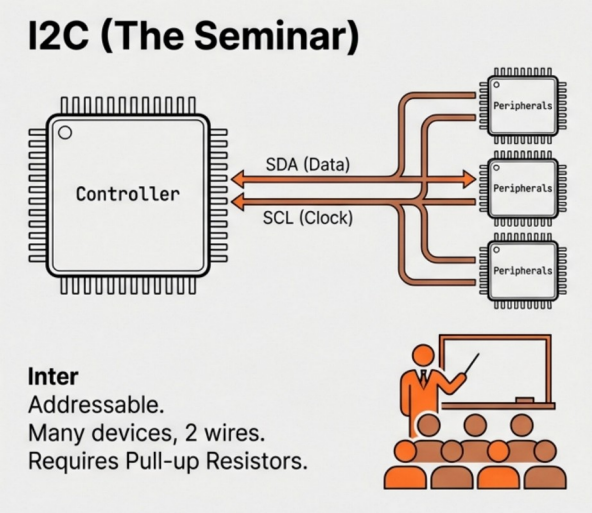
The Seminar

Architecture

Controller ↔️ Multiple Peripherals

SDA (Data Line)

SCL (Clock Line)



Key Features

- ✓ **Addressable:** Each device has unique address
- ✓ **Many devices, 2 wires:** Bus topology
- ✓ **Requires Pull-up Resistors**

Metaphor: Like a seminar where the professor calls on students by name.

SPI

The Firehose

Architecture

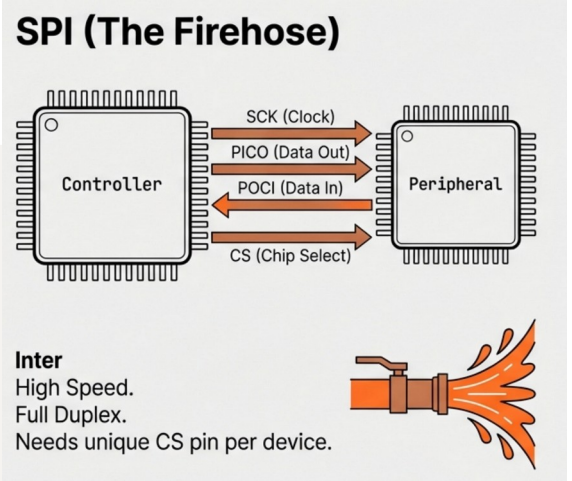
Controller ↔️ Peripheral

SCK (Clock)

PICO (Data Out)

POCI (Data In)

CS (Chip Select)



Key Features

- ✓ **High Speed:** 10MHz+ data rates
- ✓ **Full Duplex:** Simultaneous send/receive
- ✓ **Needs unique CS pin per device**

Metaphor: Like a firehose—high volume, point-to-point, no addressing needed.

COMPARISON

Wired Protocol Selection Matrix

Choose the Right Protocol for Your Application

Protocol	Wire Count	Speed	Topology	Best For
I2C	2 wires SDA + SCL	Standard 100-400 kHz	Multi-point Bus architecture	Sensors, OLEDs, clean layouts
SPI	3 + 1/device SCK, PICO, POCI + CS	Blazing 10 MHz+	Point-to-Point Star architecture	SD Cards, displays, LED strips
UART	2 wires TX + RX	Variable Baud-dependent	Point-to-Point Direct connection	Debugging, PC, legacy hardware

I2C: Best for multiple sensors on a single bus

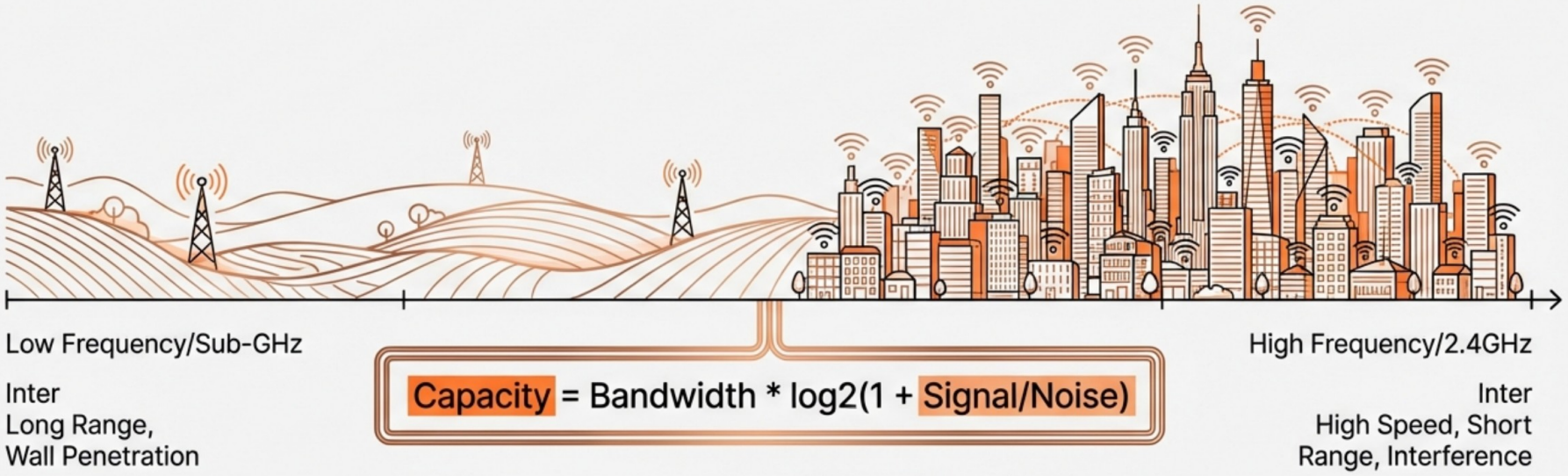
SPI: Best for high-speed data transfer

UART: Best for debugging and simple connections

WIRELESS FUNDAMENTALS

Zoning the Airwaves

The Physics of Wireless Communication



Key Trade-offs

Range ↑

Speed ↓

Power ↓

Penetration ↑

Lower frequencies travel farther and penetrate obstacles better, but carry less data.

The Cocktail Party Effect

2.4GHz is crowded with WiFi, Bluetooth, and microwave ovens. Signal strength must overpower the noise.

Modulation Types

AM/OOK: On/Off Keying

FM: Frequency Shift

LoRa: Chirp Spread Spectrum

ISM Bands

Industrial, Scientific, and Medical frequency bands are license-free for communication.

PERSONAL AREA NETWORKS

The Public Square

Bluetooth & RFID Technologies

Bluetooth / BLE

The Digital Handshake

How It Works

Devices perform a **"handshake"** to establish connection, then exchange low-energy **"heartbeats"** to maintain the link. Perfect for wearables and short-range device pairing.

Technical Details

- **Hardware:** nRF52, ESP32
- **Architecture:** GATT Profile
  Services & Characteristics
- **Range:** ~10-100m
  2.4 GHz frequency

Use Cases: Smartwatches, fitness trackers, wireless earbuds

RFID / NFC

Passive Interaction

How It Works

The **tag harvests energy** from the reader's electromagnetic field—no battery required! When brought close, the tag powers up and transmits its data.

Technical Details

- **Hardware:** MFRC522
  13.56 MHz frequency
- **Power:** Passive (no battery)
  Energy from reader field
- **Range:** ~4-10cm
  Very short range

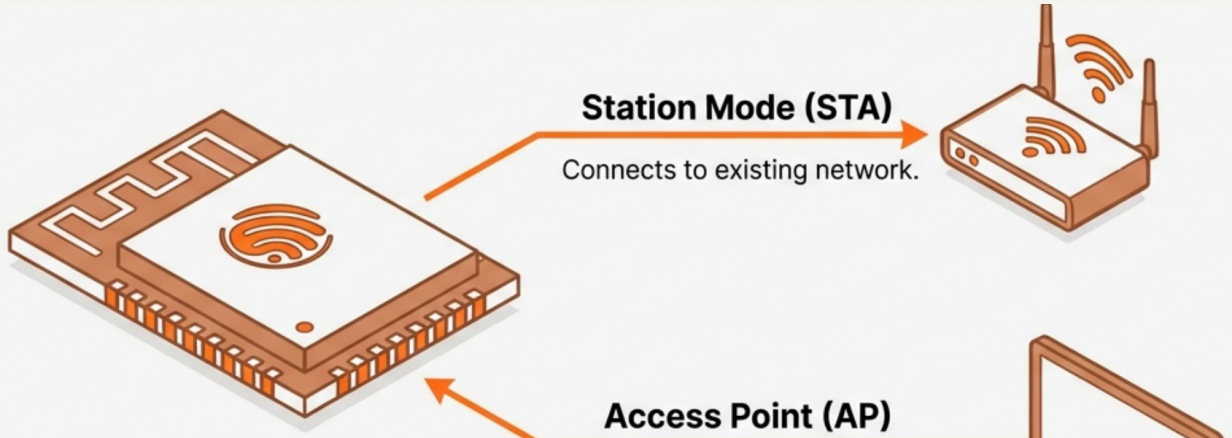
Use Cases: Access cards, inventory tracking, contactless payments

PAN (Personal Area Network): Designed for communication within a person's workspace (~10m range)

THE HIGHWAY

Wi-Fi & The Local Network

High Power, High Throughput · The Gateway to the Internet



Communication Styles

- **Client:** Chip asks Google for time.
- **Server:** Chip hosts a webpage to toggle LEDs.
- **Protocols:** HTTP (Text-heavy, reliable) vs UDP (Fast, fire-and-forget).

Communication Styles

Client
Chip asks Google for time

Server
Chip hosts webpage to toggle LEDs

Protocols
HTTP vs UDP

Protocol Comparison

HTTP Reliable & Heavy

- ✓ Text-heavy protocols
- ✓ Guaranteed delivery
- ✓ Web pages, APIs

UDP Fast & Light

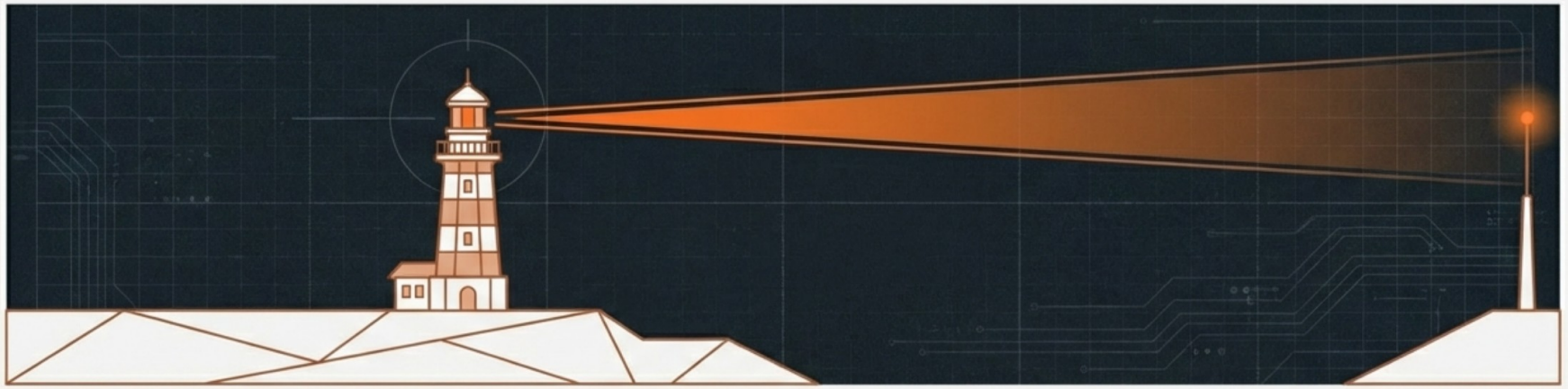
- ✓ Fire-and-forget
- ✓ Low latency
- ✓ Streaming, gaming

Key Insight: Wi-Fi is the gateway between your device and the vast internet.

THE HORIZON

LoRa & Long Range

Reaching Kilometers with Minimal Power



The Trade-off: Bandwidth for Distance

LoRa (Long Range) uses **Sub-GHz frequencies** (433, 868, 915 MHz) to send small packets kilometers away using minimal power.

Frequency

Sub-GHz bands
433 / 868 / 915 MHz

Range

Kilometers
2-15 km typical

Power

Minimal consumption
Years on single battery

Best Use Cases

- Agricultural sensors
- Smart city monitoring
- Environmental tracking
- Asset tracking

Network

LoRaWAN (The Things Network)

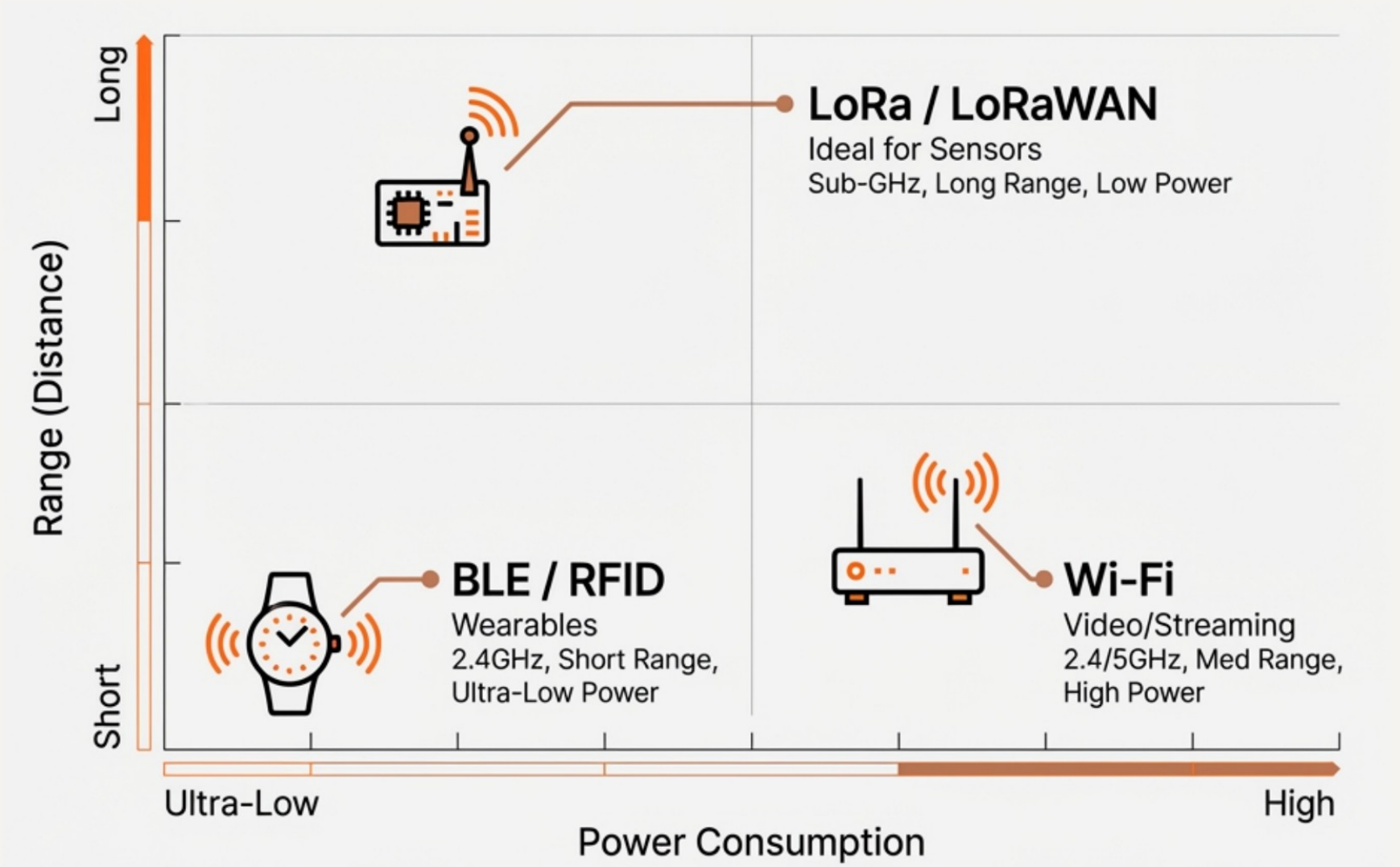
Hardware

RA-08, SX1262 modules

SELECTION GUIDE

Wireless Protocol Selection Matrix

Range vs. Power Consumption Trade-offs



Decision Rules

Need Video?
→ Wi-Fi

1-Year Battery?
→ BLE or LoRa

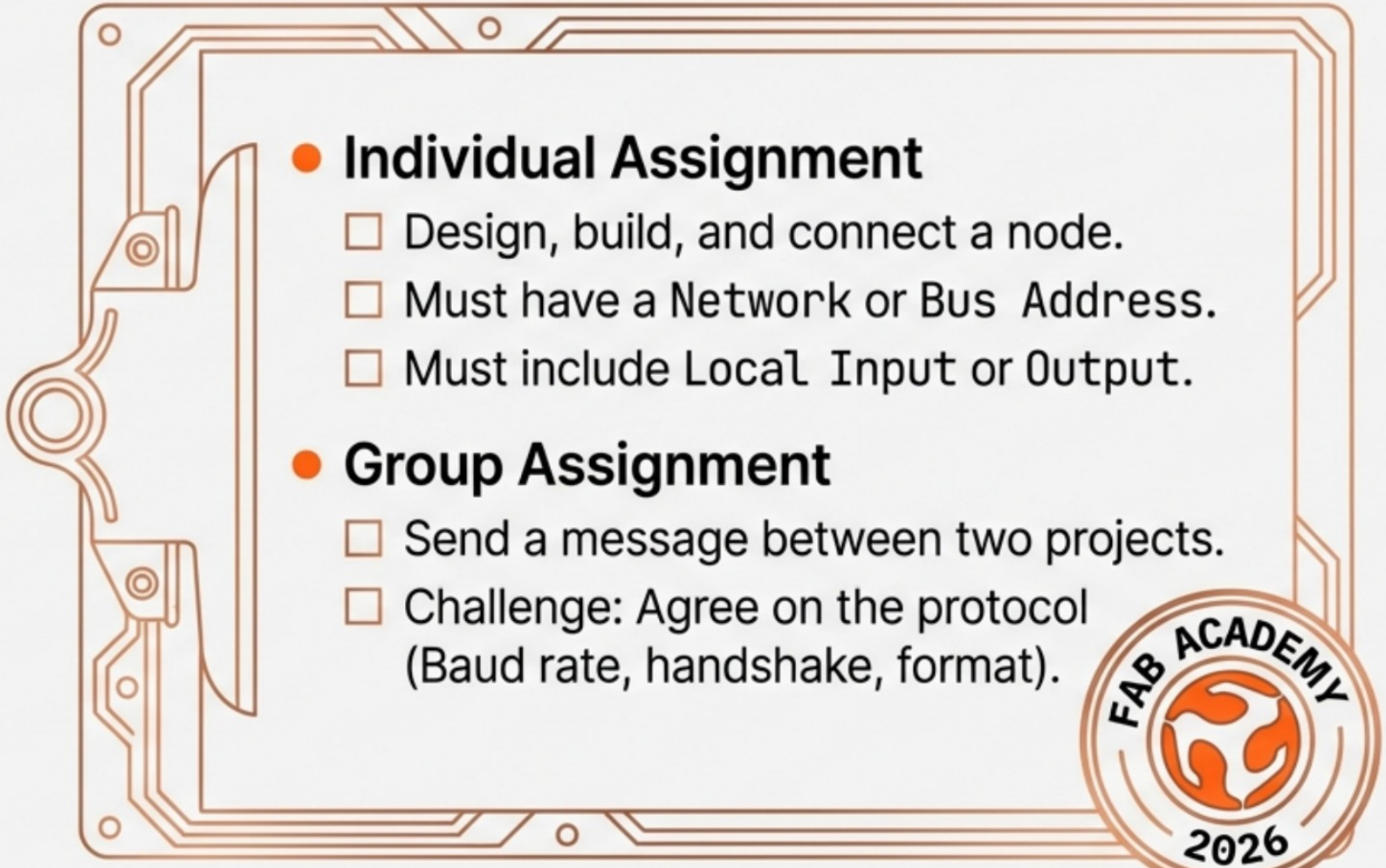
Talk to Phone?
→ BLE

Quick Reference

- BLE/RFID: Wearables
- Wi-Fi: Video/Streaming
- LoRa: Sensors (long range)

The Assignment: Build Your Network

fabacademy.org/2026/classes/networking_communications



- **Individual Assignment**
  - ☐ Design, build, and connect a node.
  - ☐ Must have a `Network` or `Bus Address`.
  - ☐ Must include `Local Input` or `Output`.
- **Group Assignment**
  - ☐ Send a message between two projects.
  - ☐ Challenge: Agree on the protocol (Baud rate, handshake, format).

The Maker's Protocol Map: Choosing Your Hardware Communication Method

A decision-making guide for beginners to select the correct communication protocol for hardware projects, balancing the Five Pillars: Data Rate, Range, Power Consumption, Cost, and Reliability.

WIRED PROTOCOLS
(Arduino Essentials)

Connection Type: Wired (Bus/1-to-1)

YOUR HARDWARE PROJECT

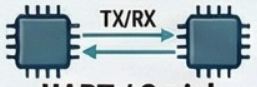
WIRELESS METHODS
(Maker Favorites)

Connection Type: Wireless

Protocol Comparison Guide

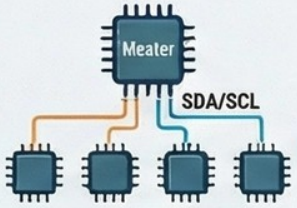
Protocol	Range	Speed	Complexity
UART/Serial	Short	Moderate	Very Low
I2C	Short	Moderate	Low
SPI	Short	High	Moderate

DEFINE THE BOUNDARY:
Internal (Inside Device) vs. **External** (Between Devices)



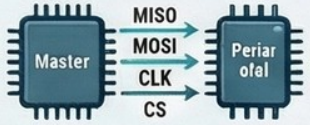
UART / Serial
(The Absolute Basic)

Asynchronous method, only two wires (TX/RX), connects two devices over short distances. Very Low Complexity.



I2C
(The Multi-Device Bus)

Uses two wires (SDA/SCL) and pull-up resistors to connect multiple devices with addresses. Low Complexity.



SPI
(The Speed Demon)

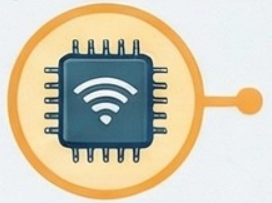
Synchronous method, faster than I2C, uses MISO/MOSI/Clock; more wires per device. Moderate Complexity.

Range: Short, Complexity: Speed: Moderate Low

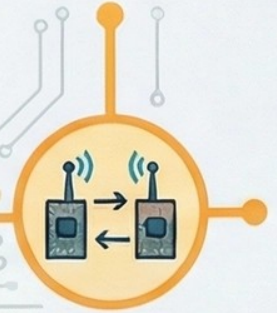
Range: Short Complexity: Speed: High Moderate

Bluetooth / BLE
(Phone Connectivity)

Ideal for short-range PAN to connect to smartphone or laptop. Moderate power. <10m Range, Moderate Speed, Moderate Complexity.



Wi-Fi / ESP32
(The IoT Standard)



nRF24L01+
(Tlowimare RF+)

Best for high-data rates and Cloud/Internet connectivity. High power consumption. <50m Range, Very High Speed, High Complexity.

nRF24L01+
(Simple RF)

Popular 2.40Hz module for simple, low-cost wireless communication between custom deviees. Moderate Speed, Moderate Complexity.

ADVANCED REFERENCE
(For Complex Projects)

LoRa / LoRaWAN
(The Long Distance King)

Kilometer range communication, very low power, extremely low data rates for remote sensors. <10km Range, Very Low Speed, High Complexity.

CAN & RS-485
(Industrial Strength)

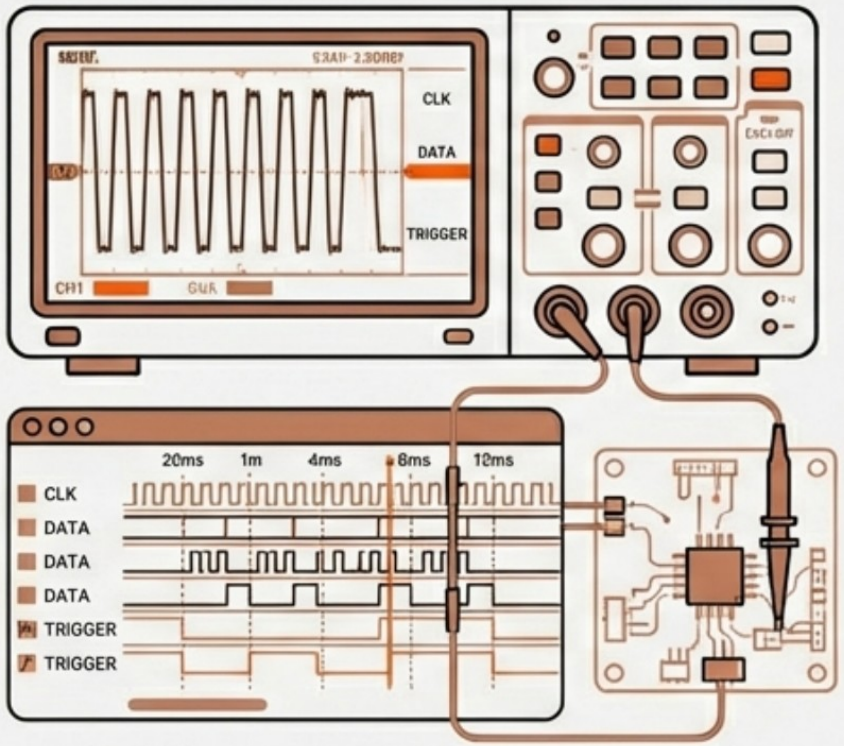
Robust; wired protocols for noiey environments like care/factories; reliability over long cables.

The OSI 7-Layer Model

Advanced networking hierarchy from Physical to Application layers.

Debugging & Safety Protocols

The Eyes



You cannot debug serial blind.
Visualize the waveform to check timing.

The Analyst

Analyze network packets.
See what is actually being sent.

The Hazards

- **Avoid Shorts** (Power vs Ground).
- **Voltage Levels** (3.3V vs 5V).
- **RF Regulations** (Stay in ISM bands).

THE ART OF CONNECTION

Communication is not just about moving bits from A to B

It is about **location, parallelism, modularity, and interference**.

You are not just coding a board; you are **designing a digital society**.

1

Pick the Layer

Understand your stack

2

Agree on Protocol

Establish common ground

3

Check Timing

Synchronize your clocks

4

Listen First

Then talk