

## Timing budget

Wi-Fi will never be deterministic, so prove the worst-case gap fits inside what the tightest timeout leaves for the radio.

### Where each timeout comes from

| Connection                          | Timeout                                                                                              | Example                                                                                 |
|-------------------------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| <b>CIP Safety input connection</b>  | $RPI \times (\text{timeout multiplier} + \text{network delay multiplier})$                           | 40 ms at Input RPI 10 ms, Timeout multiplier 2, Network delay multiplier 200 %          |
| <b>CIP Safety output connection</b> | $\text{safety task period} \times (\text{timeout multiplier} + \text{network delay multiplier} - 1)$ | 60 ms at Safety task period 20 ms, Timeout multiplier 2, Network delay multiplier 200 % |
| <b>EtherNet/IP standard I/O</b>     | $RPI \times \text{connection timeout multiplier}$ , but never less than the minimum timeout          | 100 ms at RPI 20 ms, Connection timeout multiplier 4 x, Minimum timeout 100 ms          |
| <b>PROFINET IO</b>                  | $\text{update time} \times \text{accepted update cycles without IO data}$                            | 12 ms at Update time 4 ms, Accepted update cycles without IO data 3                     |
| <b>PROFIsafe</b>                    | F-monitoring time, entered directly                                                                  | 100 ms at F-monitoring time (F_WD_Time) 100 ms                                          |

### How to use the budget

1. List every connection on the link: safety, standard I/O, fleet traffic.
2. Take the tightest timeout configured in the project, not the default.
3. Example: CIP Safety input at defaults is  $10 \text{ ms} \times (2 + 2) = 40 \text{ ms}$ .
4. Subtract what the wired path and endpoints spend. Measure it; do not guess.
5. What remains is the outage budget: the longest gap Wi-Fi may ever cause.
6. Measure the worst-case roam on the real vehicle, client, and security.
7. Pass only if the worst gap fits. One gap over the budget faults the connection.
8. Raising a timeout is the machine builder's call. It lengthens the worst case.
9. Time is distance: at 30 mph (13.41 m/s), each 100 ms is about 1.3 m.

### Published roam interruption ranges (typical, measure your own)

| Roam                                                                 | Typical interruption              |
|----------------------------------------------------------------------|-----------------------------------|
| <b>Full 802.1X reauthentication</b>                                  | No published range: measure yours |
| <b>PSK four-way handshake (no fast roaming)</b>                      | 55 to 520 ms                      |
| <b>PMK caching and opportunistic key caching</b>                     | No published range: measure yours |
| <b>802.11r fast BSS transition</b>                                   | 15 to 90 ms                       |
| <b>Vendor fast-roam and make-before-break schemes (vendor claim)</b> | 63 to 150 ms                      |
| <b>Wi-Fi 7 multi-link operation</b>                                  | No published range: measure yours |
| <b>802.11bn seamless mobility domain</b>                             | No published range: measure yours |

Planning aid, not a safety calculation. Safety functions, reaction times, and stopping distances come from the machine builder's risk assessment and the applicable standards.

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