Chapter 7
Data Transmission and Wireless Communication in Smart Fabrics

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ABSTRACT

Smart fabrics integrate sensors, compute, and radios into deformable, washable textiles. This chapter is a practical guide to end-to-end data links in e-textiles, covering wired buses (I^2C/SPI/UART/CAN-FD), short-range wireless (BLE 5.x, IEEE 802.15.4/Thread), body-centric options (UWB for ranging, capacitive human-body links), and backhaul (LoRaWAN, NB-IoT/LTE-M). We map core requirements—range, latency/jitter, reliability, energy per bit, security/privacy, comfort, and washability—to protocol and topology choices. RF topics include textile/embroidered antennas, fabric transmission lines, impedance control, and SAR. A compact

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link-budget method models on-body loss and duty cycling for early feasibility and battery-life estimates. We define a reproducible test regimen (throughput, latency, packet-error rate, energy profiling, and S-parameter stability under bend/stretch/laundering). Four garment-level case studies illustrate sensor-to-cloud integration trade-offs. The chapter concludes with checklists for resilient interconnects, secure OTA updates, and on-garment TinyML.

INTRODUCTION

Smart fabrics are moving from research prototypes to deployed systems in health monitoring, sports, industrial safety, and human–computer interaction. Their success depends less on any single sensor than on preserving a robust data path from yarn-level conductors and garment modules to gateways and cloud services while the textile bends, wicks moisture, and tolerates repeated laundering. Unlike rigid wearables, e-textiles operate in a mechanically and chemically active environment: conductive traces stretch and oxidize, contact resistances drift, and antenna elements detune in proximity to lossy human tissue. These effects accumulate across wash cycles, shifting resistance, S-parameters, and ultimately eroding link margin (Dulal et al., 2022; Lee & Park, 2024).

This chapter addresses the communication problem end-to-end. At the garment scale (sleeves, waistbands, collars), designers must decide when wired interconnects are preferable to wireless links. Short, deterministic, ultra-low-energy buses, I^2C, SPI, UART, and CAN-FD, are effective for aggregating dense sensors with minimal idle power and simple firmware, provided routing avoids high-flex regions and connector fatigue. Wireless links, in turn, reduce mechanical connectors, improve comfort, and enable modular maintenance and upgrades.

Among short-range radios, Bluetooth Low Energy (BLE) is the default for phone-tethered use. BLE 5.x adds practical "dials": the LE 2M PHY for higher throughput, the LE Coded PHY for extended range via FEC, and Extended Advertising for scalable multi-node broadcasting, allowing rate/sensitivity/battery-life trade-offs without changing bands (Bluetooth SIG, 2019). In parallel, IEEE 802.15.4/Thread supports low-power mesh, UWB provides precise ranging for localization, and body-area standards cover medical and fitness wearables.

RF performance on the body is not business-as-usual. Embroidered or printed antennas and laminated foils must maintain impedance and radiation efficiency on curved, lossy, perspiring surfaces. Common textile implementations, planar patch/PIFA or CPW-fed monopoles, exhibit resonance down-shifts, pattern distortion, and SAR constraints near tissue. Recent reviews highlight the importance of substrate choice, spacer thickness, stitch density, and S-parameter stability under bending