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DISTRIBUTED FILTERING FOR NETWORKED SYSTEMS UNDER STOCHASTIC UNCERTAINTIES AND FDI ATTACKS

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ABSTRACT

Signal estimation in multi-sensor stochastic systems has grown into a significant research area due to its high relevance in numerous applied and theoretical fields. Within this domain, distributed estimation has attracted considerable attention. This approach is particularly useful when sensor nodes are spatially distributed according to a predetermined network topology, allowing each node to act as a local fusion center. By combining its own measurement data with information received from neighboring nodes, each sensor can significantly improve estimation performance. This collaborative strategy offers distinct advantages, including ease of implementation, robustness, scalability, and high reliability. While the foundations and challenges of these multi-sensor architectures have been extensively surveyed in recent literature (e.g., [1], [2], [3]), networked systems remain inherently prone to simultaneous random flaws and cyber-threats which, if not appropriately modeled, can substantially deteriorate estimator performance.

To address these challenges, this paper investigates the distributed linear filtering problem for systems where sensor measurements are simultaneously affected by random parameter matrices ([4], [5], [6]), perturbed by time-correlated additive noises ([4], [7]), and vulnerable to linear false data injection (FDI) attacks ([8], [9]). The inclusion of random parameter matrices provides a unified framework that covers a wide range of common network-induced uncertainties, such as multiplicative noise, sensor gain degradation, and missing measurements. Furthermore, the infinite-step time correlation of the measurement noises makes the algorithm highly suitable for high-frequency sampling applications where noise is significantly correlated over consecutive periods. Additionally, the stochastic nature of the FDI attacks is modeled via time-varying Bernoulli random variables, which reflect realistic cyber-security vulnerabilities where different nodes experience distinct random attacks.

Under a covariance-based methodology, the proposed distributed filtering algorithm operates in two stages: first, intermediate estimators based on local and adjacent node measurements are designed; second, these intermediate estimators from neighboring sensors are combined using least-squares matrix-weighted linear combinations. Notably, this covariance-driven technique does not require prior knowledge of the signal evolution model and provides optimal estimators under the mean squared error criterion without additional structural assumptions.

Keywords Distributed estimation · Networked stochastic systems · Random parameter matrices · Time-correlated noise · False data injection attacks · Covariance-based filtering

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