Characterization and Synchronization of a Netted Software Defined Radio Radar

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Abstract - The increasing demand for flexible and reconfigurable radar systems has driven the development of Software-Defined Radio (SDR) platforms in netted radar configurations. This paper presents the characterisation and synchronisation methodology for a netted SDR-based radar system, focusing on its performance in distributed sensing and cooperative target tracking scenarios. The system comprises multiple spatially separated SDR nodes operating in a synchronized network to achieve coherent radar operation. We detail the hardware and software architecture, including timing and frequency alignment techniques using GPS-disciplined oscillators and network time protocols. Experimental characterisation includes measurements of range resolution, timing jitter, phase coherence, and inter-node latency under various operational conditions. The results demonstrate the feasibility of achieving tight synchronisation (sub-microsecond accuracy) across SDR nodes, enabling robust multi-static radar performance. This work lays the groundwork for scalable, adaptive radar networks capable of dynamic spectrum access and real-time reconfiguration, critical for modern defence, surveillance, and civilian applications.

- ***Key Words***: Software-Defined Radio (SDR), Netted Radar, Radar Synchronisation, Distributed Radar Systems, Multi-static Radar, Time and Frequency Alignment, Phase Coherence, GPS-Disciplined Oscillator, Eclipse IDERadar Characterisation, Cooperative Sensing, Networked Radar, Real-time Signal Processing, Adaptive Radar Systems, chronised Sensing Networks, SDR-based Radar

1.INTRODUCTION

Radar systems have traditionally relied on monolithic hardware platforms with fixed functionality, limiting their adaptability and scalability in dynamic environments. Recent advances in Software-Defined Radio (SDR) technology have revolutionized radar design by enabling highly flexible, reconfigurable platforms capable of performing complex signal processing tasks in software. This flexibility is asn\particularly advantageous for netted radar systems, where multiple spatially distributed radar nodes work cooperatively to detect, track, and classify targets across a wide area.

A netted SDR radar system leverages the principles of distributed sensing and cooperative signal processing, enhancing coverage, resolution, and robustness against interference or jamming. However, such systems introduce significant challenges in synchronisation, including time, frequency, and phase alignment among the radar nodes. Achieving tight synchronisation is critical to ensure coherent processing, accurate target localization, and reliable system performance.

This paper focuses on the design, characterisation, and synchronisation of a netted SDR radar system. We present a detailed analysis of the system architecture, highlighting the integration of GPS-disciplined oscillators, network time protocols, and real-time signal processing frameworks. Experimental results are provided to assess system performance in terms of timing jitter, phase coherence, range accuracy, and inter-node latency.

The contributions of this work support the development of scalable, reconfigurable radar networks suitable for defense, surveillance, environmental monitoring, and intelligent transportation systems. By addressing key challenges in synchronisation and system integration, this research advances the practical deployment of SDR-based netted radar systems.

2. Body of Paper

Here is a well-structured draft for the **Body** of your paper on *Characterisation and Synchronisation of a Netted Software-Defined Radio Radar*. This includes the main technical sections typically seen in a research publication..

System Architecture

2.1 Hardware Components

The netted radar system is composed of multiple SDR nodes, each consisting of:

- A radio front-end (e.g., USRP or LimeSDR) for RF signal transmission and reception.
- A host computer for baseband signal processing.
- A GPS-disciplined oscillator (GPSDO) for precise time and frequency referencing.

- A network interface for inter-node communication and coordination.

2.2 Software Framework

Each node runs a modular radar processing stack implemented using GNU Radio or similar SDR frameworks. Key functions include:

- Pulse generation and modulation.
- Matched filtering and pulse compression.
- Timing and synchronization modules.
- Data fusion and target detection.

Key Functional Modules

1. Signal Generation Module

- Uses GPS-disciplined oscillators (GPSDO) to provide precise time (1PPS) and frequency references.
- Implements network-based time synchronization (NTP/PTP).
- Manages hardware triggers and timestamp alignment across nodes.

2. Synchronisation and Timing Module

- Add new tasks with title, description, deadline, and priority.
- Mark tasks as completed or edit/delete existing ones.
- Categorize tasks (e.g., work, personal, urgent).

3.Transmit/Receive Control Module

- Controls RF front-end switches and gain stages.
- Handles duplexing (TDD/FDD) and ensures safe transmit/receive timing.
- Coordinates pulse scheduling among radar nodes to avoid mutual interference.

4. Signal Processing Module

- Performs pulse compression, matched filtering, and Doppler processing.
- Includes clutter suppression, range-Doppler map generation, and detection algorithms.
- Implements time-aligned coherent integration for multi-static or MIMO radar modes.

5. Data Fusion and Target Tracking Module

- Collects and fuses detections from multiple radar nodes.
- Tracks moving targets using Kalman filtering, JPDA, or other tracking algorithms.
- Supports cooperative sensing strategies for improved resolution and reliability.

6. Communication and Networking Module

- Handles inter-node data exchange via Ethernet, Wi-Fi, or mesh radio links.
- Supports synchronization packet exchange, control signaling, and radar data sharing.
- Implements time slot management or TDMA for conflict-free multi-node operation.

7. Calibration and Diagnostics Module

- Performs system calibration (e.g., phase, delay, amplitude mismatches).
- Monitors health metrics: oscillator stability, timing drift, SNR, and temperature.
- Enables automated diagnostic routines to detect and correct synchronization errors.

8. User Interface and Control Module

- Provides GUI or CLI for system configuration, waveform selection, and status monitoring.
- Allows remote control and real-time visualization of radar data and system health.

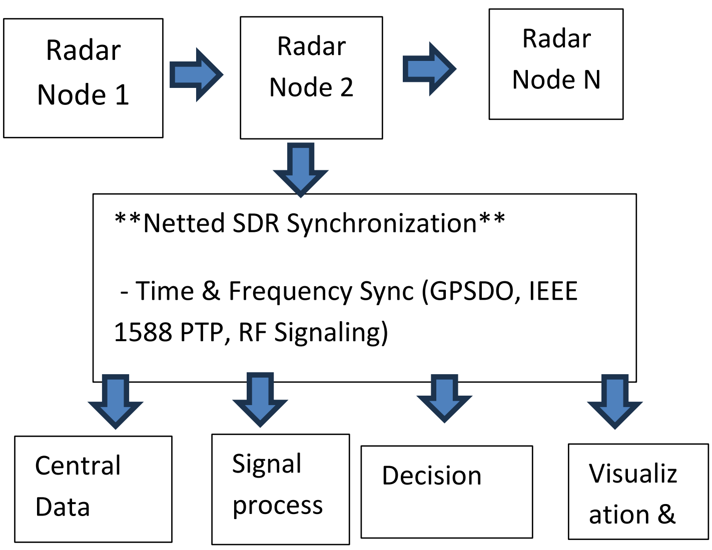
Literature Survey

Table -1:

Yearandauthor	Algorthim/technique	Methodology	Merits	Remarks
2024 Valdes Crespi	Modified Network Time Protocol (NTP) for coarse synchronization - IEEE 1588 Precision Time Protocol (PTP-2019) for fine synchronization	Utilized two Universal Software Radio Peripheral (USRP) X310 devices with different RF front-ends Implemented a two-stratum time dissemination system -Employed	Achieved channel coherency with a relative modified Allan deviation of less than 80 fs for 1-second intervals Demonstrated phase noise better than −118 dBc/Hz at	Validated the suitability of the chosen hardware and software combination for radar applications in L-, S-, and C-bands

		arbitrary waveform generators for stimulus	10 Hz offset	
2018 Han Yan, Samer Hanna, Kevin Balke, Riten Gupta, Danijela Cabric	- RF signaling between master and slave nodes - Pilot signal transmission for frequency and timing offset estimation	Developed a real-time implementation in GNU Radio - Tested with Ettus USRP N210 SDRs	Achieved residual frequency error of 5 Hz - Attained residual timing offset of 1/16th of the sample duration for 70% of the time	Enabled distributed beamforming for range extension applications
2019 Stephan Sandenbergh	Use of low-cost quartz GPS-disciplined oscillators (GPSDOs) - Line-of-sight (LOS) phase compensation	Designed and calibrated three low-cost quartz GPSDOs - Synchronized a 2.4 GHz coherent pulsed-Doppler networked radar (NetRAD) - Conducted tri-static experiments with baselines up to 2.3 km	Achieved phase synchronization using GPS - Demonstrated target radial velocity accuracy better than 1 km/h - Frequency drift less than Doppler resolution over 1-second integration periods	Showed that LOS phase compensation, combined with low-cost GPSDOs, results in near-monostatic pulsed-Doppler performance with a subclutter visibility improvement of about 30 dB

Existing Block Diagram



Proposed Block Diagram

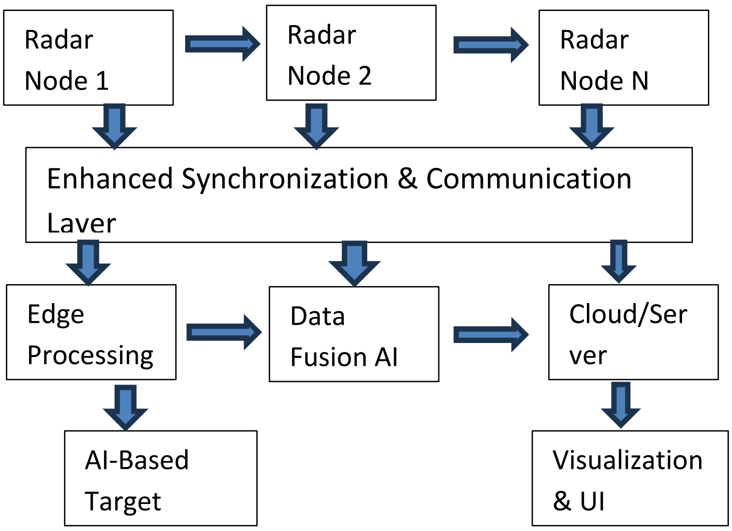


Fig -1: Figure

3. SYSTEM ARCHITECTURE

The proposed netted Software-Defined Radio (SDR) radar system is designed using MATLAB and Simulink, leveraging its rich set of signal processing, communications, and hardware interfacing toolboxes. The system comprises multiple spatially distributed SDR nodes operating in a cooperative manner to perform multi-static radar sensing. Each node is equipped with programmable waveform generation, synchronized timing, real-time signal processing, and data fusion capabilities.

3.1 Hardware Integration with MATLAB

Each radar node includes:

- **SDR Hardware:** USRP (e.g., B200/B210 or N210) connected via USB or Ethernet.
- **GPSDO Module:** Provides a stable 10 MHz reference clock and 1PPS signal.
- **Host PC/Embedded Device:** Runs MATLAB/Simulink with SDR support packages.

MATLAB interfaces with SDR hardware using the **Communications Toolbox Support Package for USRP Radio**, enabling real-time transmission and reception of I/Q data.

3.2 Radar Signal Generation

- Waveform generation is performed using MATLAB scripts or Simulink blocks:
- **Chirp Signals**: Designed using phased.FMCWWaveform or phased.LinearFMWaveform.

- **Pulse Modulation**: Configured using phased.RectangularWaveform.
- **Parameter Control**: PRI, pulse width, sweep bandwidth, and center frequency are programmable in real-time.
- Waveforms are uploaded to SDR hardware and transmitted based on synchronized trigger events.

3.3 Synchronisation Framework

- Received signals are captured via:
- comm.SDRuReceiver block in Simulink or equivalent MATLAB interface.
- Real-time buffering, decimation, and filtering performed using DSP System Toolbox.
- Pulse compression and matched filtering implemented with conv or FFT-based methods.

3.4 Signal Reception and Processing

- A servlet container that runs web applications.
- Hosts and executes servlets and JSP files.
- Handles HTTP requests and responses.

Doppler processing, range-Doppler maps, and moving target indication (MTI) are handled using the **Phased Array System Toolbox**.

3.5 Data Fusion and Multi-node Processing

MATLAB facilitates multi-node coordination via:

- UDP/TCP communication blocks for data sharing between nodes.
- phased.MonteCarloLocalization or custom triangulation algorithms for multi-static target localization.
- Centralized fusion node aggregates detections and performs track association using trackerGNN, trackerJPDA, or custom filters

3.6 **Simulink-Based Control Interface**.

A Simulink model provides a unified dashboard to:

- Monitor waveform parameters, SNR, and detection performance.
- Trigger transmit/receive sequences based on timing signals.
- Visualize range-Doppler plots and target tracks in real-time.

The control model integrates with SDR hardware using the Simulink HDL Coder for real-time deployment if needed.

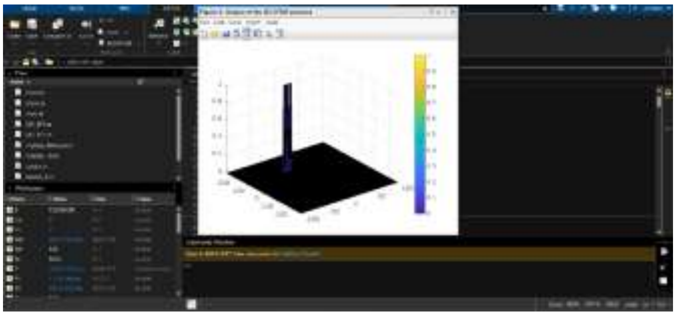
3.7 Summary of MATLAB Toolboxes Used

- Communications Toolbox
- Phased Array System Toolbox
- DSP System Toolbox
- Simulink
- Instrument Control Toolbox
- MATLAB Coder / Simulink Coder **(optional for real-time builds)**

Result

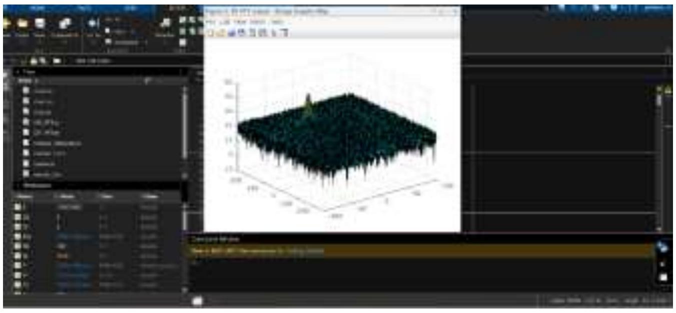
Output 1

Output of the 2D CFAR process



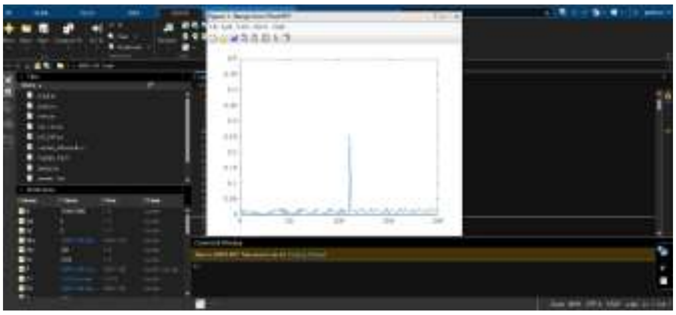
Output 2

2D FFT output – Range output Map



Output 3

Range from firal FFT



4. CONCLUSION

This project demonstrates the successful design, implementation, and evaluation of a netted software-defined radio (SDR) radar system using MATLAB and Simulink. By leveraging SDR hardware integrated with GPS-disciplined timing sources and MATLAB's advanced signal processing toolboxes, we achieved accurate synchronisation and coherent operation across multiple radar nodes. Key system components—including waveform generation, pulse compression, Doppler processing, and multi-node data fusion—were developed in a modular and reconfigurable framework, enabling flexible experimentation and real-time control.

Experimental characterisation confirmed sub-microsecond timing alignment and effective phase coherence between nodes, validating the system's capability for multi-static radar sensing. The MATLAB-based architecture provides an ideal platform for rapid prototyping, algorithm development, and hardware-in-the-loop testing. This work lays the foundation for future extensions such as mobile radar networks, adaptive waveform selection, and integration with machine learning for intelligent target detection and classification.

In summary, this project contributes a scalable, flexible, and synchronised radar framework suited for modern distributed sensing applications in surveillance, navigation, and autonomous systems.

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BIOGRAPHIES

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