

Special Topic: Millimeter-Wave and Terahertz Phased-Array and System-Integration Technologies

# Demonstration of tracking and communication based on sub-terahertz phased-array system for next-generation intelligent mobile scenarios

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To meet the demands for Gbps-level throughput and low latency in low-altitude platform networks (LAPN) and vehicle-to-everything (V2X) applications, the spectrum is shifting towards millimeter-wave (mmWave) and Terahertz (THz) bands, which offer abundant bandwidth. Phased arrays, leveraging high-gain beamforming and electronic scanning, are pivotal for realizing these scenarios [1].

While extensive beam tracking schemes—ranging from hierarchical search and model-based to recent learning-based approaches—have been established for mmWave systems [2–5], their direct applicability to the THz band is hindered by distinct physical constraints. Unlike the wide-narrow beam combinations used in mmWave, the severe THz path loss necessitates dual-end high-gain beams, resulting in a codebook explosion that renders conventional scanning prohibitive. Furthermore, the prohibitive latency of data-driven models and the stringent non-linearity of THz RF front-ends challenge the deployment of existing algorithms in real-time, long-range mobile scenarios.

This study reports a 94 GHz phased-array tracking and communication system. We propose a low-complexity frequency division multiplexing (FDM) architecture that decouples the beacon and communication signals to achieve high-sensitivity tracking with zero time-domain overhead. We further introduce the acquisition-tracking-re-locking (ATL) scheme, centered on EKF-based motion-aware adaptive tracking and history-buffered interruption recovery. Additionally, a co-optimization of power control and modulation format is adopted to mitigate non-linear constraints. More details are provided in Appendixes A–E.

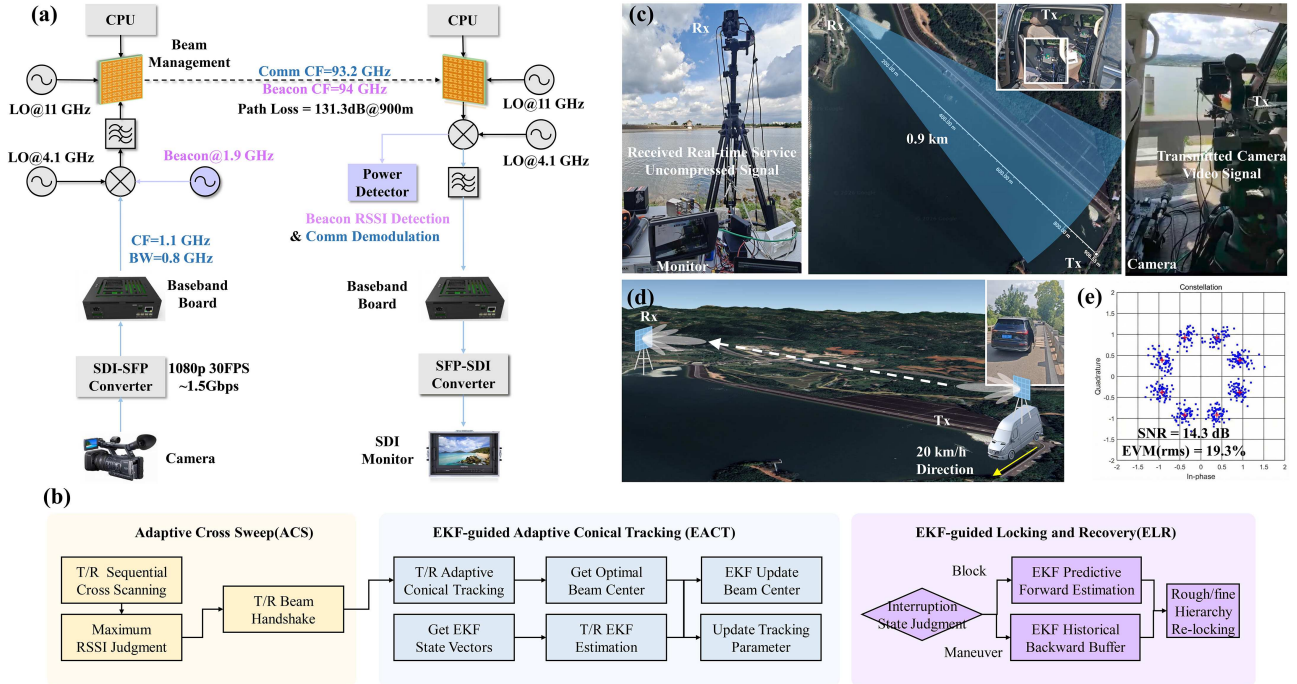
**Tracking and communication architecture.** Figure 1(a) illustrates the system architecture. We utilize a 64-channel phased-array module integrated via AiP technology using four commercial W-band 16-channel silicon transceiver chips (Model: CCAR91601F). The array features a 3-dB beamwidth of  $10^\circ$  and a scanning range (3-dB gain drop) of  $\pm 30^\circ$ . We adopt an FDM

architecture where the communication signal and tracking beacon are transmitted independently and processed, which offers three key advantages. (1) High sensitivity and robustness: Compared to monitoring the RSSI of wideband communication signals, the narrowband continuous wave beacon enhances receiver sensitivity, maintaining closed-loop feedback with high SNR. (2) Zero time-domain tracking overhead: Unlike time division multiplexing (TDM) methods in standards like IEEE 802.11ad that occupy time slots for beam training, FDM does not occupy communication frames, thereby eliminating time-domain tracking overhead. (3) Low deployment complexity: It eliminates complex inter-frame handshake protocols, facilitating low-latency processing on FPGA platforms and easy porting to bidirectional tracking links.

**Tracking algorithm scheme.** The proposed ATL scheme comprises three core components as shown in Figure 1(b). (1) Adaptive cross-scanning (ACS): For initial blind acquisition without priors, we employ a transceiver sequential iterative cross-scanning strategy. By iteratively reducing the scanning range based on detection results, the system quickly converges to the direction of maximum RSSI, completing the beam handshake. (2) EKF-guided adaptive conical tracking (EACT): To address the limitations of traditional conical track in narrow-beam, high-dynamic scenarios, this method fuses EKF state predictions with conical track observations to update the beam center in real-time. This achieves adaptive regional guidance enhancement and improves predictive capability. Additionally, motion-aware resource scheduling is introduced: utilizing the angular velocity estimated by the EKF, the algorithm dynamically regulates the track radius and sampling number. Specifically, it expands the track range and increases sampling points during rapid target maneuvers to prevent lock loss, while contracting the range during steady states, thereby realizing a dynamic balance between tracking robustness and demodulation SNR. (3) EKF-guided locking and recovery (ELR): To address interruptions caused by blockage or severe maneuvering,

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**Figure 1** (Color online) (a) System architecture; (b) tracking scheme; (c) experimental diagram of Tx/Rx; (d) schematic diagram of vehicle mobile communication; (e) demodulated constellation.

we establish a history buffering window based on state vectors and RSSI. The algorithm intelligently distinguishes interruption types by analyzing historical data features and backtracks to a valid “anchor point” to guide a hierarchical scan, realizing rapid link self-healing.

**Experimental demonstration and discussion.** After completing indoor verification (max tracking speed  $10^\circ/\text{s}$ ), we deployed the 94 GHz mobile system at Sancha Lake, Chengdu. As shown in Figures 1(c) and (d), the transmitter was mounted on a vehicle traveling at 20 km/h along a trajectory perpendicular to the receiver, located 900 m away on the opposite shore. A camera fed a 1.5 Gbps real-time uncompressed FHD video stream into the FPGA. A baseband based on Xilinx RFSoc ZU27DR generated a 0.8 GHz bandwidth communication signal, which, along with a 1.9 GHz CW beacon from a signal generator (USBG6000), was up-converted via a secondary mixing link to 93.2 GHz (communication) and 94 GHz (beacon) for transmission. To address the long-range link budget challenge while avoiding non-linear distortion from RF front-end saturation, we proposed a power and modulation co-optimization strategy. By selecting a low-PAPR single-carrier (SC) waveform and 8PSK modulation (which is insensitive to amplitude compression), the system pushed the EIRP to 50 dBm while maintaining demodulation quality. The receiver employed a Zero-IF architecture with FPGA demodulation, displaying real-time video on an SDI monitor. The beam control algorithm ran on an RK3588 embedded platform. Measurements indicated a single-beam closed-loop refresh latency (including acquisition, processing, and command issuance) of approximately 5 ms, effectively supporting link stability under high dynamics. Vehicular experimental results indicate that during movement covering an azimuth change of approximately  $15^\circ$ , the ATL scheme achieved precise mainlobe tracking, suppressing received power fluctuations to within 1 dB. As shown in the demodulation constellation diagram in Figure 1(e), the link maintained a block error rate (BLER) below  $1 \times 10^{-8}$  in dynamic scenarios, successfully supporting the

stable backhaul of real-time uncompressed FHD video.

**Conclusion.** In this study, we investigated the system architecture, tracking scheme, and experimental validation for Sub-THz phased-array communication for next-generation intelligent mobile scenarios. We reported a dynamic demonstration at 93.2 GHz over 900 m, achieving 1.5 Gbps real-time uncompressed video transmission. To our knowledge, this is the first experimental demonstration of a phased-array tracking and communication system in the Sub-THz band that meets strict bit error rate requirements while carrying actual service traffic. The proposed scheme provides empirical support and a feasible path for the application of future THz phased arrays in high-mobility scenarios such as V2X and intelligent transportation.

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**Supporting information** Appendixes A–E. The supporting information is available online at [info.scichina.com](http://info.scichina.com) and [link.springer.com](http://link.springer.com). The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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