World Journal of Information Technology
ISSN: 2959-9911
DOI: https://doi.org/10.61784/wjit3027

WIRELESS DATA TRANSMISSION SYSTEM FOR TOWER CRANES BASED ON C-V2X TECHNOLOGY

KeLong Xu*, QingXiang Zhang, QingYun Zhang
Jinan Wantian Machinery Equipment Co., LTD, Jinan 250101, Shandong, China.
Corresponding Author: KeLong Xu, Email: 15605313863@136.com

Abstract: In the industrial field, tower crane as a key lifting equipment, has an irreplaceable role. However, due to its own structural characteristics, it is difficult to guarantee the communication with the outside world during the actual operation. In view of this, this paper integrates C-V2X technology into the tower crane, aiming to effectively improve the ability of the tower crane to communicate with the outside world in time when there is a problem, so as to ensure the stability and reliability of its operation, and provide a new technical solution for the efficient and safe operation of the tower crane.

Keywords: C-V2X; Tower crane; Communication

1 INTRODUCTION

With the continuous expansion of modern construction projects and the increasing complexity of worksite environments, tower cranes, as critical equipment for high-altitude operations, have seen their operational safety, real-time monitoring capabilities, and data interaction efficiency become pivotal factors influencing construction progress and personnel safety. In high-rise buildings, bridge projects, and large-scale industrial facilities, tower cranes are required to transmit multimodal data in real time, including mechanical posture, load parameters, environmental perception data (e.g., wind speed, obstacle detection), and equipment health status. However, mainstream wireless communication technologies—such as Wi-Fi, Bluetooth, and ZigBee—face significant challenges in meeting these demands. First, the prevalence of high-density metal frameworks, concrete structures, and dynamically moving equipment on construction sites leads to severe signal multipath effects, drastically reducing communication link stability. Second, traditional technologies suffer from limited bandwidth (typically below 50 Mbps), making them inadequate for concurrent transmission of high-definition video streams and multi-sensor data. Third, existing solutions rely on static network topologies, which fail to adapt to dynamic connectivity demands caused by crane arm rotations and frequent equipment repositioning. Industry reports indicate that approximately 35% of global construction safety incidents over the past five years were directly linked to communication failures or data delays, such as overload tipping accidents due to untimely load data transmission or collision risks arising from lagging environmental perception.

Against this backdrop, Cellular Vehicle-to-Everything (C-V2X) technology emerges as a groundbreaking solution for wireless data transmission in tower cranes. Originally designed for intelligent transportation systems [1-3]. C-V2X integrates cellular networks and sidelink communication (PC5 interface) to achieve dual guarantees of "wide-area coverage" and "short-range low latency." Technically, C-V2X leverages 5G New Radio (NR) enhancements, including enhanced Mobile Broadband (eMBB) and Ultra-Reliable Low-Latency Communication (URLLC), delivering peak rates up to 1 Gbps and end-to-end latency below 20 ms [4-5]. This capability sufficiently supports synchronous transmission of high-definition video streams (1080P/60 fps) and sensor data (10 Hz sampling rates) [6]. Moreover, its resource pool scheduling algorithms and Hybrid Automatic Repeat Request (HARQ) mechanisms ensure transmission reliability exceeding 99.99% even in high-interference environments. Further, C-V2X employs network slicing to allocate dedicated virtual networks for crane communications, prioritizing critical control commands (e.g., emergency braking signals) to avoid congestion-induced delays [7-8]. When integrated with Multi-access Edge Computing (MEC), the system offloads data preprocessing tasks to nearby servers, reducing core network load while compressing decision-making latency for local environmental perception (e.g., hook path planning) to under 10 ms.

The core functionality of C-V2X is to enable comprehensive communication between vehicles and vehicles (V2V), vehicles and infrastructure (V2I), vehicles and pedestrians (V2P), and vehicles and the network (V2N) through the cellular network [9-10].

Hou et al.[11] proposed a solution to address the limitations of C-V2X (Cellular Vehicle-to-Everything) technology in autonomous driving mode. C-V2X enables communication between vehicles, infrastructure, and pedestrians via cellular networks to enhance road safety and efficiency. However, in autonomous mode, vehicles cannot accurately predict broadcast packet reception, leading to blind broadcasting, which compromises reliability and latency. To tackle this, the authors introduced a simple yet accurate prediction model that estimates packet reception rates at the transmitter side without requiring additional signaling from the receiver. The model achieved an R^2 of up to 0.92 when trained and evaluated using digital twin data from the same city, and an R^2 of 0.90 when transferred to a different city, demonstrating strong generalization capabilities.

He et al. [12] proposed a collaborative autonomous driving framework (CCAD) to address the safety limitations of single-agent intelligent vehicles, such as autonomous vehicles and those equipped with ADAS systems. While these vehicles rely solely on their own sensors, their limited perception coverage often leads to accidents. To mitigate this, the authors introduced a C-V2X-enabled framework that connects vehicles with each other and with infrastructure, enabling multi-angle perception and safety-critical information sharing. The CCAD framework utilizes Roadside Units (RSUs), Onboard Units (OBUs), and edge-computing devices to process and transmit data in real time. A case study demonstrated the framework's effectiveness in providing infrastructure-based collaborative lane-keeping guidance when vehicles lose lane detection, significantly enhancing safety. The study highlights CCAD's potential to improve single-agent vehicle safety and enable broader collaborative autonomous driving applications.

However, there is currently almost no research on integrating C-V2X technology into tower cranes. This paper proposes the integration of C-V2X technology into the tower crane system to achieve real-time monitoring of working conditions, timely identification of potential failure risks, and improvement of work efficiency. This provides a new direction for the intelligent development of tower cranes.

2 CURRENT STATUS OF TOWER CRANES

Zhu et al. [13]conducted a systematic literature review to explore crane-lift automation (CLA) in construction, analyzing 106 journal articles and 15 products. The study categorizes CLA into four levels: Operator Assistance, Partial Automation, High Automation, and Full Automation. Key technologies examined include sensing and perception, planning and decision-making, and motion control. Findings highlight the dominance of camera-based sensing and the growing use of intelligent path re-planning and closed-loop control strategies. The authors identify six research directions for achieving higher automation levels, emphasizing multi-sensor integration for real-time collision-free path re-planning. This review serves as a milestone in CLA research, providing a foundation for advancing autonomous crane technologies.

Caporali et al. [14] addressed the challenge of controlling tower crane movements while considering the crane as a deformable system subject to vibrations. They developed a solution that incorporates the normal vibration modes of the crane and the swaying of the payload during motion. Using a "command smoothing" method within an open-loop system, the original operator commands are adjusted to reduce payload sway and structural vibrations. The tower crane, modeled as a highly nonlinear underactuated system, accounts for structural deformations. The iterative calculation of sway angles and velocity profiles for crane motors demonstrates significant attenuation of vibrations when an anti-sway system is applied. Results show improved performance in payload movement, including shorter rotation profiles and damped oscillations, while minimizing horizontal and vertical oscillations in the crane structure. This approach enhances both operational efficiency and structural stability. Schematic diagram of tower crane can be seen in figure 1.

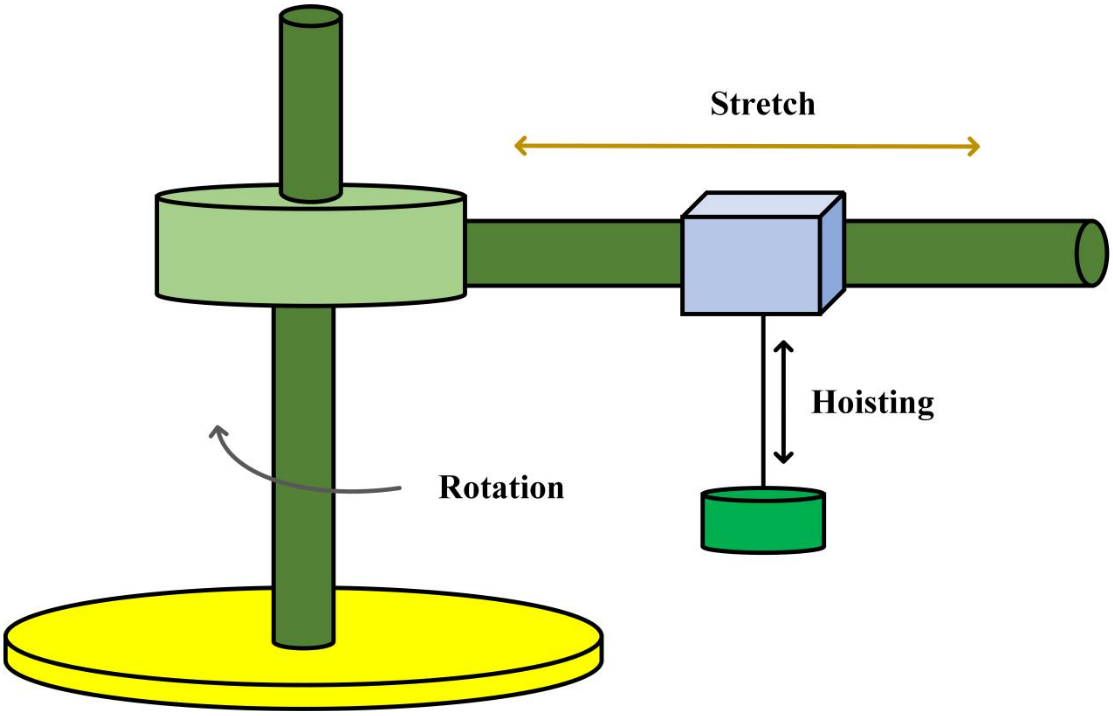

Figure 1 Schematic Diagram of Tower Crane

3 C-V2X TECHNOLOGY DEVELOPMENT STATUS

C-V2X technology enables efficient communication between devices and other systems through cellular networks. As a critical component of Intelligent Transportation Systems, it offers advantages such as low latency and broad coverage. In recent years, C-V2X has played a crucial role in fields like intelligent transportation systems and autonomous driving.

C-V2X technology enables seamless communication across four core scenarios to enhance road safety, efficiency, and connectivity. Vehicle-to-Vehicle (V2V) supports direct real-time data exchange between vehicles, enabling collision warnings by sharing positions and speeds, coordinated platoon driving to optimize traffic flow, and emergency braking alerts to prevent rear-end collisions. Vehicle-to-Infrastructure (V2I) connects vehicles with traffic systems, such as traffic lights and roadside sensors, facilitating traffic signal optimization for route efficiency, real-time road condition updates (e.g., construction zones), and smart parking guidance to locate available spaces. Vehicle-to-Pedestrian (V2P) links vehicles with pedestrians via smartphones or wearables, issuing safety alerts when pedestrians enter hazardous zones, enhancing visibility through wearable devices, and providing interactive navigation via mobile apps. Vehicle-to-Network (V2N) integrates vehicles with cloud platforms for remote services, including real-time traffic monitoring, remote diagnostics for maintenance, and dynamic navigation with updated maps and route planning. Together, these interconnected systems create a cohesive ecosystem that reduces accidents, optimizes traffic management, and paves the way for advanced autonomous driving solutions (figure 2).

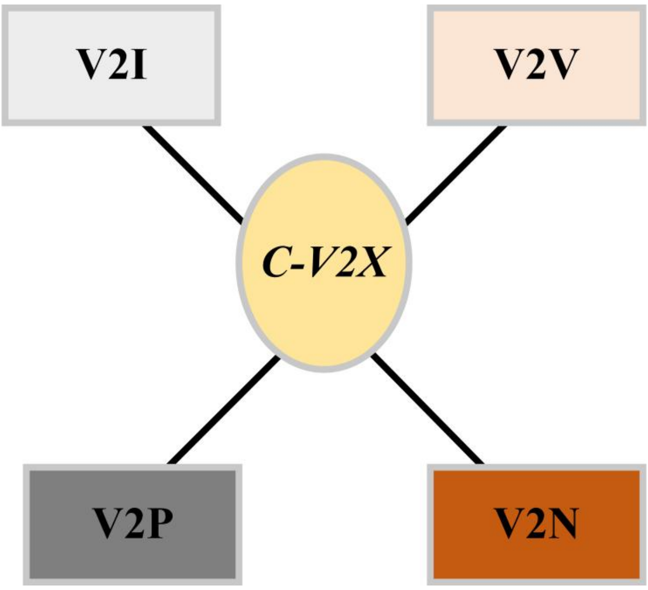

Figure 2 Four Types of C-V2X Technology

4 APPLICATION OF C-V2X IN TOWER CRANE

Integrating C-V2X technology into tower crane systems enables intelligent management and safety-coordinated control of construction site operations. The implementation process is outlined as follows:

4.1 Data Collection and Local Processing

The tower crane's embedded sensors (e.g., inclinometers, load sensors, anemometers) collect equipment status and environmental data (e.g., tilt angle, load weight, wind speed) in real time. These data are transmitted to the ECU (Electronic Control Unit) for immediate analysis. If anomalies (e.g., overload or strong wind) are detected, the ECU triggers a local warning mechanism (e.g., alarms or operational restrictions).

4.2 C-V2X Real-Time Communication

Direct Device-to-Device Connectivity:
Using the C-V2X module, the tower crane establishes direct communication links with nearby cranes, construction vehicles, and workers' smart devices (e.g., safety helmets or handheld terminals). This enables real-time sharing of position, operating radius, and motion trajectories to prevent collisions. For example, if two cranes' booms risk overlapping, the system automatically issues avoidance commands or halts operations.
Cloud Interaction:
Critical data (e.g., equipment health status, construction progress) are uploaded to a cloud server via the cellular network. The cloud employs AI algorithms to analyze historical data, predict potential failures, optimize maintenance schedules, and support remote monitoring and task dispatching.

4.3 Cloud-Based Coordination and Global Optimization

The cloud server integrates data from multiple cranes, vehicles, and environmental sensors to generate a global construction view. This allows dynamic adjustments to operational plans. For instance: Restricting crane operating heights based on real-time wind speed. Coordinating multiple cranes to collaboratively lift large components, minimizing idle time.

4 EMERGENCY RESPONSE AND SAFETY ENHANCEMENT

As shown in figure 3, when sensors detect critical risks (e.g., structural instability), the ECU: Issues emergency evacuation alerts to on-site personnel via C-V2X. Automatically executes safety protocols (e.g., locking hooks, lowering booms).Meanwhile, the cloud server synchronously logs incident data for post-incident analysis and accountability tracing. This integration enhances construction safety, operational efficiency, and intelligent decision-making, paving the way for next-generation smart tower crane systems.

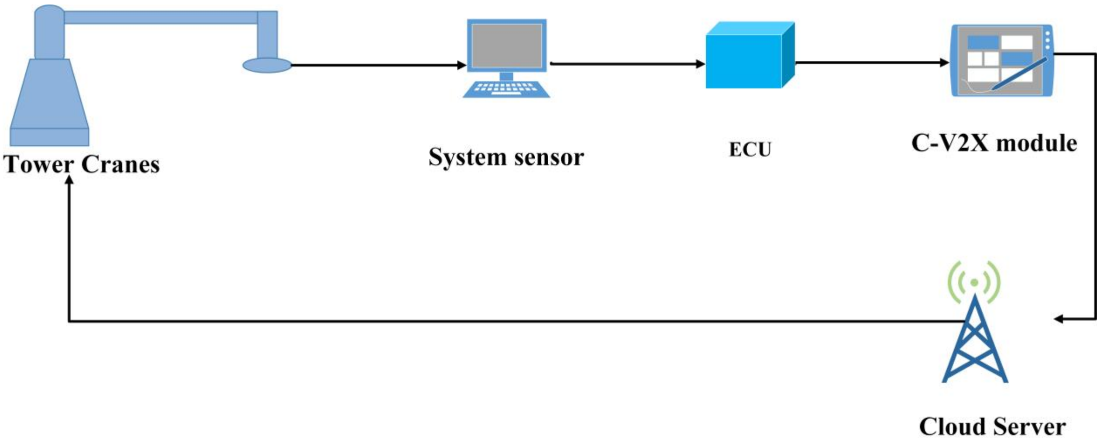

Figure 3 Working Flowchart of the New Tower Crane Combined with C-V2X

5 CONCLUSIONS

The integration of C-V2X technology into tower crane systems significantly enhances the safety, efficiency, and intelligence of construction site operations. Its core advantages include the following aspects:

5.1 Low Latency and High-Reliability Communication

Real-Time Assurance: C-V2X leverages cellular networks (4G/5G) via direct communication (PC5 interface) and network-based communication (Uu interface), enabling millisecond-level low-latency transmission to ensure real-time interaction between tower cranes and surrounding devices (other cranes, vehicles, worker terminals). Anti-Interference Capability: In complex construction environments (e.g., dense metal structures, strong electromagnetic interference), C-V2X's cellular communication outperforms traditional short-range technologies (Wi-Fi, Bluetooth) in stability and coverage range.

5.2 Multi-Dimensional Collaborative Safety Control

Collision Prevention: By sharing real-time positions, operating radii, and motion trajectories of cranes, the system predicts risks of boom overlap or proximity to personnel/vehicles, automatically triggering avoidance protocols or shutdown commands. Environmental Awareness: Integrating data such as wind speed, load weight, and tilt angle, the system dynamically adjusts crane parameters (e.g., height or load limits) to prevent structural instability caused by extreme weather or operational errors. Emergency Response: Upon detecting high-risk events (e.g., structural anomalies), the system broadcasts evacuation alerts to nearby devices and personnel and enforces safety protocols (e.g., locking hooks) to minimize accident impacts.

5.3 Global Optimization and Efficiency Improvement

Cloud-Based Collaborative Scheduling: Data from multiple cranes and vehicles are uploaded to the cloud via the Uu interface. AI algorithms generate a global construction view to optimize lifting sequences and path planning, reducing equipment idle time. \Predictive Maintenance: Long-term analysis of equipment health data (e.g., motor vibration, gear wear) on the cloud predicts potential failures and schedules proactive maintenance, avoiding unplanned downtime. Resource Integration: Coordinating multiple cranes to collaboratively transport large components (e.g., steel beams, prefabricated modules) breaks single-machine limitations and shortens project timelines.

5.4 Flexible Scalability and Compatibility

Multi-Device Interconnection: C-V2X enables seamless connectivity with on-site devices (smart helmets, construction vehicles, drones) to build a unified IoT platform. Standardized Protocols: Based on 3GPP standards, the technology is compatible with future upgrades (e.g., 5G-Advanced or 6G), ensuring adaptability to evolving technical requirements.

5.5 Data-Driven Intelligent Decision-Making

Digitalized Construction Processes: Real-time operational data (e.g., lifting cycles, energy consumption, fault records) provide quantitative insights for site management, enabling refined cost control.Accountability Tracing: All operational commands and risk events are logged on the cloud, facilitating post-incident analysis and process optimization.

5.6 Cost-Benefit Balance

Reduced Accident Losses: Proactive safety controls minimize collision and overturning risks, lowering economic losses and legal liabilities.Extended Equipment Lifespan: Predictive maintenance prevents overload or excessive wear, reducing long-term operational costs.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This work was supported by the Innovation Capability Improvement Project of Science and Technology smes of Shandong Province [Grant number: 2022TSGC2138].

REFERENCES

[1] Miao LL, Chen SF, Hsu YL, et al. How does C-V2X help autonomous driving to avoid accidents? Sensors, 2022, 22(2): 686. DOI: 10.3390/s22020686.

[2] Gupta A, Fernando X. Federated reinforcement learning for collaborative intelligence in UAV-assisted C-V2X communications. Drones, 2024, 8(7): 321. DOI: 10.3390/drones8070321.

[3] Hou P, Li B, Wang ZS, et al. Joint hierarchical placement and configuration of edge servers in C-V2X. Ad Hoc Networks, 2022, 131: 102842. DOI: 10.1016/j.adhoc.2022.102842.

[4] Yoshioka S, Nagata S. Cellular V2X standardization in 4G and 5G. IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, 2022, E105A(5): 754–762. DOI: 10.1587/transfun.2021WBI0001.

[5] Flowers B, Ku YJ, Baidya S, et al. Utilizing reinforcement learning for adaptive sensor data sharing over C-V2X communications. IEEE Transactions on Vehicular Technology, 2024, 73(3): 4051–4066. DOI: 10.1109/TVT.2023.3322068.

[6] Maglogiannis V, Naudts D, Hadiwardoyo S, et al. Experimental V2X evaluation for C-V2X and ITS-G5 technologies in a real-life highway environment. IEEE Transactions on Network and Service Management, 2022, 19(2): 1521–1538. DOI: 10.1109/TNSM.2021.3129348.

[7] Clancy J, Mullins D, Ward E, et al. Investigating the effect of handover on latency in early 5G NR deployments for C-V2X network planning. IEEE Access, 2023, 11: 129124–129143. DOI: 10.1109/ACCESS.2023.3334162.

[8] Hakeem SAA, Kim H. Multi-zone authentication and privacy-preserving protocol (MAPP) based on the bilinear pairing cryptography for 5G-V2X. Sensors, 2021, 21(2): 665. DOI: 10.3390/s21020665.

[9] Sabeeh S, Wesolowski K, Sroka P. C-V2X centralized resource allocation with spectrum re-partitioning in highway scenario. Electronics, 2022, 11(2): 279. DOI: 10.3390/electronics11020279.

[10] Lekidis A, Bouali F. C-V2X network slicing framework for 5G-enabled vehicle platooning applications. 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), ELECTR NETWORK, 2021, Apr. 25-28. DOI: 10.1109/VTC2021-Spring51267.2021.9448769.

[11] Hou Y, Zhang Z, Li WZ, et al. Digital twin based packet reception prediction for C-V2X networks. 2023 IEEE 98th Vehicular Technology Conference (VTC2023-Fall), Hong Kong, 2023, Oct. 10-13. DOI: 10.1109/VTC2023-Fall60731.2023.10333667.

[12] He YK, Wu BF, Dong Z, et al. Towards C-V2X enabled collaborative autonomous driving. IEEE Transactions on Vehicular Technology, 2023, 72(12): 15450–15462. DOI: 10.1109/TVT.2023.3299844.

[13] Zhu AM, Zhang ZQ, Pan W. Technologies, levels and directions of crane-lift automation in construction. Automation in Construction, 2023, 153: 104960. DOI: 10.1016/j.autcon.2023.104960.

[14] Caporali RPL. Anti-sway method for reducing vibrations on a tower crane structure. International Journal of Nonlinear Sciences and Numerical Simulation, 2023, 24(1): 171–184. DOI: 10.1515/ijnsns-2021-0046.