IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 22 January 2024, accepted 4 February 2024, date of publication 12 February 2024, date of current version 21 February 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3365133

RESEARCH ARTICLE

Adaptive Sidelink Open Loop Power Control Optimization Strategies for Vehicle-to-Vehicle Communications in 5G-NR-V2X

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This work was supported by the Institute of Information and Communications Technology Planning and Evaluation (IITP) Grant by the Korea Government through Ministry of Science and ICT (MSIT) (Development of ultra high-speed V2X communication-based autonomous driving service technologies) under Grant 2021-0-01140.

ABSTRACT In the rapidly evolving landscape of 5G-NR-V2X communication systems, the demand for efficient and adaptive power control mechanisms is paramount to address the challenges posed by high-density vehicular environments. This paper introduces the adaptive sidelink open loop power control (AS-OLPC) algorithm as a pioneering solution. The primary objective is to enhance vehicle-to-vehicle (V2V) communication reliability through real-time signal-to-interference-plus-noise ratio (SINR) estimation, interference level measurements, and dynamic power adjustments. The main problem addressed in this research is the need for improved communication throughput in complex urban scenarios. Our specific objectives involve the development and evaluation of AS-OLPC against conventional open loop power control (OLPC) algorithms. To assess the algorithm's effectiveness, an extensive simulation setup replicates realistic urban and highway scenarios. Key metrics such as packet reception ratio (PRR), interference levels, and energy efficiency are employed for analysis. The results showcase the adaptability and superior performance of AS-OLPC, establishing it as a promising solution for optimizing communication throughput in 5G-NR-V2X networks.

INDEX TERMS 5G-NR-V2X, vehicle-to-everything (V2X), sidelink communications, C-V2X services, vehicle-to-vehicle communication, open loop power control (OLPC).

I. INTRODUCTION

In the rapidly evolving landscape of 5G new radio (5G-NR) technology, vehicle-to-everything (V2X) communication stands out as a pivotal framework for enabling seamless connectivity in modern vehicular networks. With the proliferation of smart vehicles and the integration of intelligent transportation systems, the demand for efficient and reliable V2V communication has reached new heights. Sidelink communication, a fundamental component of 5G-NR, facilitates direct communication between neighboring devices without relying on traditional base stations. This technology holds significant promise for enhancing vehicular safety, optimizing traffic flow, and improving overall transportation efficiency [1].

Nevertheless, ensuring robust sidelink communication in vehicular networks is challenging due to the inherent dynamism marked by rapid mobility, fluctuating channel conditions, and varying interference levels. Overcoming these hurdles requires innovative strategies to adapt to real-time conditions and maintain steadfast communication links in urban traffic scenarios [2].

OLPC is a fundamental technique in wireless communication systems, including the latest 5G New Radio networks, aimed at optimizing signal quality and enhancing communication reliability. Unlike closed loop power control (CLPC), which relies on feedback from the receiver to adjust transmission power, OLPC operates without direct feedback, making

The associate editor coordinating the review of this manuscript and approving it for publication was Tariq Umer.

it particularly useful in scenarios where real-time feedback may be challenging to obtain [3], [4], [5], [6].

In OLPC, the transmitting device operates at fixed power levels predetermined by system parameters [7], ensuring adequate coverage and signal strength over specific distances. And OLPC techniques play a crucial role in mitigating interference from neighboring devices. The general process of OLPC as shown in Figure 1. The process begins with measuring channel state parameters, including signal strength. The system then decides to augment or diminish transmission power based on predetermined thresholds and strategic considerations. Devices are instructed to execute necessary power modifications, balancing transmission power and interference levels to avoid signal overlap, reduce collisions, and enhance overall network efficiency [8]. Its adaptability to dynamic environments, with rapidly fluctuating signal strength and interference levels, makes OLPC indispensable for maintaining stable communication links. While OLPC offers significant advantages, implementation challenges persist. Research focuses on adapting OLPC techniques to diverse communication scenarios, handling interference from multiple sources, and optimizing power levels for varying channel conditions. The integration of OLPC with advanced technologies, such as beamforming and Massive MIMO, presents both new opportunities and challenges. In the context of the increasingly prevalent 5G-NR-V2X networks, ongoing research into OLPC techniques is crucial. It plays a pivotal role in shaping the future of intelligent vehicular communication, ensuring seamless connectivity, and contributing to the realization of smart transportation systems on a global scale [9].

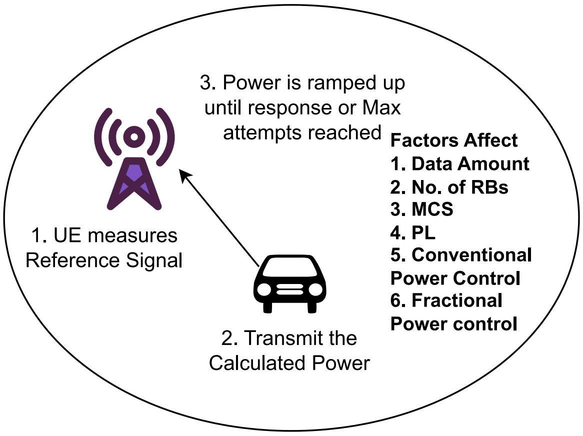

FIGURE 1. OLPC process and influencing factors.

In response to these imperatives, this study explores adaptive open loop power control optimization for sidelink communication in 5G-NR-V2X networks. By dynamically adjusting transmission power based on Signal-to-Interference SINR and interference level measurements, our approach aims to enhance signal reception, mitigate interference, and improve PRR [10]. This research is motivated by the urgent need to enhance the reliability of V2V communication, laying the foundation for safer and more efficient urban transportation systems.

The primary contribution of this paper lies in the introduction of the AS-OLPC algorithm, a novel and adaptive approach to OLPC specifically tailored for 5G-NR-V2X communication scenarios. AS-OLPC dynamically adjusts transmission power levels based on real-time channel conditions, optimizing communication performance in the dynamic and challenging environments of vehicular networks.

- Efficiency in High-Density Traffic Environments: The AS-OLPC algorithm excels in high-density traffic scenarios, crucial for urban traffic management. Adapting to congested scenarios, it ensures reliable communication, minimizes interference risks, and contributes to the overall robustness of vehicular communication.
- Precision in SINR Estimation: The paper contributes the precision of SINR estimation in the AS-OLPC algorithm. This accuracy enables informed decisions on power adjustments, maintaining a delicate balance between signal quality and interference mitigation.
- Comprehensive Performance Analysis: The paper thoroughly analyzes AS-OLPC performance across diverse scenarios, including varying vehicle densities, communication distances, and channel conditions. This evaluation provides valuable insights into the algorithm's behavior in real-world situations, offering a holistic understanding of its strengths and limitations.

II. RELATED WORKS

In the realm of vehicular communication, the optimization of SL OLPC has emerged as a focal point of research, driven by the increasing demand for reliable and efficient communication in connected vehicle environments. As vehicular networks evolve towards 5G-NR-V2X standards, the intricacies of adapting OLPC strategies to the unique dynamics of these networks become important. This paper conducts a comprehensive exploration into the state-of-the-art in SL OLPC, this exploration encompasses a spectrum of related works, ranging from the broader landscape of sidelink communications in Vehicular Networks to the specific challenges of adapting OLPC techniques to dynamic and densely populated urban traffic scenarios. The following sections delve into the intricacies of existing research, highlighting the significance of OLPC as a solution for the optimization of communication in 5G-NR-V2X networks.

In [11], the authors propose to allow SL Tx UEs to send and receive sidelink control information (SCI) in an additional paired direction directly opposite to the primary direction. This helps eliminate hidden node interference while reducing the number of exposed nodes. The application of this strategy can lead to an improvement in average PRR over state-of-the-art techniques under the highest traffic loads. In [12], the authors propose an adaptive transmission power and message interval control scheme called ATOMIC for

Mode 4 of C-V2X. This scheme allows each vehicle to utilize real-time channel awareness and neighbor information to reduce channel contention, thereby improving reliability and latency. In [9], in order to solve the performance degradation problem faced by S-SPS technology, the authors propose a scheme in which the transmission power and reception threshold are adaptively adjusted according to the proposed channel load adjustment method, and the system performance can be significantly improved. In [13], the authors propose a novel composite transmission/reception strategy that is well suited for directional SL systems. In this strategy, the SL UE sends and receives the first phase SCI in an additional "pairing" direction that is directly opposite to the intended transmission direction. In [14], to solve the packet loss problem when vehicle density is high, the authors propose an adaptive power control scheme and tested the impact of the power control algorithm on high-priority event messages and suggest that only when event messages adaptive power control is used only when channel access is requested. In study [15], the authors employ the mean field game (MFG) theoretical framework and formulate a cost function that integrates D2D communication performance with the transmission power cost of the D2D transmitter. Within this power control methodology, factors such as the remaining battery energy of the D2D transmitter, interference induced by the ubiquitous D2D transmitter on other devices, and the interference originating from all other devices towards the universal D2D receiver are taken into account. In [16], the authors explore power control mechanisms, and they focus on optimizing power levels during cooperative retransmissions to achieve minimal energy consumption while meeting stringent latency and reliability requirements. The proposed approach gradually increases transmission power with each retransmission attempt, balancing reliability and energy efficiency. In [17], the authors propose to use an adaptive and dynamic loss compensation technique for estimating the proper transmission power. In [18], the authors consider an optimal power allocation for retransmissions. Transmit power levels are adjusted based on wideband average SNR and path-loss measurements while maintaining desired reliability and latency performance.

The reviewed part of related works underscores the evolving landscape of sidelink OLPC in vehicular communication, providing a foundation for the exploration of the proposed adaptive sidelink open loop power control (AS-OLPC) algorithm. The synthesis of existing literature reveals a collective effort to address the complexities of vehicular communication, with notable contributions spanning from general challenges in Sidelink Communication to the intricacies of adapting OLPC strategies in dynamic urban traffic scenarios.

III. PROBLEM FORMULATION

The design and evaluation of the proposed AS-OLPC algorithm require a comprehensive understanding of the system model and the methodology employed for analysis. In this section, we delineate the sidelink communication architecture, conduct a comparative study of existing OLPC algorithms, detail the simulation setup, and outline the metrics used for performance evaluation [19].

A. CHANNLE MODEL

The system model revolves around the sidelink communication paradigm, emphasizing the direct V2V communication between user equipments (UEs). This paradigm encompasses V2V scenarios, reflecting the versatility of sidelink communication in various applications. The focus is on establishing reliable, low-latency communication links between UEs, fostering the exchange of critical information in real-time [20]. Central to the simulation model are UEs equipped with sidelink communication capabilities. These UEs engage in direct communication, forming ad-hoc connections without relying on traditional network infrastructure. The simulation assumes a realistic representation of radio channel characteristics, encompassing factors such as path loss, shadowing, and multipath fading. To capture the dynamic nature of vehicular networks, the simulation incorporates realistic mobility patterns for UEs. This includes variations in speed, direction, and density of vehicular movement, reflecting the complexities of urban and highway traffic scenarios. In the context of the specified vehicle type with a higher antenna position, the vehicle's dimensions include a length of 5 meters, a width of 2 meters, and a height of 1.6 meters, with the antenna extending to the same height. It's noteworthy that within a given lane, uniform speed is maintained among all vehicles. Furthermore, it's important to emphasize that the distribution of vehicle types is consistent across lanes and is not influenced by lane-specific factors [21].

Moreover, the V2V sidelink channel is modeled based on the LOS, NLOS and NLOSv. For the Highway scenario, the probability of LOS is calculated by [22]:

$$P(LOS) = \min\{1, A * D^2 + B * D + C\} \tag{1}$$

where the $A = 2.1013*10^{-6}$, $B = -0.002$ and $C = 1.0193$. And for the Urban case, is measured by:

$$P\,(LOS) = \min\,\{1,\, 1.05 * \exp\,(-0.0114 * D)\} \tag{2}$$

and probability of NLOSv is:

$$P\,(NLOSv) = 1 - P\,(LOS) \tag{3}$$

The pathloss (PL) is computed following the recommendations of 3GPP for vehicular communications, for the Highway case:

$$PL = 32.4 + 20\log_{10}(D_{3D}) + 20\log_{10}(F_C) \tag{4}$$

And for Urban case, PL is calculated by:

$$PL = 38.77 + 16.7\log_{10}(D_{3D}) + 18.2\log_{10}(F_C) \tag{5}$$

where the F_C denotes the center frequency and D_{3D} denotes the Euclidean distance between transmitter and receiver in 3D space [23].

B. OPEN LOOP POWER CONTROL ALGORITHMS

The management of power control in V2X communications pose a formidable challenge due to its inherent characteristics of mobility, distributed nature, point-to-point interactions, and the broadcast nature of message dissemination. In contrast to conventional LTE networks where uplink power control is facilitated through Base Station-transmitted transmit power control (TPC) commands to UEs, such feedback mechanisms are unavailable in the sidelink of cellular vehicle-to-everything (C-V2X) communication. This limitation arises from the absence of designated receivers providing feedback during sidelink transmissions in V2X scenarios [4].

Moreover, the indiscriminate use of higher transmission power may not necessarily enhance PRR in dense networks, as it may lead to increased interference levels [24]. Conversely, in sparser environments, higher transmission power could extend message propagation distances. In response to the inherent limitations of conventional power control mechanisms, our proposed algorithm introduces a novel paradigm—Sidelink Adaptive Open Loop Power Control for C-V2X, the process as shown in Figure 2. The proposed algorithm is used for SINR estimation by sensing Rx power and using it as a reference signal. And based on this, Tx power is dynamically adjusted to meet reliable signal transmission requirements. Since the proposed algorithm dynamically adjusts the Tx power intensity based on real-time perception, it is expected to show high adaptability to various operating environments. Departing from the conventional reliance on TPC commands, this algorithm leverages real-time channel sensing measurements to dynamically adapt transmission power. By incorporating channel conditions into the decision-making process, our algorithm aims to optimize the trade-off between extending message propagation distances and managing interference levels. This innovative OLPC mechanism holds promise for significantly enhancing the efficiency of sidelink C-V2X communication.

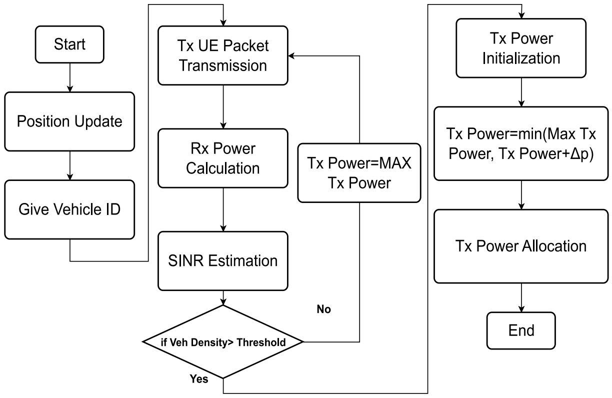

FIGURE 2. **Block diagram of the proposed AS-OLPC process.**

To comprehensively evaluate the efficacy of our proposed algorithm, we conduct a meticulous comparative analysis against traditional OLPC approach. This evaluation focuses on the key parameter PRR that poses unique challenges to V2X communications. A detailed exploration of PRR will provide insights into the impact of algorithms on communication link reliability under different network configurations and densities.

Furthermore, the proposed AS-OLPC algorithm is designed to exhibit adaptability to varying network densities. In high-density scenarios, the algorithm intelligently adjusts transmission power to mitigate interference effects, optimizing communication links. Conversely, in sparser environments, the algorithm maximizes transmission power to capitalize on extended message propagation distances. This holistic approach positions our Channel Sensing-Based OLPC algorithm as a promising solution for addressing the nuanced challenges of power control in V2X communication.

C. FEASIBILITY ANALYSIS OF THE PROPOSED AS-OLPC

Leveraging the well-established concept of SINR estimation, the algorithm establishes a theoretical framework for dynamic power control. This foundation enables the algorithm to adapt transmission power levels based on real-time conditions, providing a robust and theoretically rigorous approach to power control in vehicular communication scenarios.

The adaptability of the OLPC algorithm is a pivotal aspect of its feasibility. In dynamic vehicular environments, the algorithm dynamically adjusts transmission power levels, showcasing its practical applicability. This adaptability is seamlessly integrated into the algorithm's flow, wherein, post the transmission of a packet, it engages in SINR estimation. If the current vehicular density surpasses a predefined threshold, the algorithm initializes transmission power at a conservative level, ensuring a cautious start in high-density scenarios. Subsequent power adjustments, with a fixed incremental value, continue until the transmitted power reaches a maximum threshold. The adaptability of the algorithm, rooted in a theoretical understanding of SINR-based power control, positions it as a versatile and robust solution for real-world vehicular communication challenges.

A critical element contributing to the algorithm's correctness is the precision of SINR estimation. The feasibility analysis scrutinizes the algorithm's capability to estimate SINR consistently and accurately in real-time. This precision is pivotal for making informed decisions regarding power adjustments, and it directly ties into the algorithm's adaptability. Accurate SINR estimations ensure that power adjustments align closely with the actual communication conditions, enhancing the algorithm's reliability. This emphasis on SINR estimation precision reinforces the feasibility of the OLPC algorithm, establishing its potential for practical deployment in dynamic vehicular communication environments.

IV. PROPOSED SL OLPC OPTIMIZATION TECHNIQUE

The AS-OLPC algorithm proposed in this study is designed to enhance the reliability and efficiency of V2V communication in 5G-NR-V2X networks. Unlike traditional OLPC techniques, AS-OLPC adapts dynamically to real-time channel conditions with considering interference, ensuring optimal power levels for sidelink communication without the need for direct receiver feedback.

A. SIDELINK COMMUNICATION ARCHITECTURE

In the SINR Estimation and Adaptive Power Adjustment phase of the AS-OLPC algorithm, the system initiates real-time measurements to assess the quality of the communication channel. Upon the completion of each data transmission, the receiving device meticulously calculates the received signal strength and evaluates the interference levels present in the received signal. These parameters are crucial for computing the SINR, a pivotal metric that characterizes the channel conditions.

The SINR value serves as a key indicator of the communication link's quality. If the computed SINR falls below a predetermined optimal threshold, suggesting suboptimal signal reception and potential communication instability, AS-OLPC initiates an adaptive power adjustment process. This process aims to enhance the SINR value by incrementally increasing the transmission power level.

Adaptive Power Adjustment in AS-OLPC involves a controlled power increment, denoted as Δp, which represents the step size for power level adjustments. By judiciously increasing the transmission power, AS-OLPC seeks to improve the SINR, ensuring a more robust and reliable communication link. However, these power adjustments are conducted within predefined limits to prevent excessive interference with neighboring devices and to maintain energy efficiency.

The adaptive nature of AS-OLPC's power adjustment mechanism allows the algorithm to respond dynamically to changing channel conditions. Continuous SINR monitoring and subsequent power adjustments enable AS-OLPC to optimize the communication link, maximizing the probability of successful packet reception. This meticulous balance between power adjustment, SINR enhancement, and interference mitigation forms the cornerstone of AS-OLPC's ability to adapt to real-time communication challenges in high-density vehicular environments.

B. PROPOSED AS-OPLC ALGORITHM

The Vehicle Density-Based Initialization phase of the AS-OLPC algorithm is essential for adapting communication strategies to the specific vehicular environment. In this phase, AS-OLPC assesses the density of vehicles within the communication range to determine the appropriate power level settings for the initial communication link establishment.

Upon detecting a high vehicle density, indicating a densely populated urban area or a scenario with numerous neighboring vehicles, AS-OLPC employs a cautious approach to ensure stable communication initiation. It sets the initial transmission power level to a moderate value. This deliberate decision is made to avoid potential interference issues and to establish a reliable baseline communication link.

Algorithm 1 Adaptive Sidelink Open Loop Power Control

```
Parameters initialization: $P_{tx} = 23dBm$
Vehicle position update
Vehicle number $V_{no}$ detection
SINR estimation:
$SINR_{est} = \frac{(P_{txRB} \cdot AG_{rx})/(PL \cdot D_{ij}^{\beta})}{(K_{si} \cdot P_{txRB} + P_{noise}) + \sum_{\substack{k \neq j \\ k \in K_{sub}}} (P_{txRB} \cdot AG_{rx})/(PL \cdot D_{ij}^{\beta})}$
Interference evaluation:
    $Inter_{av} = (1 - \beta) \cdot Inter_{av} + \beta \cdot Inter_{ainst}$
if $Vehicle\ Densisy \geq \rho_{threshold}$:
    then:
        Tx power initialization: $P_{tx}(x) = 10dBm$
        if SINR<$SINR_{Target}$
        $P_{tx}(x + 1) = \min(23, P_{tx}(x) + SINR_{est} + Inter_{av})$
else:
        $P_{tx}(x) = P_{max}$
output
        $P_{tx}(x)$
```

The moderate initial power level serves as a foundation for the subsequent adaptive power control strategies implemented by AS-OLPC. By starting with a moderate power setting, AS-OLPC minimizes the risk of signal overlap and collision with neighboring devices, fostering a stable communication foundation. This strategic initialization provides a robust starting point for AS-OLPC's adaptive algorithms to adjust the transmission power dynamically as the communication session progresses.

Moreover, AS-OLPC continuously monitors the vehicle density during the communication session. If the density surpasses the predefined threshold or fluctuates significantly due to changes in traffic patterns, AS-OLPC can dynamically adjust its power control strategies. This adaptive response ensures that AS-OLPC remains responsive to the evolving vehicular environment, maintaining efficient and reliable communication links in high-density scenarios.

During the AS-OLPC processing, first upon packet transmission initiation, the algorithm initializes the transmission power level (Tx power) to a predefined starting value. After transmission, the algorithm calculates the received power at the intended receiver, considering the effects of path loss, shadowing, and potential interference. AS-OLPC leverages accurate SINR estimation techniques to evaluate the quality of the received signal. The SINR estimation is measured by:

$$SINR_{est} = \frac{(P_{txRB} \cdot AG_{rx})/(PL \cdot D_{ij}^{\beta})}{(K_{si} \cdot P_{txRB} + P_{noise}) + \varphi} \tag{6}$$

where P_{txRB} is the uplink transmit power per resource block, AG_{rx} is the receiver antenna gain, PL is the path loss at 1 m. D_{ij}^{β} is the distance between the transmitter and receiver, β represents the loss exponent, P_{noise} is the noise power level for each resource block, and φ is calculated based on:

$$\varphi = \sum\nolimits_{\substack{k \neq j \\ k \in K_{sub}}} (P_{txRB} \cdot AG_{rx})/(PL \cdot D_{ij}^{\beta}) \tag{7}$$

where the K_{sub} represents the set of vehicles using CAM resources for the transmission, $K_{si} \in [0,\ 1]$ is the self-cancellation parameter. As the half-duplex mode is assumed in this work, $K_{si} = 0$ is utilized. Based on the SINR estimation, the algorithm dynamically adjusts the Tx power for the subsequent transmission. If the estimated SINR indicates a suboptimal reception quality, the Tx power is incrementally increased to enhance the signal robustness. Conversely, if the SINR suggests a sufficient reception quality, the algorithm may decrease the Tx power to conserve energy and avoid unnecessary interference. This step involves the assessment of both the desired signal and any interfering signals in the channel. AS-OLPC incorporates a check for the current vehicle density. If the density surpasses a predefined threshold, indicating a potentially congested environment, the algorithm may prioritize conservative power adjustments to mitigate interference risks. AS-OLPC employs an iterative approach to power adjustment, iteratively repeating steps SINR estimation and interference measurement until the Tx power reaches a predefined maximum or the desired SINR is achieved.

The algorithm concludes the current transmission cycle, and the process is repeated for subsequent data packets. The iterative, adaptive nature of AS-OLPC ensures its responsiveness to the varying and dynamic conditions of vehicular communication environments. By integrating accurate SINR estimation and adaptive power adjustment, AS-OLPC aims to enhance the reliability, efficiency, and adaptability of Sidelink communication in 5G-NR-V2X networks.

The careful consideration of vehicle density during initialization, coupled with AS-OLPC's adaptive power adjustment mechanisms, underscores the algorithm's ability to adapt to the complex and dynamic nature of urban vehicular networks. By strategically initializing the communication parameters, AS-OLPC establishes a strong foundation for subsequent adaptive optimizations, ensuring seamless V2V communication in high-density environments.

C. INTERFERENCE MANAGEMENT

The Dynamic Power Control Adaptation Strategies employed by the AS-OLPC algorithm play a pivotal role in optimizing communication reliability and efficiency in high-density vehicular environments. These strategies are designed to adapt transmission power dynamically based on real-time SINR measurements and vehicle density evaluations, ensuring robust and interference-free communication links [25].

The AS-OLPC continuously monitors the SINR of the communication channel in real-time. The SINR metric provides crucial insights into the quality of the communication link, indicating the ratio of the desired signal strength to interference and noise levels [26]. By closely monitoring SINR, AS-OLPC gains a nuanced understanding of the channel conditions, enabling adaptive power adjustments. When SINR measurements indicate suboptimal communication quality, AS-OLPC initiates incremental power adjustments. The algorithm incrementally increases the transmission power level by a predefined value (Δp) to enhance SINR. This incremental approach ensures a controlled response, preventing sudden power surges that could lead to unnecessary interference. The stepwise power adjustment allows AS-OLPC to explore higher power levels gradually, seeking the optimal transmission power for reliable signal reception. AS-OLPC employs adaptive thresholds for SINR, dynamically adjusting the target SINR values based on the vehicular environment. Adaptive thresholds enable AS-OLPC to differentiate between varying communication scenarios, ensuring tailored responses to different channel qualities. Additionally, AS-OLPC operates within predefined power limits, preventing excessive power consumption and interference. By adhering to these limits, AS-OLPC optimizes communication efficiency while maintaining energy conservation.

D. IMPACT OF CHANNEL CONDITIONS

This part within the AS-OLPC algorithm delves into the profound effects that dynamic channel conditions exert on the algorithm's adaptive strategies. This phase encapsulates a comprehensive understanding of how AS-OLPC navigates the intricate landscape of vehicular communication, optimizing performance metrics while contending with the inherent challenges posed by varying channel states.

AS-OLPC's responsiveness to real-time channel conditions stands out as a pivotal factor in optimizing performance. The algorithm continuously monitors the SINR of the communication channel, adapting transmission power levels dynamically to counteract the effects of channel variability. This real-time adaptation ensures that AS-OLPC remains agile and responsive, addressing fluctuations in signal quality caused by factors such as mobility, interference, and environmental changes. The core of AS-OLPC's impact on channel conditions lies in its SINR-guided power adjustments. When the SINR falls below optimal thresholds, indicating degraded channel conditions, AS-OLPC incrementally adjusts transmission power. This meticulous process aims to mitigate the impact of channel fading, interference, and noise, ensuring that the algorithm operates optimally in dynamic urban environments where channel conditions can change rapidly. And the algorithm incorporates adaptive thresholds for SINR, allowing the algorithm to differentiate between varied channel states. Adaptive thresholds ensure that AS-OLPC tailors its responses based on the specific challenges posed by different channel conditions. This adaptability is crucial for navigating scenarios with varying signal strengths, interference levels, and multipath effects, enhancing the algorithm's ability to maintain reliable communication links across diverse urban environments. The impact of channel conditions on AS-OLPC extends to optimizing reliability amidst channel fluctuations. By dynamically adjusting transmission power based on SINR measurements, AS-OLPC seeks to mitigate the effects of fading and interference, enhancing the reliability of V2V communications. This adaptive approach enables AS-OLPC to overcome the challenges presented by high-density vehicular environments, where channel conditions are subject to rapid and unpredictable changes. Additionally, the algorithm intelligently navigates the balance between optimizing communication reliability and managing potential drawbacks. The algorithm incrementally adjusts power levels within predefined limits, ensuring that the impact on neighboring devices and energy efficiency is carefully considered. This balanced approach reflects AS-OLPC's commitment to optimizing channel conditions while mitigating adverse effects on overall network performance.

The integration of the AS-OLPC algorithm into the communication system holds significant implications for overall throughput. AS-OLPC's primary contribution to improved throughput lies in its ability to enhance the reliability of communication links. Through dynamic adjustments of transmission power based on real-time SINR measurements, AS-OLPC mitigates the impact of signal fading and interference. This results in a more robust and stable communication link, reducing the likelihood of packet losses and retransmissions. The consequent reduction in communication errors directly translates to an increase in successful data transmissions, positively influencing overall system throughput. And effectively mitigate interference from neighboring devices. In high-density urban environments where multiple devices share the same communication space, interference can significantly degrade throughput. By dynamically adapting transmission power levels to minimize interference effects, AS-OLPC optimizes the utilization of available bandwidth. The reduction in interference contributes to a more efficient use of the communication spectrum, fostering higher throughput by minimizing collisions and maximizing successful data transmissions.

AS-OLPC's intelligent power control strategies effectively mitigate interference from neighboring devices. In high-density urban environments where multiple devices share the same communication space, interference can significantly degrade throughput. By dynamically adapting transmission power levels to minimize interference effects, AS-OLPC optimizes the utilization of available bandwidth. And the adaptive power control mechanisms of AS-OLPC not only enhance reliability but also contribute to energy efficiency, a factor intricately linked to overall system throughput. By dynamically adjusting transmission power levels based on SINR measurements, AS-OLPC minimizes unnecessary power consumption. This not only extends the battery life of mobile devices but also ensures a more judicious use of resources. Improved energy efficiency translates into more sustainable and prolonged communication sessions [27].

V. SIMULATIONS AND RESULT DISCUSSIONS

The main objective of this section is to utilize machine learning algorithms to analyze the vehicle state and signal phase state model and achieve accurate vehicle categorization in order to enable the accurate transmission of collision avoidance alerts.

A. EVALUATION PARAMETERS

In the evaluation of the proposed algorithm's performance, the selection of the PRR as a pivotal evaluation parameter is grounded in its fundamental role in assessing the algorithm's efficacy. PRR stands as a cornerstone metric, quantifying the proportion of data packets that are successfully received in relation to the total packets transmitted, offering insights into the communication reliability achieved by the algorithm in real-world scenarios. Its utilization is driven by a fundamental need to understand the ratio of effective communications to the overall transmission effort. It is particularly pertinent in dynamic and challenging communication environments, such as those encountered in vehicular ad hoc networks (VANETs), where the algorithm's ability to reliably transmit and receive critical information is paramount [14]. And PRR accounts for both successful and unsuccessful transmissions, it offers a comprehensive assessment of algorithmic performance. Successful transmissions signify the effectiveness of the algorithm under specific conditions, while failures may indicate potential areas for improvement. Higher PRR guarantees more reliable communication and is calculated as below Equation (8):

$$PRR = \frac{P_r}{P_r + P_{SL} + P_{TL}} \tag{8}$$

where P_r, P_{SL} and P_{TL} represent the total received packets, SINR packet loss, and packet loss of transmitting respectively.

In conjunction with PRR, the evaluation incorporates the modulation and coding scheme (MCS) to further characterize the algorithm's performance. MCS represents the combination of modulation and error-correction coding applied to the transmitted signal [28]. The selection of appropriate MCS significantly influences the system's capacity to transmit data reliably in the presence of noise and interference. In conjunction with PRR, the evaluation incorporates the MCS to further characterize the algorithm's performance. MCS represents the combination of modulation and error-correction coding applied to the transmitted signal. The selection of appropriate MCS significantly influences the system's capacity to transmit data reliably in the presence of noise and interference.

The choice of MCS reflects the algorithm's adaptability to varying channel conditions and its ability to optimize communication parameters based on real-time requirements. The evaluation will explore how the algorithm dynamically adjusts MCS, ensuring an optimal balance between data

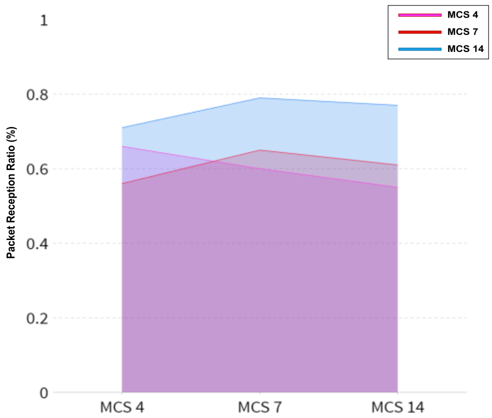

FIGURE 3. The influence of MCS variations on PRR.

rate and reliability under diverse communication scenarios. By integrating PRR and MCS into the evaluation framework, we aim to provide a more comprehensive assessment of the proposed algorithm's performance. Based on the Figure 3, we select to use MSC 4 in Urban scenario with congested traffic and use MCS 7 in Highway scenario and Urban scenario with medium traffic [29].

B. SIMULATION SETUP AND SCENARIOS

Contemplate a C-V2X network comprising various VUEs, strategically distributed through a 1-D Poisson point process with an adjustable density. For the Urban scenario, 2 lanes with 3.5 meters width in each direction with road grid size 433 m$*$250 m, and simulation area size 1299 m$*$ 750 m. VUE moves with a predefined speed and when they reach the end of the road, they loop around and enter the opposite direction. Within the intersection, a VUE follows different paths, the assumptions are the vehicle proceeding straight, turning left, and turning right, with respective probabilities of 0.5, 0.25, and 0.25 [20].

TABLE 1. List of Simulation Parameters for the AS-OLPC.

Parameters	Value
Carrier frequency	5.9 GHz
Bandwidth	10 MHz
Number of blocks for Urban	9
Number of horizontal lanes per block	4
Road length for Highway	4 km
Lanes of the road	3 lanes in each direction
Mean speed in Highway	120 km/h
Mean speed in Urban	60 km/h
Standard deviation of speed	7 km/h
Message size	350 Bytes
Carrier sense threshold	-94 dBm
Transmission power range	10-23 dBm
MCS	4/7
Channel model	CDL
Duplexing type	HD
Antenna gain	3 dB
Noise figure of the receiver	6 dB

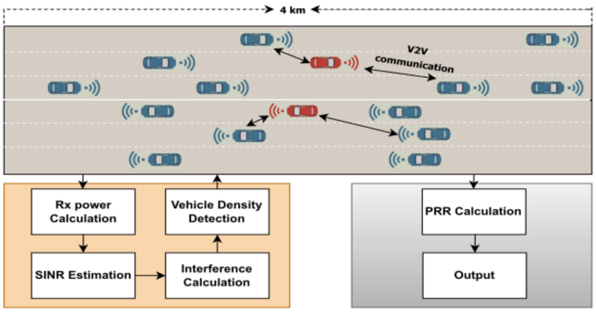

FIGURE 4. The AS-OLPC based power control in highway scenario.

The highway length is set to 4 km with three lanes in each direction, and the width of each lane is 4 m [30]. In this scenario, VUE moves with a predefined speed and when they reach the end of the road, they loop around and enter the opposite direction, as shown in Figure 4.

The VUE periodically broadcasts CAMs via V2V sidelink communication. For the C-V2X system, single carrier frequency-division multiple access (SC-FDMA) is used in a 10-MHz-wide channel. Each VUE automatically selects radio resources using the allocation procedure of SB-SPS. And the self-interference cancellation coefficient is set as -110 dB to effectively eliminate interference between its own transmission and reception. The average duration of the interval for the CBR calculation is set to 100 ms to ensure the provide more real-time performance metrics of channels [31]. To evaluate the efficacy of AS-OLPC under varying traffic congestion conditions, we manipulate vehicle densities to medium congested, heavy congested while maintaining an average speed of 60 km/h in Urban scenario and the mean speed for Highway scenario is set to 120 km/h [32]. We further set the standard deviation of vehicle speeds at 7 km/h to approximate real-world traffic conditions. As traffic conditions transition, AS-OLPC facilitates the necessary adjustments. Consequently, the transmission power fluctuates within a 10–23 dBm range. The main simulation parameters are the same as those listed in Table 1 [23].

C. EXPERIMENTAL RESULTS AND ANALYSIS

We first compare the PRR performance under fixed vehicle density conditions in a highway environment. As a comparison, the original OLPC scheme, different Tx power and the proposed AS-OLPC algorithm are compared, as shown in Figure 5. It can be seen that at close range, high Tx power results in worse channel reliability. Currently, higher Tx power causes higher interference levels. On the contrary, AS-OLPC is in the initialization Tx power state, that is, Tx power $=$ 10 dBm, so the proposed OLPC performance curve overlaps with the Tx power $=$ 10 dBm curve. In the case of long distance, because low Tx power cannot support effective packet transmission distance, PRR gradually decreases,

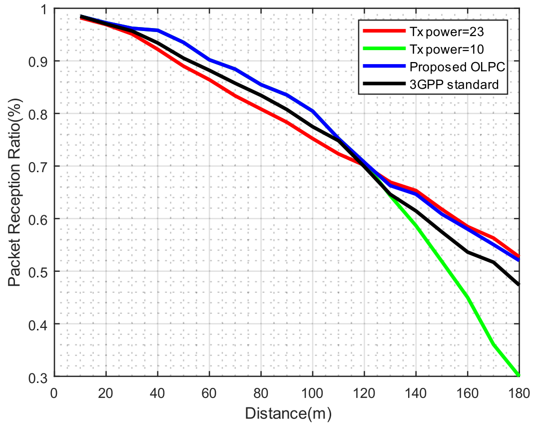

FIGURE 5. PRR performance in Highway scenario with vehicle density = 200.

and the gain of high Tx power on transmission distance is reflected. This is the drop shown by low Tx power when distance = 110 m. At this time, the proposed OLPC begins to control the Tx power to gradually increase, and the PRR performance move closer to Tx power = 23 dBm in a short period of time, which also demonstrated the rapid response of the proposed OLPC. And it can be seen that the performance of the proposed OLPC is always better than the predetermined power control algorithm.

Figure 6 depicts the performance of the proposed OLPC in a medium congested urban environment, comparing various Tx power levels. Similar to the testing conducted in a fixed vehicle density environment, the performance curve of the proposed OLPC aligns with the performance curve achieved at the maximum Tx power for longer distances. This alignment indicates that the proposed OLPC strategically chooses to operate at maximum Tx power in such scenarios. At shorter distances, the PRR performance of the proposed OLPC mirrors that of Tx power set at 10 dBm. During this phase, the proposed OLPC, in order to mitigate interference resulting from potent Tx power, makes the judicious decision to utilize the minimum Tx power setting based on SINR estimation. This adaptive behavior ensures optimal performance in close-proximity scenarios while avoiding undue interference caused by excessive transmission power.

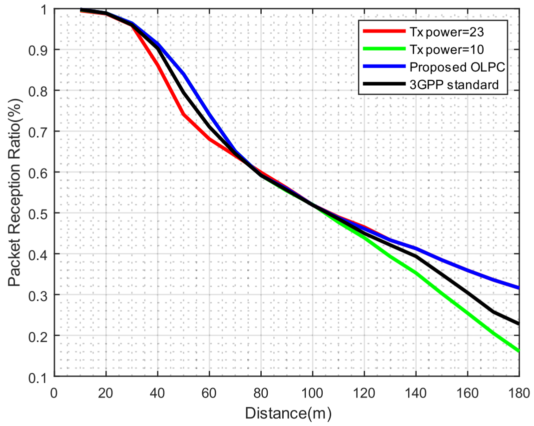

FIGURE 6. Performance of AS-OLPC in medium Urban scenario.

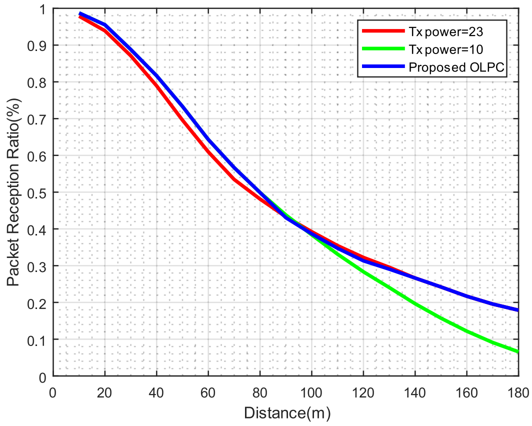

FIGURE 7. Performance of AS-OLPC in congested Urban scenario.

As shown in Figure 7, in a congested Urban environment, the proposed OLPC strategy initially employs lower transmission power. This approach serves the purpose of mitigating interference generated by the transmission power within the system. As the distance between communication entities increases, the OLPC mechanism dynamically adjusts the transmission power, ensuring that it is incrementally raised to guarantee a satisfactory transmission distance. This adaptive control mechanism effectively manages interference levels in the congested urban environment, optimizing the overall performance of the system.

Figure 8 shows the PRR performance of the proposed OLPC in diverse highway scenarios with varying vehicle densities. In instances of low vehicle density, the PRR performance of the proposed OLPC aligns with that of Tx power set at 23 dBm. This alignment suggests that, at this

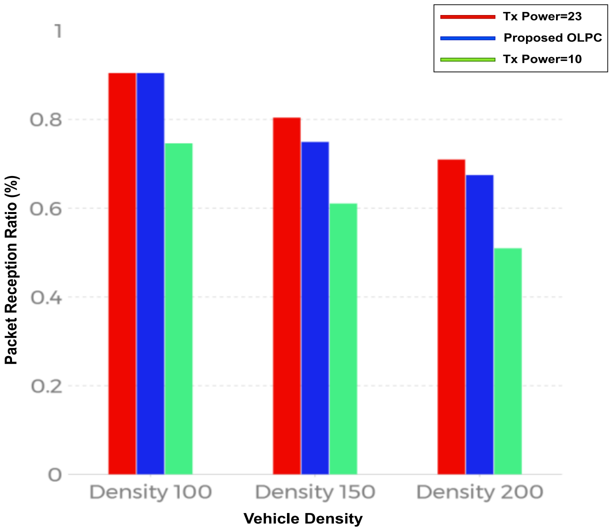

FIGURE 8. PRR performance of AS-OLPC in various density scenarios.

point, the vehicle density has not met the activation standard for AS-OLPC. Consequently, the system consistently opts for the maximum Tx power value as the transmission parameter. As the vehicle density increases, a general reduction in PRR across all conditions is observed. Nevertheless, the proposed OLPC consistently maintains a higher PRR compared to the fixed Tx power scenario at 10 dBm. This is achieved through the OLPC's dynamic adjustment of transmission power, approaching performance levels akin to those achieved under the condition of maximum transmission power. The adaptability of the proposed OLPC contributes to sustaining PRR, even in scenarios of heightened vehicle density, by intelligently adjusting transmission power based on dynamic environmental conditions. Therefore, the proposed OLPC showcases promising interference avoidance capabilities in congested scenarios, ensuring reliable PRR even over extended transmission distances. Furthermore, its use of lower Tx power in proximity contributes to energy efficiency, making it a comprehensive solution for varying highway conditions.

VI. CONCLUSION

In conclusion, this study has presented an in-depth exploration of AS-OLPC in various traffic scenarios for 5G-NR-V2X communications. The introduction of AS-OLPC addresses the unique challenges posed by vehicular communication, offering an adaptive and intelligent power control mechanism specifically designed for the dynamics of V2V scenarios. The introduction of AS-OLPC addresses the unique challenges posed by vehicular communication, offering an adaptive and intelligent power control mechanism specifically designed for the dynamics of V2V scenarios. The algorithm's emphasis on SINR estimation precision contributes to accurate and real-time assessment of communication conditions. This precision enhances the algorithm's ability to dynamically adjust transmission power for optimal performance. AS-OLPC's optimization for 5G-NR-V2X networks leverages the capabilities of 5G technology, providing an advanced and reliable solution for vehicle communication.

The comprehensive performance analysis covered various scenarios, including different vehicle densities, communication distances, and channel conditions. This analysis provides valuable insights into the algorithm's behavior across diverse real-world scenarios. The research outcomes underscore the significance of adaptive power control mechanisms in the evolving landscape of vehicular communication. AS-OLPC not only addresses existing challenges but also opens avenues for future advancements in enhancing the reliability, efficiency, and intelligence of communication in connected vehicle environments.

However, the algorithm's performance in highly dynamic urban environments with rapidly changing traffic patterns warrants further investigation. Enhancements to AS-OLPC to accommodate scenarios with increased vehicular mobility and varying communication distances would contribute to its robustness and practical applicability. And the study primarily focused on the 5G-NR-V2X context; however, the algorithm's adaptability to other communication standards and technologies remains an area for future exploration. Furthermore, an in-depth analysis of AS-OLPC's energy efficiency and its impact on the overall power consumption of connected vehicles represents an avenue for future research. Developing strategies to strike a balance between communication reliability and energy conservation aligns with the broader goals of sustainable and ecofriendly vehicular communication systems.

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