

Backscatter-Aided NOMA V2X Communication under Channel Estimation Errors

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Abstract—Backscatter communications (BC) has emerged as a promising technology for providing low-powered transmissions in nextG (i.e., beyond 5G) wireless networks. The fundamental idea of BC is the possibility of communications among wireless devices by using the existing ambient radio frequency signals. Non-orthogonal multiple access (NOMA) has recently attracted significant attention due to its high spectral efficiency and massive connectivity. This paper proposes a new optimization framework to minimize total transmit power of BC-NOMA cooperative vehicle-to-everything networks (V2XneT) while ensuring the quality of services. More specifically, the base station (BS) transmits a superimposed signal to its associated roadside units (RSUs) in the first time slot. Then the RSUs transmit the superimposed signal to their serving vehicles in the second time slot exploiting decode and forward protocol. A backscatter device (BD) in the coverage area of RSU also receives the superimposed signal and reflect it towards vehicles by modulating own information. Thus, the objective is to simultaneously optimize the transmit power of BS and RSUs along with reflection coefficient of BDs under perfect and imperfect channel state information. The problem of energy efficiency is formulated as non-convex and coupled on multiple optimization variables which makes it very complex and hard to solve. Therefore, we first transform and decouple the original problem into two sub-problems and then employ iterative sub-gradient method to obtain an efficient solution. Simulation results demonstrate that the proposed BC-NOMA V2XneT provides high energy efficiency than the conventional NOMA V2XneT without BC.

Index Terms—Backscatter communication (BC), non-orthogonal multiple access (NOMA), vehicle-to-everything (V2X), channel estimation error, energy-efficient communication.

I. INTRODUCTION

The nextG (i.e., beyond 5G) transportation systems are expected to improve traffic control, traffic efficiency, reliability, and passenger safety [1]. Vehicle-to-everything (V2X) communication is one of the emerging technologies to make these applications available [2]. The V2X networks (V2XneT) include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-roadside unit (V2R), vehicle-to-pedestrian (V2P), vehicle-to-unmanned-aerial-vehicle (V2U), and vehicle-to-satellite (V2S) [3]. Thus, a connected network in the form

of internet-of-vehicles (IoV) is formed which must support high reliability, massive connectivity, while providing energy efficient communications and low transmission latency [4]. It is also important to mention here that the 3rd generation partnership project (3GPP) is already working on the V2XneT solutions for public safety [5]. However, one of the critical issues in existing V2XneT is the use of the conventional orthogonal multiple access (OMA) technique that can only accommodate a limited number of vehicle connections on the available frequency spectrum. This scarcity of available frequency spectrum can cause traffic and data congestion in dense V2XneT. To address this issue, researchers in academia and industry are exploring new air interface techniques.

Recently, non-orthogonal multiple access (NOMA) has been recognized as one of the promising air interface techniques for 6G wireless networks due to high spectral efficiency and massive connectivity [6]. The important feature of NOMA is the use of the power-domain for multiple access, compared to previous air interface techniques that relied on other domains, i.e., time, frequency, and code [7]. In NOMA, multiple vehicles can access the same spectrum/time resource for communications. More specifically, multiple vehicles can be multiplexed through different power levels by using the superposition coding technique at the transmitter side. Then the vehicle with strong channel conditions can apply SIC and decode its desired signal [8]. In NOMA communications, by allocating more power, the quality of services of vehicles with weak channel conditions can be guaranteed.

With the increase in the number of vehicles and the requirements of high data rates, energy consumption increases significantly. This is very problematic as one of the main issues in green V2XneT is the increasing levels of CO₂ emissions [9]. Thus, there has been increased interest to use ambient radio frequency (RF) waves for communications between different vehicles. In this regard, a promising technology is backscatter communications (BC) which can ease the situation [10]. Using existing RF resources, BC can transfer the data between different vehicles in the network. Therefore, BC can extend the lifetime of devices (that act as tags) by reflecting the existing RF signals towards intended vehicles without exploiting any oscillatory circuitry. The performance of BC

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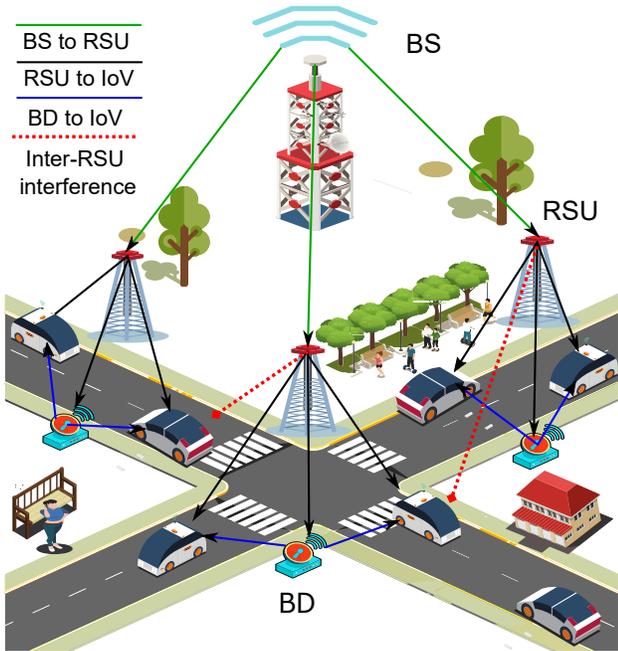


Fig. 1: System Model of BC-NOMA V2X communications.

in different scenarios using conventional OMA technique has been extensively studied in literature [11]–[17].

Researchers in industry and academia have recently conducted studies on resource optimization of BC-NOMA networks. For example, Khan *et al.* [18] have provided an energy-efficient optimization framework for multi-cell BC-NOMA IoV networks under the assumption of imperfect SIC decoding error. To improve the minimum throughput, the work in [19] has proposed a resource allocation framework for optimizing power, time and reflection coefficient in full-duplex BC-NOMA networks. Besides that, the work of [20] has presented the optimization of power and reflection coefficient for green communications in BC-NOMA systems. To enhance spectral efficiency, the authors of [21] have explored a new problem of resource management in multi-cell BC-NOMA networks under the assumption of SIC decoding error. Moreover, to minimize interference between uplink and downlink transmission, Ding *et al.* [22] have investigated the achievable sum rate maximization problem for the BC-NOMA system. The problem of physical layer security is also investigated in [23] for the BC-NOMA system, where the transmit power and reflection coefficient have jointly optimized to maximize the sum secrecy rate. Of late, the problem of improving energy efficiency is investigated by Ahmed *et al.* [24] for multi-cell BC-NOMA network to simultaneously optimize the transmit power and reflection coefficient under SIC decoding error.

Although many works have been carried out on BC-NOMA networks, the existing works have considered perfect channel state information (CSI) in their system models, which are not practical in real scenarios. To the best of our knowledge, the problem of energy-efficient communication for BC-NOMA cooperative V2XneT under imperfect CSI has not been

investigated previously. Therefore, this paper investigates a new problem to simultaneously optimize the transmit power of base station (BS), roadside units (RSUs), and reflection coefficient of backscatter devices (BDs) under perfect and imperfect CSI. To solve the optimization problem efficiently, we first transform and decouple the original problem into two sub-problem and then adopt the iterative sub-gradient method. Simulation results are also provided to demonstrate the effect of channel estimation error and the benefits of the proposed optimization framework against the benchmark optimization. The rest of the paper is structured as: the second section studies the system model and problem formulation; the third section presents the proposed optimization solution; the fourth section discusses the simulations results; the fifth section concludes this paper.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Consider a BC-NOMA cooperative V2XneT, as illustrated in Figure 1. In the proposed model, we consider a single BS and multiple RSUs, where each RSU accommodates two vehicles using decode-and-forward protocol. We also consider a BD in the coverage area of RSUs. The direct link from BS to vehicles is missing due to high shadowing. In this work, it is assumed that: i) All the devices in the network are equipped with single antenna; ii) The CSI over all links is imperfect due to the channel estimation errors; iii) The wireless channels are independent and undergo Rayleigh fading. This model considers half duplex communication, where the transmission process is completed in two different time slots. In the first time slot, a BS sends the superimposed signal to its serving RSUs utilizing NOMA protocol. In the second time slot, RSUs first decode the superimposed signal and then forward it to its serving vehicles.

A. First Time Slot (transmission from BS to RSUs)

In the first time slot, transmission between BS and RSUs takes place. Although we consider two RSUs for simplicity, our model can be easily extended to multiple RSUs, which will be investigated in our future study. A superimposed signal that BS transmits (denoted as x) can be expressed as

$$x = \sum_{m=1}^2 \sqrt{P\alpha_m}x_m, \quad (1)$$

where P is the transmit power of BS and α_m denotes the power allocation coefficient of the RSU (denoted as R_m), for $m \in \{1, 2\}$. Moreover, x_m represents the unit power signal of R_m . The channel from BS to R_m can be modeled as $h_m = H_m \times d_m^{-\zeta}$, where H_m is the Rayleigh fading coefficient, d_m denotes the distance from BS to R_m and ζ represents the path-loss exponent [25]. In this work, we consider the error in channel estimation, hence the CSI is imperfect. Using the minimum mean square error (MMSE) model, the channel of R_m from the BS is estimated as $h_m = \hat{h}_m + \epsilon_m$, where \hat{h}_m is the estimated channel gains of h_m with variance $\sigma_{\hat{h}_m}^2$ and ϵ_m represents the estimated channel error with zero mean

and $\sigma_{\epsilon_m}^2$ variance. For the convenience of discussion, the case of constant estimation error ($\sigma_{\epsilon_m}^2 = \sigma_{\epsilon}^2$) for all channels is considered in this work. It is important to note that both \hat{h}_m and ϵ_m are uncorrelated. The signal that R_m receives from BS can be expressed as

$$y_m = \hat{h}_m x + \epsilon x + \varpi_m, \quad (2)$$

where ϖ_m is the additive white Gaussian noise (AWGN) with zero mean and σ^2 variance. We assume that the channel gains of RSUs are arranged as $\hat{h}_1 > \hat{h}_2$. Therefore, R_1 can apply SIC to decode its signal while R_2 cannot apply SIC and decode its signal by treating the signal of R_1 as a noise. Based on these observations, the data rate C_1 and C_2 can be written as $C_1 = t_1 B \log_2(1 + \gamma_1)$ and $C_2 = t_1 B \log_2(1 + \gamma_2)$, where t_1 shows the first transmission slot which should be equal to 1/2. The terms γ_1 and γ_2 are the signal-to-interference-plus-noise-ratio (SINR) which can be stated as

$$\gamma_1 = \frac{|\hat{h}_1|^2 P \alpha_1}{P \sigma_{\epsilon}^2 (\alpha_1 + \alpha_2) + \sigma^2}. \quad (3)$$

$$\gamma_2 = \frac{|\hat{h}_2|^2 P \alpha_2}{|\hat{h}_2|^2 P \alpha_1 + P \sigma_{\epsilon}^2 (\alpha_1 + \alpha_2) + \sigma^2}. \quad (4)$$

B. Second Time Slot (transmission from RSUs to vehicles)

In this time slot, transmission between RSUs and vehicles takes place. The RSUs first regenerate the superimposed signal and then forward it. The signal that R_m transmits (denoted as s_m) can be written as

$$s_m = \sum_{i=1}^2 \sqrt{Q_m \beta_{i,m}} s_{i,m}, \quad (5)$$

where Q_m is the transmit power of R_m , $\beta_{i,m}$ represents the power allocation coefficients of the vehicle (denoted as $V_{i,m}$), for $i \in \{1, 2\}$ and $s_{i,m}$ denotes the unit power signals of $V_{i,m}$. The channels used in this time slot can be modeled and estimated similar to the first time slot. However, for the simplicity, we denote the channel from R_m to $V_{i,m}$ as $\hat{h}_{i,m}$. Without loss of generality, we assume that the channel gains of $V_{1,m}$ is stronger than $V_{2,m}$, i.e., $|\hat{h}_{1,m}|^2 > |\hat{h}_{2,m}|^2$.

During the transmission in the second time slot, a BD in the geographical area of R_m (stated as B_m) also receives the superimposed signal s_m from R_m . B_m first harvests energy from s_m , then modulate its own message z_m and reflect it towards $V_{i,m}$, where $\mathbb{E}[|z_m|^2] = 1$ and $\mathbb{E}[\cdot]$ represents the expectation operation. Since we consider imperfect CSI, therefore the signal that $V_{i,m}$ and receives from R_m can be expressed as

$$y_{i,m} = \hat{h}_{i,m} s_m + \sqrt{\xi_m} \hat{h}_{i,m}^b \hat{h}_{b,m} s_m z_m + \epsilon s_m + \epsilon \sqrt{\xi_m} + \varpi_{i,m}, \quad (6)$$

where ξ_m is the reflection coefficient of B_m and $\hat{h}_{i,m}^b$ denotes the channel gain between B_m and $V_{i,m}$. Further, $\hat{h}_{b,m}$ represents the channel gain between R_m and B_m while $\varpi_{i,m}$ states the AWGN. Based on the received signal in (6), the data rate of $V_{1,m}$ and $V_{2,m}$ can be formulated as

$C_{1,m} = t_2 B \log_2(1 + \gamma_{1,m})$ and $C_{2,m} = t_2 B \log_2(1 + \gamma_{2,m})$, where t_2 shows second slot, $\gamma_{1,m}$ and $\gamma_{2,m}$ are the SINRs as

$$\gamma_{1,m} = \frac{Q_m \beta_{1,m} (|\hat{h}_{1,m}|^2 + \xi_m |\hat{h}_{1,m}^b|^2 |\hat{h}_{b,m}|^2)}{\sigma_{\epsilon}^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{1,m}' + \sigma^2}. \quad (7)$$

$$\gamma_{2,m} = \frac{Q_m \beta_{2,m} (|\hat{h}_{2,m}|^2 + \xi_m |\hat{h}_{2,m}^b|^2 |\hat{h}_{b,m}|^2)}{\Pi_{2,m} + \sigma_{\epsilon}^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{2,m}' + \sigma^2}. \quad (8)$$

where $\Omega_{1,m} = \xi_m |\hat{h}_{1,m}^b|^2 |\hat{h}_{b,m}|^2$ and $\Omega_{2,m} = \xi_m |\hat{h}_{2,m}^b|^2 |\hat{h}_{b,m}|^2$ refer to the useful received from the BDs. Furthermore, $\Pi_{2,m} = Q_m \beta_{1,m} (|\hat{h}_{2,m}|^2 + \xi_m \hat{h}_{2,m}^b \hat{h}_{b,m})$ is the interference due to NOMA transmission, and $I_{i,m}' = |\hat{h}_{i,m}'|^2 Q_{m'}$ is the co-channel interference among RSUs. According to the decode and forward protocol at RSUs, the end-to-end rate can be calculated as [26]

$$\bar{C} = \frac{1}{2} \min\{C_m, C_{i,m}\}. \quad (9)$$

Then, the sum rate of V2XneT can be expressed as

$$\bar{C}_{sum} = \sum_{m=1}^2 \sum_{i=1}^2 \frac{1}{2} \min\{C_m, C_{i,m}\}. \quad (10)$$

C. Problem Formulation

The objective of this work is to provide energy-efficient communication in BC-NOMA V2XneT by optimization the transmit power of BS, RSUs, and reflection coefficient of BDs. It can be achieved by formulating the following optimization problem

$$\begin{aligned} \text{(P)} \quad & \min_{\alpha_m, \beta_{i,m}, \xi_m} \left\{ \sum_{m=1}^2 P \alpha_m + \sum_{m=1}^2 \sum_{i=1}^2 Q_m \beta_{i,m} \right\} \\ \text{s.t. (A1)} \quad & \sum_{m=1}^2 C_m \geq C_{min}, \\ \text{(A2)} \quad & \sum_{i=1}^2 C_{i,m} \geq C_{min}, m \in \{1, 2\}, \\ \text{(A3)} \quad & \sum_{m=1}^2 P \alpha_m \leq P_{max}, \\ \text{(A4)} \quad & \sum_{m=1}^2 \alpha_m \leq 1, \\ \text{(A5)} \quad & \sum_{i=1}^2 Q_m \beta_{i,m} \leq Q_{max}, m \in \{1, 2\}, \\ \text{(A6)} \quad & \sum_{i=1}^2 \beta_{i,m} \leq 1, m \in \{1, 2\}, \\ \text{(A7)} \quad & 0 \leq \xi_m \leq 1, m \in \{1, 2\}, \end{aligned} \quad (11)$$

where the objective of (P) is to minimize the total transmit power of the BC-NOMA V2XneT. Constraints (A1) and (A2) ensure the minimum rate and first and second slots, where C_{min} shows the minimum rate threshold. Constraints (A3) and (A5) limit the transmit power of BS and RSUs, where

P_{max} and Q_{max} are the maximum power budget that BS and RSU. Constraints (A4) and (A6) describe the power allocation according to NOMA protocol. Constraint (A7) controls the reflection coefficient of BD.

III. PROPOSED SOLUTION

The problem (P) is coupled on multiple variables which makes it very complex and hard to solve. Thus, we first transform and decouple it into two sub-problems, i.e., 1) power allocation at BS; 2) power allocation at RSUs and reflection coefficient at BDs. Then, we adopt iterative sub-gradient method to obtain sub-optimal yet efficient solution [27]. For any given value of transmit power at RSUs and reflection coefficient at BDs, the power minimization problem in (11) can be simplified as:

$$\min_{(\alpha_1, \alpha_2)} P(\alpha_1 + \alpha_2) \quad (12)$$

$$\begin{aligned} \text{s.t. (A8): } & |\hat{h}_1|^2 P \alpha_1 \geq (2^{C_{min}} - 1)(P \sigma_\epsilon^2 (\alpha_1 + \alpha_2) + \sigma^2), \\ \text{(A9): } & |\hat{h}_2|^2 P \alpha_2 \geq (2^{C_{min}} - 1) \times \\ & (|\hat{h}_2|^2 P \alpha_1 + P \sigma_\epsilon^2 (\alpha_1 + \alpha_2) + \sigma^2), \\ \text{(A10): } & P(\alpha_1 + \alpha_2) \leq P_{max}, \\ \text{(A11): } & \alpha_1 + \alpha_2 \leq 1, \end{aligned}$$

where the objective in (12) is to minimize the total BS transmit power. Constraint (A8) and constraint (A9) guarantee the minimum rate of R_1 and R_2 , respectively. Constraint (A10) limits the transmit power of BS while constraint (A11) is the power allocation limit of R_1 and R_2 . To solve (12), we employ a sub-gradient method, in which we first define the Lagrangian function and then compute its derivation with respect to α_1 and α_2 . Here we omit the detail derivation for sake of simplicity and limited space, the value of α_1^* and α_2^* can be expressed as

$$\alpha_1^* = P + \lambda_1 P + (2^{C_{min}} - 1) \psi_2 (|\hat{h}_2|^2 P + P \sigma_\epsilon^2) + \psi_1 ((2^{C_{min}} - 1) P \sigma_\epsilon^2 - |\hat{h}_1|^2 P) + \lambda_2 \alpha_2 \quad (13)$$

$$\alpha_2^* = P + \lambda_1 P + (2^{C_{min}} - 1) P \psi_1 \sigma_\epsilon^2 + \psi_2 ((2^{C_{min}} - 1) P \sigma_\epsilon^2 - |\hat{h}_2|^2 P) + \lambda_2 \alpha_1 \quad (14)$$

where $\psi_1, \psi_2, \lambda_1, \lambda_2$ are the Lagrangian multipliers. Next we iteratively update α_1, α_2 and the Lagrangian multipliers as

$$\alpha_1^{(itr+1)} = (\alpha_1(itr) - \delta(itr) \alpha_1^*)^+ \quad (15)$$

$$\alpha_2^{(itr+1)} = (\alpha_2(itr) - \delta(itr) \alpha_2^*)^+ \quad (16)$$

$$\psi_1^{(itr+1)} = (\psi_1(itr) - \delta(itr) (|\hat{h}_1|^2 P \alpha_1 - (2^{C_{min}} - 1) P \sigma_\epsilon^2 (\alpha_1 + \alpha_2) + \sigma^2))^+ \quad (17)$$

$$\psi_2^{(itr+1)} = (\psi_2(itr) - \delta(itr) (|\hat{h}_2|^2 P \alpha_2 - (2^{C_{min}} - 1) (|\hat{h}_2|^2 P \alpha_1 + P \sigma_\epsilon^2 (\alpha_1 + \alpha_2) + \sigma^2)))^+ \quad (18)$$

$$\lambda_1^{(itr+1)} = (\lambda_1(itr) - \delta(itr) (P_{max} - P(\alpha_1 + \alpha_2)))^+ \quad (19)$$

$$\lambda_2^{(itr+1)} = (\lambda_2(itr) - \delta(itr) (1 - (\alpha_1 + \alpha_2)))^+ \quad (20)$$

where itr shows the iteration index and δ is the nonnegative step size. The above iterative process will continue until the required criterion is satisfied.

Accordingly, for a given transmit power at BS, the problem of power allocation at RSUs and reflection coefficient of BDs can be formulated as

$$\min_{(\beta_{1,m}, \beta_{2,m}, \xi_m)} \sum_{m=1}^2 Q_m (\beta_{1,m} + \beta_{2,m}) \quad (21)$$

$$\begin{aligned} \text{s.t. (A12): } & Q_m \beta_{1,m} (|\hat{h}_{1,m}|^2 + \Omega_{1,m}) \geq (2^{C_{min}} - 1) \\ & (\sigma_\epsilon^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{1,m}^{m'} + \sigma^2), m \in \{1, 2\}, \\ \text{(A13): } & Q_m \beta_{2,m} (|\hat{h}_{2,m}|^2 + \Omega_{2,m}) \geq (2^{C_{min}} - 1) (\Pi_{2,m} \\ & + \sigma_\epsilon^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{2,m}^{m'} + \sigma^2), m \in \{1, 2\}, \\ \text{(A14): } & Q_m (\beta_{1,m} + \beta_{2,m}) \leq Q_{max}, m \in \{1, 2\}, \\ \text{(A15): } & \beta_{1,m} + \beta_{2,m} \leq 1, m \in \{1, 2\}, \\ \text{(A16): } & 0 \leq \xi_m \leq 1, m \in \{1, 2\}, \end{aligned}$$

where constraints (A12) and (A13) ensure the minimum rate of $V_{1,m}$ and $V_{2,m}$, respectively. Constraint (A14) and constraint (A15) control the transmit power of RSUs according to the NOMA protocol while (A16) is the reflection coefficient constraint. Similar to (12), we exploit the sub-gradient method to obtain the efficient solution. After necessary calculation, the value of β_1^*, β_2^* , and ξ_m can be stated as

$$\beta_{1,m}^* = Q_m (1 - |\hat{h}_{1,m}|^2 \eta_{1,m} - \xi_m |\hat{h}_{1,m}^b|^2 |\hat{h}_{b,m}|^2 \eta_{1,m} + (2^{C_{min}} - 1) (\eta_{1,m} + \eta_2) \sigma_\epsilon^2 + \mu_m) \quad (22)$$

$$\beta_{2,m}^* = Q_m (1 - |\hat{h}_{2,m}|^2 \eta_{2,m} - \xi_m |\hat{h}_{2,m}^b|^2 |\hat{h}_{b,m}|^2 \eta_{2,m} + (2^{C_{min}} - 1) (\eta_{1,m} + \eta_{2,m}) \sigma_\epsilon^2 + \mu_m) \quad (23)$$

$$\xi_m^* = -\beta_{1,m} |\hat{h}_{1,m}^b|^2 |\hat{h}_{b,m}|^2 \eta_{1,m} Q_m - \beta_{2,m} |\hat{h}_{2,m}^b|^2 |\hat{h}_{b,m}|^2 \times \eta_{2,m} Q_m + (2^{C_{min}} - 1) (\eta_1 + \eta_{2,m}) \sigma_\epsilon + v_m \quad (24)$$

where $\eta_{1,m}, \eta_{2,m}, \mu_m, \zeta_m, v_m$ are the Lagrangian multipliers. Now we iteratively update β_1^*, β_2^* , and ξ_m along with the Lagrangian multipliers as

$$\beta_{1,m}^{(itr+1)} = (\beta_{1,m}(itr) - \delta(itr) \beta_{1,m}^*)^+ \quad (25)$$

$$\beta_{2,m}^{(itr+1)} = (\beta_{2,m}(itr) - \delta(itr) \beta_{2,m}^*)^+ \quad (26)$$

$$\xi_m^{(itr+1)} = (\xi_m(itr) - \delta(itr) \xi_m^*)^+ \quad (27)$$

$$\eta_{1,m}^{(itr+1)} = (\eta_{1,m}(itr) - \delta(itr) (Q_m \beta_{1,m} (|\hat{h}_{1,m}|^2 + \xi_m |\hat{h}_{1,m}^b|^2 |\hat{h}_{b,m}|^2 - (2^{C_{min}} - 1) (\sigma_\epsilon^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{1,m}^{m'} + \sigma^2)))^+ \quad (28)$$

$$\eta_{2,m}^{(itr+1)} = (\eta_{2,m}(itr) - \delta(itr) (Q_m \beta_{2,m} (|\hat{h}_{2,m}|^2 + \xi_m |\hat{h}_{2,m}^b|^2 |\hat{h}_{b,m}|^2 - (2^{C_{min}} - 1) (\Pi_{2,m} + \sigma_\epsilon^2 (Q_m (\beta_{1,m} + \beta_{2,m}) + \xi_m) + I_{2,m}^{m'} + \sigma^2)))^+ \quad (29)$$

$$\mu_m^{(itr+1)} = (\mu_m(itr) - \delta(itr) (Q_{max} - Q_m (\beta_{1,m} + \beta_{2,m})))^+ \quad (30)$$

$$\zeta_m^{(itr+1)} = (\zeta_m(itr) - \delta(itr) (1 - (\beta_{1,m} + \beta_{2,m})))^+ \quad (31)$$

$$v_m^{(itr+1)} = (v_m(itr) - \delta(itr) (1 - \xi_m))^+ \quad (32)$$

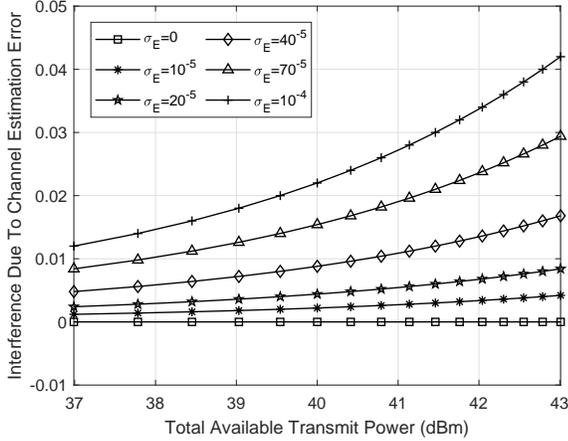


Fig. 2: The effect of increasing transmit power on the interference due to channel estimation error.

TABLE I: Simulation parameters

Parameter	Value
Total power budget (BS+RSUs)	45 dBm
Maximum reflection coefficient ξ	1
Relay (RSUs)	Decode-and-forward
Channel estimation error (σ_E)	0→0.01
Radius of BS	50 meters
Radius of RSU	20 meters
Channel realization	10^3
Minimum data rate C_{\min}	0.5 bps
Pathloss exponent (ζ)	4
Noise power density σ^2	-170 dBm
Bandwidth B	1 MHz
Circuit power	5 dBm

where (25)-(32) are iteratively updated until the selection criterion is satisfied.

IV. NUMERICAL RESULTS AND DISCUSSION

Here we present the numerical results and their discussion. We compare the considered BC-NOMA V2XneT with the conventional NOMA V2XneT without BC. In this work, we calculate the system achievable energy efficiency (Mbpj) as the sum rate of NOMA V2XneT divided by the total power consumption. Unless stated otherwise the simulation parameters are set according to Table I.

Fig. 2 shows the effect of imperfect CSI over the proposed BC-NOMA cooperative V2XneT by plotting interference due to the different values of channel estimation error versus the total available power of the system. We also plot perfect CSI where the value of $\sigma_E = 0$, which means there is no interference and the devices can perceive accurate channel gain. We note that the interference is almost negligible for the small value of σ_E . However, by increasing the values of σ_E , the interference increases significantly as the available transmit power increases. It shows how important is the channel estimation in practical V2X scenarios.

Fig. 3 shows the achievable energy efficiency of V2XneT versus the available transmit power for different values of

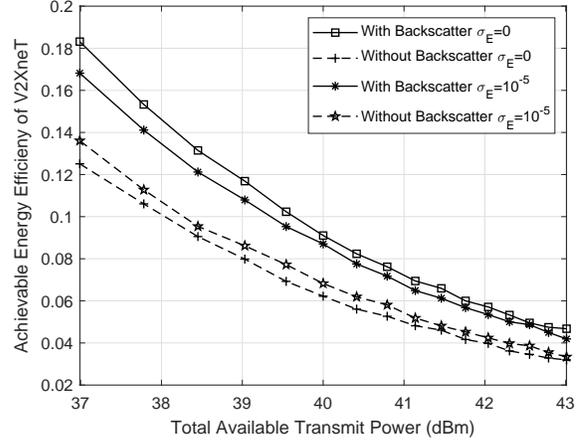


Fig. 3: Total achievable energy efficiency of V2XneT versus available transmit power by varying σ_E .

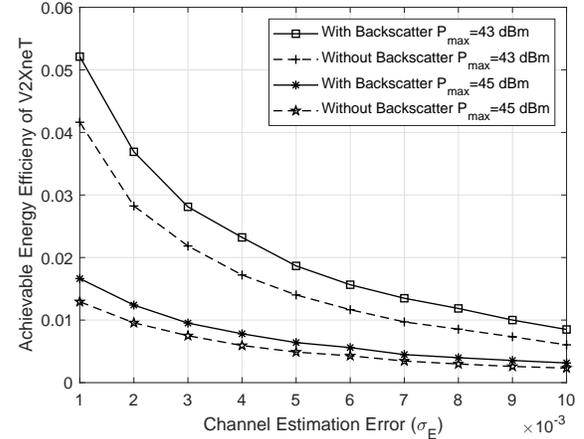


Fig. 4: The effect of channel estimation error on the total achievable energy efficiency of V2XneT by varying P_{max} .

channel estimation error. Here we plot the achievable energy efficiency of both BC-NOMA and conventional NOMA V2XneT. We note an increase in the achievable energy efficiency of both frameworks against the increasing available power of the system. We can also observe that the curves follow the bell shape such that they increase initially when the available power of the system increase. Then it starts falling when it goes to the saturating point. However, the gap between the proposed BC-NOMA V2XneT and the conventional NOMA V2XneT is considerably large, showing the proposed framework's benefits.

To further investigate the performance of the proposed BC-NOMA V2XneT, it is interesting to see the impact of varying channel estimation error on the achievable energy efficiency. Fig. 4 illustrates the system achievable energy efficiency against the varying values of σ_E for different power budgets of V2XneT. As expected, the achievable energy efficiency of both frameworks decreases as the value of σ_E increases. This is because when σ_E increases, the interference is also increased,

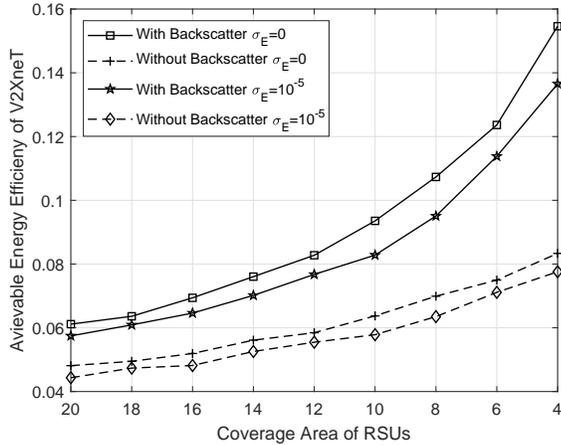


Fig. 5: The effect of RSU coverage on V2XneT performance for different values of σ_E .

which decreases the sum rate of VEXneT. However, our BC-NOMA cooperative V2XneT performs better compared to the benchmark conventional NOMA V2XneT without BC.

To show the performance of the proposed BC-NOMA V2XneT with the coverage area of RSUs, Fig. 5 investigates the achievable energy efficiency of BC-NOMA V2XneT against the varying coverage area of RSUs. We note that the achievable energy efficiency of both BC-NOMA and conventional NOMA V2XneT increases as the coverage area of RSU decreases. With small coverage, vehicles can achieve high data rate and require low transmit power for transmission. Another possible reason is the reflection of BD in the short range, resulting in comparatively high gain at vehicles. Another point worth mentioning here is that the proposed V2XneT outperforms the benchmark conventional V2XneT.

V. CONCLUSION

For NextG V2XneT, NOMA and BC are the two promising technologies to improve energy and spectral efficiency. In this work, we have presented a new resource allocation framework for BC-NOMA V2XneT to improve the energy efficiency under the assumption of channel estimation error. In particular, the original problem has been decoupled into two sub-problems and solved by the iterative sub-gradient method. Simulation results have also been provided to demonstrate the benefits of the considered BC-NOMA V2XneT. It is important to note that the single BS and two RSUs have been the focus of this work. One exciting research direction is to extend this work to investigate the application of BC-NOMA in the dense heterogeneous scenario.

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