QoS-Ensured Cooperative Vehicular Communications

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Abstract— **Vehicular communications aims to provide effective and sustainable connections between vehicles and between vehicles and infrastructure. One of the key challenges in vehicular communications, especially vehicular-to-infrastructure (V2I), is to safeguard the best performance at the lowest resource cost. In this paper, we propose a quality-of-service (QoS) ensured V2I approach which is supported by cooperative communications via vehicle-to-vehicle (V2V) relaying, to maximize throughput and minimize energy consumption among different transmission schemes. Based on the closed-form expressions of the outage probability, throughput, energy efficiency and packet loss rate for various transmission schemes concerned, we demonstrate the performance and optimization strategy of the proposed approach. We also show how the best performance trade-off between system reliability and efficiency under various environmental conditions can be achieved.**

Keywords— QoS; V2I; V2V; cooperative communications.

I. INTRODUCTION

Vehicular communications in the form of vehicle-to-vehicle (V2V), vehicle-to-infrastructures (V2I), and their combinations called V2X are becoming one of key technologies to support connected and autonomous vehicles. They are also essential for enabling diverse applications associated with traffic safety, operation efficiency and infotainment [1] [2] [3]. In a vehicular network, road users are able to access Internet services such as traffic condition broadcast, video streaming, digital map downloading, and information of road hazard and accident alarm, via fixed roadside units though V2X communications. The most recent research in this area has been focused on the vehicular ad-hoc network (VANET) [4] [5], including its connection to the Fourth-Generation or Long-Term Evolution (LTE and LTE-Advance) cellular networks and the provision of the required solutions for achieving low latency and high reliability in vehicular communications [6].

IEEE 802.11p is considered one of the popular standards designed for vehicular communications, but it has showed obvious drawbacks such as low reliability, unbounded delay, hidden node problem and intermittent V2I connectivity [7].

To tackle the problem encountered when improving quality of service (QoS), cooperative communications techniques can be applied to enhance transmission reliability by creating diversity [8]. In this case, mobile nodes (vehicles) can help each other through relaying other node's data and sharing their limited resources to improve loss performance and increase transmission coverage. However, the performance enhancement by using relays nodes is constrained by the power (energy) budget imposed and high mobility in the vehicular network [9]. This issue can potentially impede the delivery of QoS in the V2I approach. In addition, routing in vehicular networks through cooperative relaying plays an important role in forwarding the required data to other vehicles with enhanced system performance [10].

In this work, we examine the performance of both cooperative and non-cooperative transmission schemes in the context of a vehicular network, including energy consumption, throughput and packet loss rate under different conditions, such as transmission distance, relaying method and channel condition (path loss exponent). We also identify optimal transmission schemes for the whole network in a changing environment. To the best of our knowledge, the proposed approach is unique since it provides an efficient way to find the best method for transmission between any V2I links with the help of V2V and based on the models we derive.

The remainder of this paper is organized as follows. Section II discusses the relevance of this research with other work. The system models for both cooperative and non-cooperative transmission schemes for V2I communications are presented in Section III. Simulation results produced by Matlab and NS-2 and discussions are presented in Section IV. Finally, the paper is concluded in Section V.

II. RELATED WORK

Cooperative communications technologies for VANETs have been studied extensively, where two of the most common protocols of this technology are Amplify-and-Forward (AF) and Decode-and-Forward (DF) [11]. Cooperative or polarization diversity is implemented by applying these protocols to exploit the broadcast nature of wireless channels and use relays to improve link reliability and throughput [12]. In addition, the use of graph theory to formulate the problem of cooperative communications scheduling in vehicular networks is proposed in [13], in order to improve the throughput and spectral efficiency of the network.

Enhancing system efficiency is a key issue in applying cooperative communications in V2I approaches, depending on the connectivity probabilities in V2I and V2V communication scenarios in one-way and two-way platooning based VANETs [14]. Smart Antenna technologies can also contribute to the increment of the service coverage and system throughput of V2I [15]. The capacity of V2I communications can be maximized by an iterative resource allocation method [16] and the efficiency of V2I communications can be improved by applying a scheme called Distributed Sorting Mechanism (DSM) [17]. To improve power efficiency in V2I communication networks, [18] proposed a joint power and sub-carrier assignment policy under delay-aware QoS requirements. In addition, the strong dependence on the environment due to multipath propagation is also presented for a distributed energy-efficient routing method [19].

Furthermore, [20] proposed an adaptive rate adaptation algorithm integrated with a power control scheme. It minimizes energy consumption by appropriately adjusting vehicle's transmitting power, reducing network congestion and improving collision avoidance in vehicular networks. In [21] a sub-channel power control algorithm is proposed and the associated optimization problem is formulated to handle increased co-channel interference due to high mobility of vehicles in the network.

Although there have been different methods reported for improving performances in vehicular networks, there is a lack of information regarding how to choose specific transmission schemes that can ensure the best QoS under different conditions in terms of the number of relaying branches and the number of relays for a given distance between source and destination nodes.

In this paper, based on the initial work proposed in [1] our focus will be the identification of the conditions for establishing appropriate transmission strategies among different commonly used transmission schemes, including both cooperative and non-cooperative schemes for V2I communications. In cooperative communications nodes/vehicles not only transmit their own information, but also relay other nodes' information to a common destination. On the other hand, in non-cooperative communications nodes send their information directly to the destination, without relaying for one another. Our approach is to utilize the analytical models derived for these transmission schemes and to evaluate their performances in reliability, energy efficiency and throughput. Based on the trade-offs between cooperative and non-cooperative transmission schemes, we will show how to achieve the best performance through adaptive cooperative communications.

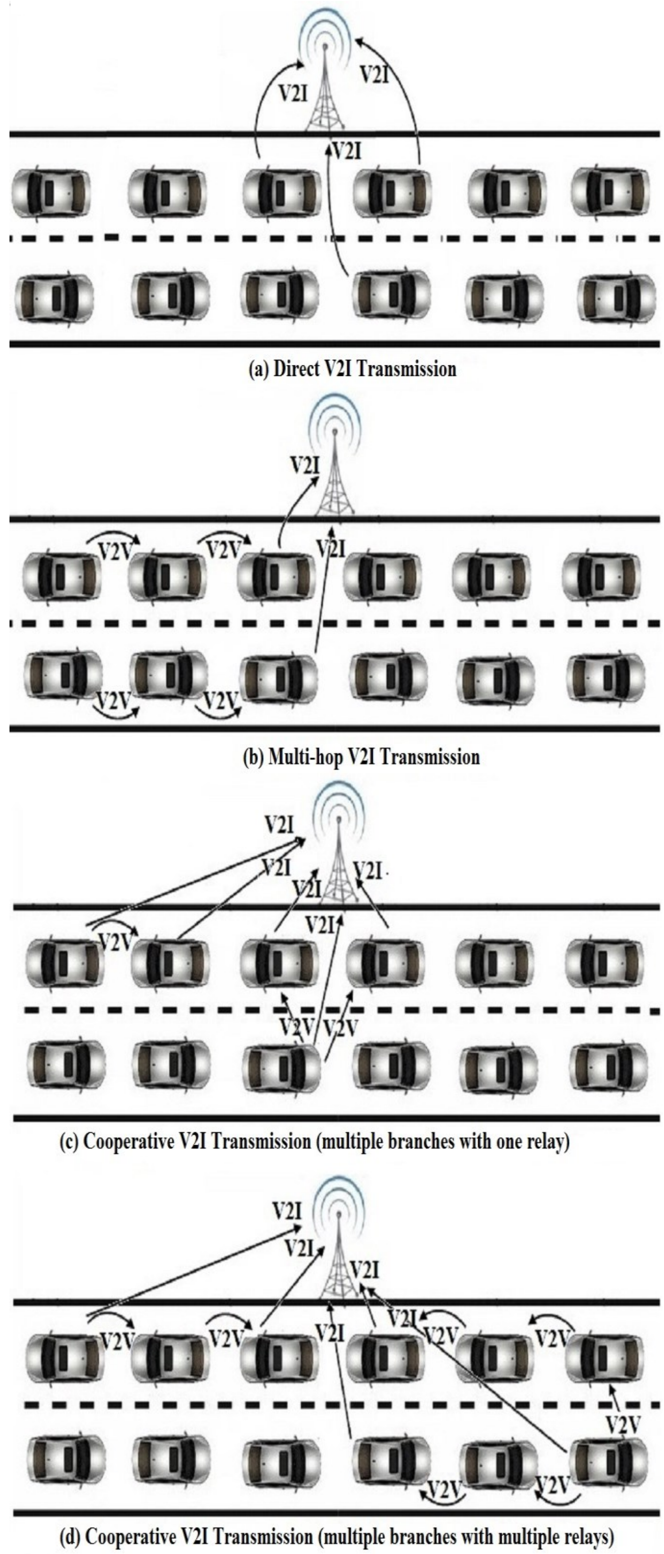

Figure 1. Different V2I transmission schemes.

III. SYSTEM MODEL

In this section, the analytical models of the required transmitting power, outage probability, energy consumption, throughput and packet loss rate in the context of a V2I network are established for both cooperative and non-cooperative transmission schemes. Based on these models, an adaptive transmission strategy can be developed to optimize the system performance.

Given a V2X network with L vehicles, for any vehicle-to-infrastructure pair (V, I), where $V \epsilon \{1, \ldots, L\}$, the goal of the optimization proposed in this work in connection to QoS is achieved by either minimizing the total energy consumed per bit (or energy efficiency) given an outage probability target, or maximizing the end-to-end throughput, (or minimizing the packet loss rate) based on the transmission distance between V2I pairs, i.e.:

$$Min \sum E_{bi} \qquad s.t.\{p_{outVI}\} \text{ or}$$

$$Max \sum S_{thi} \qquad s.t.\{d_{VI}\} \tag{1}$$

where E_{bi} and S_{thi} are the energy consumed per bit and throughput, respectively, of the i-th path between a vehicle (V) and infrastructure (I), p_{outVI} and d_{VI} are the fixed outage probability target and the total transmission distance between V and I. As V2V is part of the overall V2I, so the outage probability given in (1) is for the end-to-end V2I route which includes initial V2V links.

Four transmission schemes in the context of V2I are identified in Figure 1, including single-hop direct V2I (1a), multi-hop V2I via V2V (1b), cooperative V2I with a single relay in each relaying branch (1c), and cooperative V2I with multiple relays in each relaying branch (1d). In this work, we intend to examine the performances of different transmission schemes in terms of energy efficiency, throughput and packet loss rate, and to optimize them under different environmental conditions. In these schemes, the transmission path that forms a V2V link is selected based on the distance measurement and channel conditions in terms of the path loss exponent of the V2V link.

We consider a V2I network in which transmission links are subject to narrowband Rayleigh fading with additive white Gaussian noise (AWGN) and propagation path-loss. The channel fades for different links are assumed to be statistically mutually independent. For medium access, vehicle nodes are assumed to transmit over orthogonal channels through using the service channels specified in IEEE 801.11p [5], thus no mutual interference is considered in this system model. These channels can be reused by other vehicle away from a certain distance.

A. Non-Cooperative Transmission Scheme

Consider the transmission scheme for a direct link (V, I) as shown in Figure 1a where no relaying paths are involved. We use P_{SDir} to denote the source transmission power for this case. For direct transmissions in the V-I link, the received symbol r_{VI} and the spectral efficiency R_s (bits/sec/Hz) can be modeled as [22] [23]:

$$r_{VI} = \sqrt{P_{SDir}\, d_{VI}^{\,-\alpha}}\, h_{VI}\, s + n_{SD} \tag{2}$$

$$R_s = \frac{1}{2}\log_2\left(1 + SNR_{VI}\right) \tag{3}$$

where d_{VI} is the distance and h_{VI} is the channel coefficient of the V-I link, α is the path loss exponent, s is the transmitted symbol with unit power, and n_{SD} represents the AWGN noise vector, with variance $N_o/2$ where N_o is the thermal noise power spectral density (W/Hz).

The log-normal environment shadowing path loss model at a distance d_{ij} between node i and node j is given by [24]:

$$\gamma_{ij}[dB] = PL(d_o) + 10\alpha \log_{10}\left(\frac{d_{ij}}{d_o}\right) + X_\sigma \tag{4}$$

where X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ and with some time correlation. This variable is zero if no shadowing effect exists. The $PL(d_o)$ is the path loss at a reference distance d_o in dB. The Signal-to-Noise Ratio (SNR) of the V-I link is expressed as [22]:

$$SINR_{VI} = \frac{P_{SDir}\left|h_{VI}\right|^2 \gamma_{VI}}{N} \tag{5}$$

where $N = N_0 B$ is the noise power, and B is the system bandwidth in Hertz.

An outage occurs when the SNR at the receiver falls below a threshold β which allows error free decoding. This threshold is defined as $\beta = 2^{2R_s} - 1$, where R_s is the required system spectral efficiency. The outage probability of the single-hop transmission is given by [22] [23]:

$$p_{outVI} = p\left(SNR_{VI} \le \beta\right) = 1 - e^{\frac{-\left(2^{2R_s}-1\right)N}{P_{SDir}\left|h_{VI}\right|^2 \gamma_{VI}}} \tag{6}$$

Energy consumption is largely proportional to the requirement of maintaining a certain level of transmission reliability or the successful transmission rate. In order to maintain a required level of reliability, denoted by U, which is related to the reliability of a transmission link, the minimum outage probability is defined as:

$$p_{outDir} \le 1 - U \tag{7}$$

Combining (6) and (7) and taking the nature logarithm on both sides of the expression, we have:

$$\frac{\left(2^{2R_s} - 1\right)N}{P_{SDir}\left|h_{VI}\right|^2 \gamma_{VI}} \le \ln\left(U^{-1}\right) \tag{8}$$

The main objective for the performance optimization of a V2I network is to minimize the total energy consumption under different environmental conditions. Thus, the transmit power required to satisfy the reliability requirement or constrained by the outage probability for the direct transmission must be:

$$P_{SDir} \geq \left(2^{2R_s} - 1\right) \frac{N}{\left|h_{VI}\right|^2 \gamma_{VI}} \left(\ln\left(U^{-1}\right)\right)^{-1} \qquad (9)$$

Therefore, the total consumed energy per bit (J/bit) for the direct transmission mode can be expressed as:

$$E_{bDir} = \frac{P_{AM,Dir} + P_C}{R_b} \qquad (10)$$

where $P_C = P_{Tx} + P_{Rx}$

$$P_{AM,Dir} = \frac{\xi}{\eta} P_{SDir} \qquad (11)$$

where $P_{AM,Dir}$ is the power amplifier consumption for direct transmission which depends on the drain efficiency of the amplifier η, the average peak-to-peak ratio ξ, and the transmit power P_{SDir}, $R_b = R_s B$ is the data rate in bits/s, B is the system bandwidth, and P_C is the power consumed by the internal circuitry for transmitting (P_{Tx}) and receiving (P_{Rx}).

The throughput S_{th} and packet loss rate PLR can be simply defined, i.e.:

$$S_{th} = \frac{Total\ Received\ Payload}{Total\ Transmitted\ Time} \qquad (12)$$

$$PLR = \frac{Total\ Sent\ Packets - Total\ Received\ Packets}{Total\ Sent\ Packets} \qquad (13)$$

The multi-hop non-cooperative transmission scheme with n ($n \geq 1$) relays is shown in Figure 1b. Each relay is able to detect whether or not the packet was received correctly and will forward the information to the destination only in the case of the packet being correctly received. Otherwise, the packet is considered lost.

Given the outage probabilities of individual hops, i.e., p_{outVR_1} (from a vehicle to relay 1), $p_{outR_1R_2}$ (from relay 1 to relay 2), …, p_{outR_nI} (from relay n to infrastructure), the outage probability of the multi-hop link, p_{outMH}, is given by:

$$p_{outMH} = 1 - \left(1 - p_{outVR1}\right)\left(1 - p_{outR1R2}\right)\ldots\left(1 - p_{outRnI}\right) \qquad (14)$$

With the same mathematical treatment as in (6), p_{outMH} becomes:

$$p_{outMH} = 1 - e^{\left(2^{2R_s} \ 1\right)N} y \qquad (15)$$

where $y = \left(\frac{1}{P_{Vr1}\left|h_{Vr1}\right|^2 \gamma_{Vr1}} + \sum_{i=2}^{n} \frac{1}{P_{r1ri}\left|h_{r1ri}\right|^2 \gamma_{r1ri}} + \frac{1}{P_{rnI}\left|h_{rnI}\right|^2 \gamma_{rnI}} \right)$

We set the transmit power to be proportional to the distance between two communicating nodes. For broadcast transmission, e.g., when the source transmits, the longest distance, i.e., the distance between the source and the destination d_{SD}, is considered. Hence, the power between two communicating nodes is given by:

$$P_{ij} = XP_{SD} \qquad (16)$$

where X denotes the power coefficient between node i and node j. In our model, we assume that the value of X depends on the distance of the vehicle-infrastructure (VI), relay-relay (RR) or relay-infrastructure (RI) link. For example, the transmit power for the relay- infrastructure link is:

$$P_{RI} = \left(\lambda_{RI}\right)^{\alpha} P_{VI} \qquad (17)$$

where $\lambda_{RI} = \frac{d_{RI}}{d_{VI}}$

The power minimization problem is specified in a similar way to (7), i.e.:

$$p_{outMH} \leq 1 - U \qquad (18)$$

and the power P_{SMH} is bounded by:

$$P_{SMH} \geq \left(2^{2R_s} - 1\right) N\, y \left(ln\left(U^{-1}\right)\right)^{-1} \qquad (19)$$

Then, the total consumed energy per bit and the total consumed power for the multi-hop direct transmission are expressed as:

$$E_{bMH} = \left(p_{outMH}\right) \frac{P_{AM,MH} + P_C}{R_b} + \left(1 - p_{outMH}\right) \frac{(n * X + 1)P_{AM,MH} + (n+1)P_C}{R_b} \qquad (20)$$

$$P_{totMH} = \left(p_{outMH}\right)\left(P_{AM,MH} + P_C\right) + \left(1 - p_{outMH}\right) \left((n * X + 1)P_{AM,MH} + (n+1)P_C\right) \qquad (21)$$

where $P_{AM,MH}$ is the power amplifier consumption for multi-hop transmission.

The first term on the right-hand side of (20) corresponds to the consumed energy when the relay is not able to correctly decode the message from the vehicle, which means that this link is in outage. In this case, only the source vehicle consumes transmitting power, and the destination node and K relays consume receiving power. The second term counts for the event that the *V-I* link is not in outage, hence the relay's transmitting and processing power, and the extra receiving power at the infrastructure are involved.

B. Cooperative Transmission Scheme

In cooperative transmission, the sender V broadcasts its symbol to all potential receivers including the destination I and relays in the current time slot. The received symbol by relays, r_{sr}, the received symbol by the destination from relays, r_{rd}, and the spectral efficiency R_S can be expressed as:

$$r_{Vr} = \sqrt{P_S \, d_{Vr}^{-\alpha}}\, h_{Vr} s + n_{Vr} \tag{22}$$

$$r_{rI} = \sqrt{P_C \, d_{rI}^{-\alpha}}\, h_{rI} s + n_{rI} \tag{23}$$

$$R_s = \frac{1}{2}\log_2\left(1 + SNR_{Vr} + SNR_{rI}\right) \tag{24}$$

where P_S is the transmitted power of the source and P_C is the transmitted power of relays, h_{Vr} and h_{rI} are the channel coefficients of the vehicle-relay link and the relay-infrastructure link, respectively, n_{Vr} and n_{Vr} are the AWGN noise vectors of the vehicle-relay link and the relay-infrastructure link, respectively. SNR_{Vr} and SNR_{rI} are the signal-to-noise ratios of the *V-r* link and *r-V* link, respectively.

Two types of cooperative transmission schemes are considered here: 1) using multiple cooperative relaying branches with a single relay in each branch (MBSR) (Figure 1c), and 2) multiple relaying branches with multiple relays in each branch (MBMR) (Figure 1d). The selective decode-and-forward (SDF) relaying protocol is used in these two schemes and relays perform cooperation when the information from the source is correctly received by them. For the transmission scheme shown in Figure 1c, the outage probability is given by jointly considering the outages in *V-I*, *V-R* and *R-I* links, i.e.:

$$p_{outMB} = p_{outVI}\left(p_{outVr} + p_{outrI} - p_{outVr}p_{outrI}\right)^{K} \tag{25}$$

Based on the derivation methods used in Section III-A, the following close-form expressions can be readily obtained.

1): The outage probability of cooperative transmission with multiple (K) branches with each having multiple relays (n):

$$p_{outMHB} \approx \left(2^{2R_s} \quad 1\right)^{K+1} N^{K+1} C \tag{26}$$

where

$$C=\left(\frac{1}{\left|h_{Vr1}\right|^2 \gamma_{Vr1}} + \sum_{i=2}^{n} \frac{1}{\lambda_{ri-1ri}{}^{\alpha}\left|h_{ri-1ri}\right|^2 \gamma_{ri-1ri}} + \frac{1}{\lambda_{rnI}{}^{\alpha}\left|h_{rnI}\right|^2 \gamma_{rnI}}\right)^{K}$$

2): The power minimization problem is specified in a similar way to (7):

$$p_{outMHB} \leq 1 - U \tag{27}$$

3): The lower bound of power for cooperative transmission with multiple (K) branches and multiple relays (n):

$$P_{MHB} \geq \left(2^{2R_s} - 1\right) N \left(\frac{1}{\left|h_{VI}\right|^2 \gamma_{VI}} C\right)^{\left(\frac{1}{K+1}\right)} \left(\ln\left(U^{-1}\right)\right)^{-\left(\frac{1}{K+1}\right)} \tag{28}$$

4): The total consumed energy per bit and the total consumed power for this cooperative transmission scheme:

$$E_{bMHB} = \left(p_{outVr}\right)\frac{P_{AM,MHB} + P_{Tx} + (K+1)P_{Rx}}{R_b} + \left(1 - p_{outVr}\right)\frac{(K*n*X+1)P_{AM,MHB} + (K*n+1)P_{Tx} + (K*n+2)P_{Rx}}{R_b} \tag{29}$$

$$P_{totMHB} = \left(p_{outVr}\right)\left(P_{AM,MHB} + P_{Tx} + (K+1)P_{Rx}\right) + \left(1 - p_{outVr}\right)\left((K*n*X+1)P_{AM,MHB} + (K*n+1)P_{Tx} + (K*n+2)P_{Rx}\right) \tag{30}$$

The transmit power at relays can be reduced and consequently the energy efficiency will be improved by implementing the cooperative communications schemes, which are particularly suitable for long-range transmissions. The related results will be shown in Section IV.

IV. NUMERICAL RESULTS AND DISCUSSION

In this section, we examine the performances of different transmission schemes through Matlab and NS-2 simulations, in terms of energy efficiency (energy consumption per bit), throughput, packet loss rate, and optimum required number of branches and relays for different transmission distances in V2I links. We then reveal the conditions for selecting the optimal transmission schemes through comparisons between them. The network settings used for simulation are listed in TABLE I. Assume the spectral efficiency R_s in this scenario to be 2 bits/sec/Hz, and the required system reliability level to be 0.999. To generate mobility, related mobility-files are created in NS-2 simulation. In addition, we assume that all the vehicles are running at the same speed and keeping the same distance with each other.

In Figure 2, the energy performances of both cooperative and non-cooperative schemes are illustrated and compared. As we can see, the non-cooperative direct transmission has the lowest energy cost than all others transmission schemes for short-range (d_{VI}<33 m); the non-cooperative transmission using multi-hop relays outperforms the direct transmission for the range 33m<d_{VI}<43 m and, in particular, transmission using two intermediate relays (n=2) nodes has the lowest energy consumption for this range.

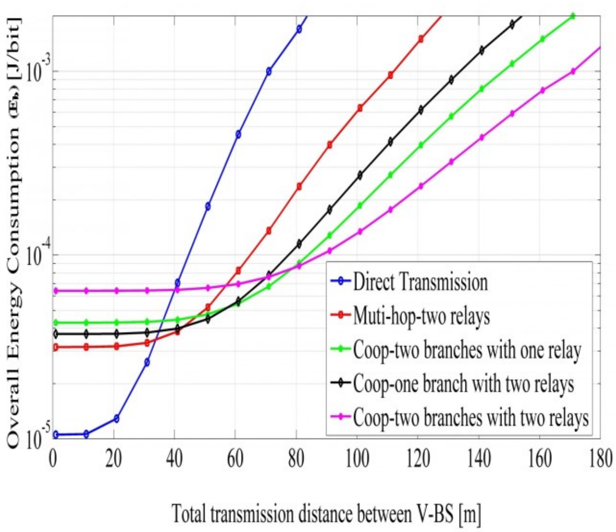

Figure 2. Total energy consumed vs total transmitted distance.

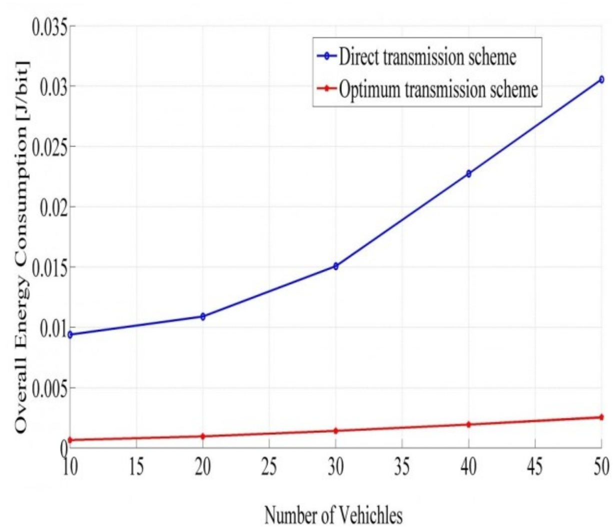

Figure 3. Overall energy consumption vs number of vehicles.

The cooperative transmission outperforms the non-cooperative transmission schemes for the range 43m<d_{VI}<58m, and the transmission using one branch with two relays (K=1, n=2) has the lowest energy consumption for this range. As distance continuously increases, the lowest energy consumption is achieved by transmission using two branches with one relay (K=2, n=1) for 58<d_{VI}< 80m, and by transmission using two branches with two relays (K=2, n=2) for d_{VI}>80m, respectively.

As shown in Figure 3, the non-cooperative direct transmission has much higher energy consumption than the optimum transmission scheme which is chosen based on the transmission distance between vehicles and infrastructure.

The results in Figure 4 show the energy performance for multi-branch and multi-relay scenarios for five different transmission distances in V2I links, i.e., 20m, 40m, 50m, 70m and 90m. Under each distance the energy performance is examined against the number of relays (n) for a different number of branches K=1, 2, … 5, employed by cooperative communications. From this examination, the optimal number of relays per branch can be found among different scenarios.

When d_{VI}=20m, the direct transmission scheme which does not need any diverse branches can be the most energy efficient transmission scheme as shown in Figure 4a. However, when increasing the distance a clear trend is shown that cooperative transmission schemes are becoming more energy efficient than the direct transmission scheme for a certain range of the number of relays used per branch. And this range is widening as the distance increases. As we can see, cooperative transmission can outperform direct transmission for n<2 when d_{VI}=40m, for n<3 when d_{VI}=50m, for n<4 when d_{VI}=70m, and for n<5 when d_{VI}=90m, as shown in Figures 4b-4e, respectively.

TABLE I. SIMULATION PARAMETERS

Parameters	Value
N_0	−174 dBm
B	10 kHz
R_s	2 bits/sec/Hz [17].
P_{TX}	97.9 mW [17]
P_{RX}	112.2 mW [17]
η	0.35
ξ	0.5
Packet Size	512 bytes
fc	5.9 GHz
α	3
Simulation time	1000 sec
Nodes	10/20/30/40/50
Velocity	5 km/h, 20 km/h, 60 km/h
Traffic Agent	TCP
Mac Protocol	IEEE 802.11p
Queue	PriQueue with size of 50 Packets
Propagation model	Log-normal shadowing Model (LOS)
Antenna	Omni-directional with height of 1m
Routing Protocol	AODV
Number of Seed	3

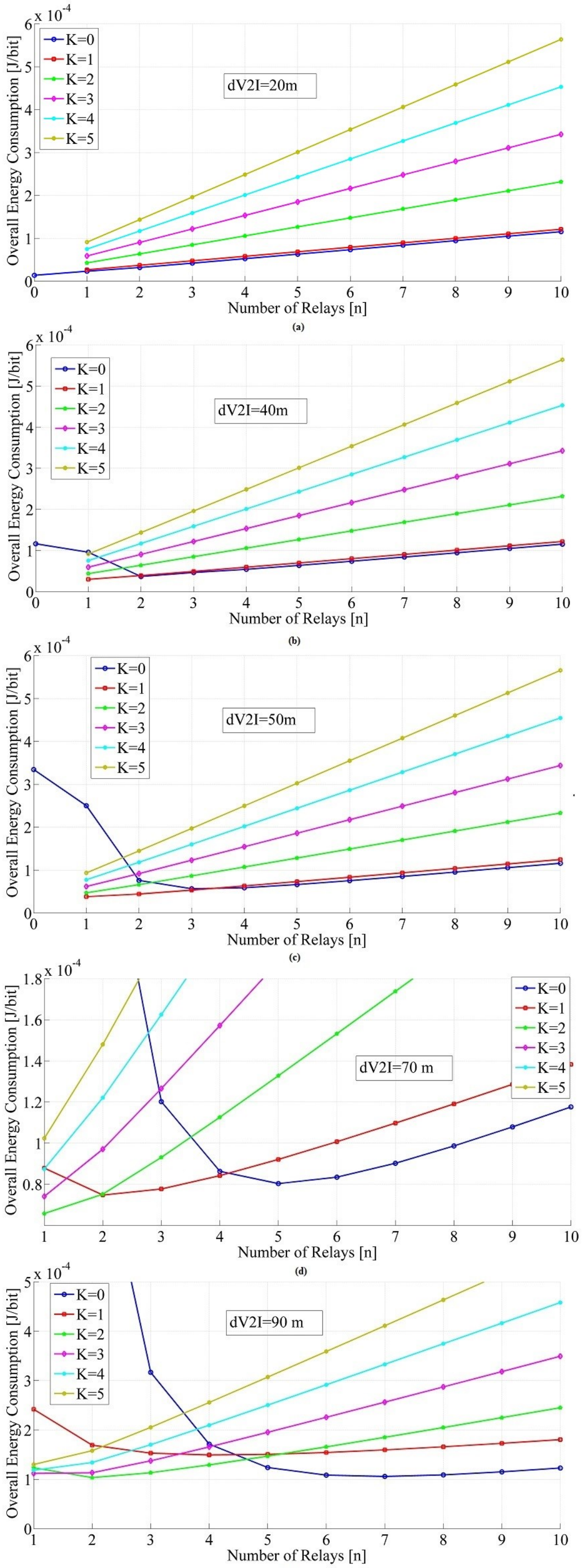

Figure 4. Overall energy consumption vs number of relays.

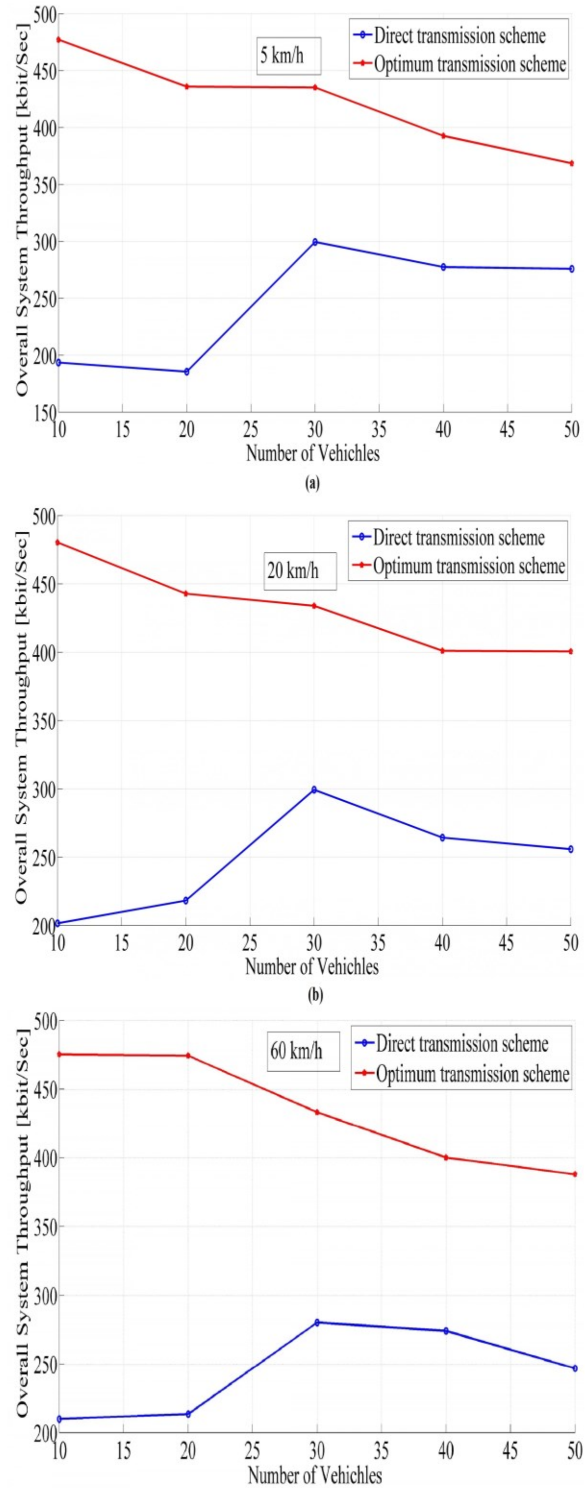

Figure 5. Overall system throughput vs number of vehicles.

The optimal transmission scheme for energy performance will be determined based on the transmission method used

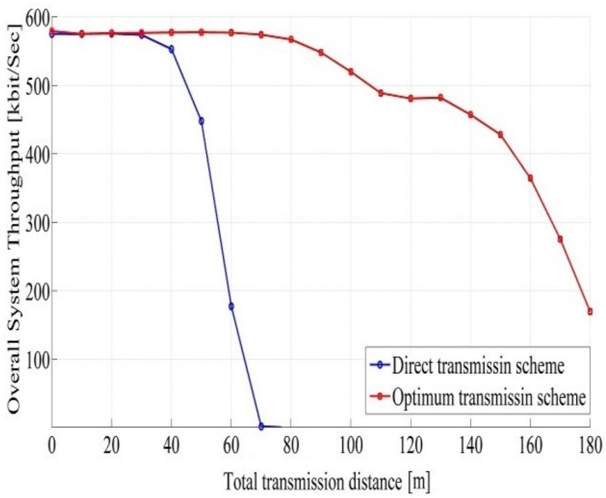

Figure 6. Overall system throughput vs total transmission distance.

and conditions discussed above. For instance, the cooperative transmission scheme with one branch (K=1) is optimal for n=2, 3 and 4 when d_{VI}=70m, while the cooperative transmission scheme with two branches (K=2) is optimal for n=2, 3 and 4 when d_{VI}=90m. This indicates that an adaptive strategy can be applied to select the transmission scheme dynamically so that the best performance can be achieved and remained.

The overall system throughput is shown in Figure 5 for three different vehicle velocities. The optimum transmission schemes through cooperative communications clearly outperform the direct transmission schemes in all cases due to the impact of diversity created by cooperative transmission. It is also noticed that the throughput of the optimum transmission scheme decreases when the number of transmitting vehicles increases. This is mainly due to congestion in medium access and increased operation overhead at the nodes that have dual responsibilities as the source as well as the relay.

Again, the overall system throughput is examined in Figure 6 but against the total transmission distance of a V2I link for both direct and optimum transmission schemes. The optimum transmission schemes clearly outperform the direct transmission schemes for all transmission distances. It is shown that the throughput of the direct transmission scheme decreases dramatically compared with the optimum transmission scheme when the distance of the V2I link involved exceeds 30 m.

Figure 7 depicts the overall packet loss rate for direct transmission and optimum transmission schemes versus the number of transmitting vehicles for different vehicle velocities. As it is shown, the packet loss rate increases when the number of transmitted vehicles increases for all the transmission schemes, which is caused by network congestion and correlated with the corresponding performance in throughput as shown in Figure 5.

The overall system packet loss rates for direct transmission and optimum transmission schemes for each transmission distance are illustrated in Figure 8. The optimum transmission scheme clearly performs better than the direct

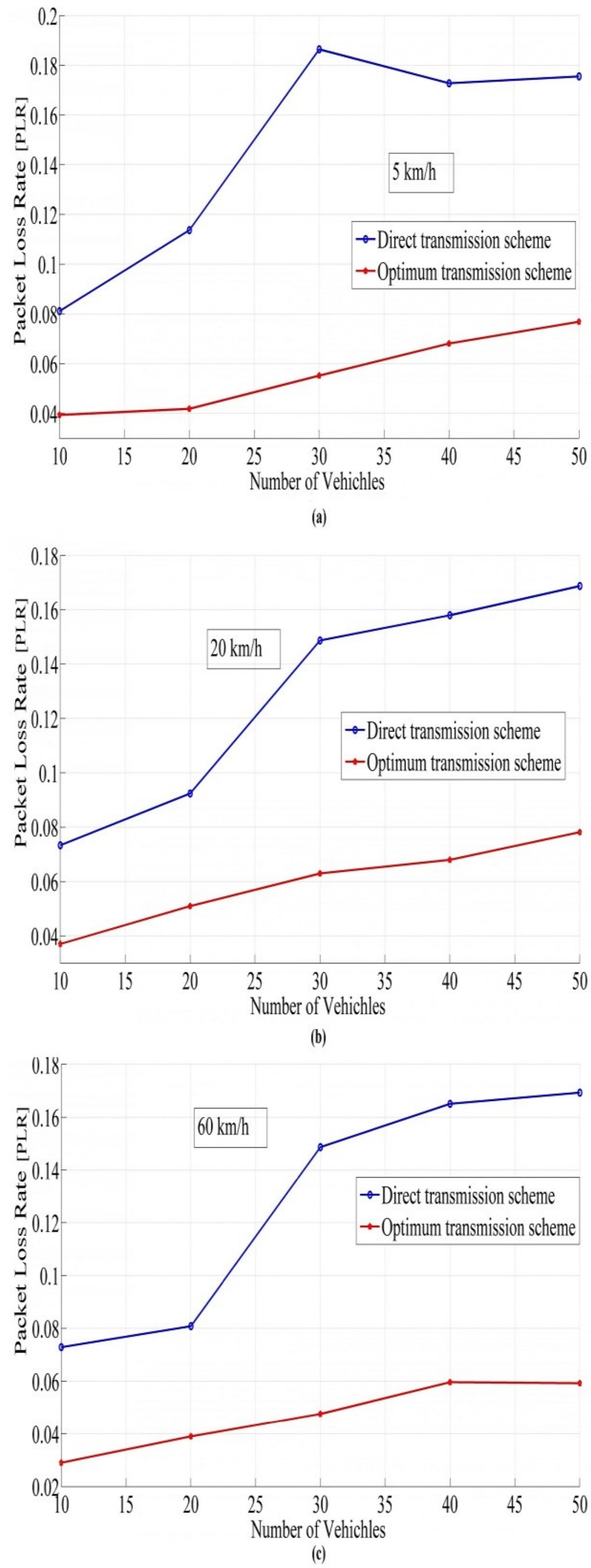

Figure 7. Packet loss rate vs number of vehicles.

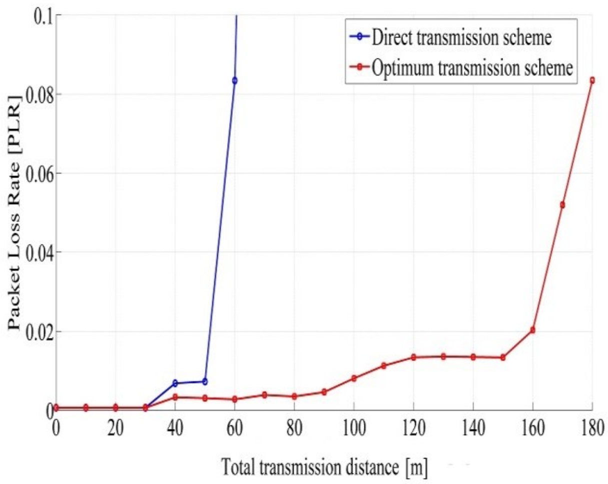

Figure 8. Packet loss rate vs total transmission distance.

transmission scheme for all transmission distances. These results are also correlated with those in Figure 6 for throughput performance, i.e., the dramatic reduction in throughput when the distance exceeds 30m is mainly caused by a sharp increase in the packet loss rate when the distance increases. It is worth mentioning that the optimum transmission schemes have much lower packet loss rates than the direct transmission schemes since when relays are used the transmission distances between adjacent nodes are reduced and, at the same time, the transmission reliability is improved due to the diversity generated through cooperative communications.

Due to the network settings in our work where most vehicles have a fairly large distance between them and the roadside base station, no major difference in performance is observed when increasing the velocity of vehicles, as shown in Figures 5 and 7. In contrast, as discussed above, the performance such as throughput is correlated with the number of vehicles which are connected to the same base station.

There are a number of factors affecting performances such as energy consumption, throughput and packet loss rate in V2X networks. Cooperative transmission utilizes additional paths and intermediate nodes to create diversity, which may cost more energy. However, this can be compensated by the diversity generated that can lower the probability of link failure and consequently reduce the number of retransmissions. Diversity can also be enhanced with the increased number of relaying branches, but this increase could be marginal when the number of branches is large and these branches are not all uncorrelated in this case.

Regarding improving the QoS performance, a clear advantage of cooperative transmission over direct transmission has been demonstrated in our results. The packet loss rate of cooperative transmission becomes much lower than that of direct transmission when the number of vehicles increases as shown in Figure 7. As a result, the throughput performance of cooperative transmission can always outperform direct transmission for a wide range of the vehicle density, as shown in Figure 4. It is also noticed that the direct transmission schemes can also perform better than cooperative transmission under certain circumstances, as discussed above and shown in Figures 2 and 4.

To achieve the best energy performance for a specified application, proper transmission schemes should be selected in an environment affected by varying environmental conditions, such as overall distance, d_{SD}; and channel quality in terms of α. The findings of this work can assist deciding when and how the cooperative or non-cooperative transmission scheme should be employed. Based on our investigation, an energy-efficient or throughput-centric transmission strategy can be formed in a V2X network by adaptively choosing proper transmission schemes under different network and transmission conditions. This involves determining the number of relaying branches and the number of relays if the cooperative scheme is to be used. By doing so, energy saving could be significant even with the direct transmission scheme in certain conditions, as demonstrated by our results.

V. CONCLUSION

We have investigated different transmission schemes for their performances on energy efficiency, throughput and packet loss rate in a vehicular network. Based on the models derived for outage probability, energy efficiency, throughput and packet loss rate, we have shown that both cooperative and non-cooperative transmission schemes can exhibit the best performance under certain environmental conditions. In addition, we have shown the required optimum numbers of branches and relays in each branch in order to enhance the system performance. The optimal transmission scheme can be identified given the distance between the source and destination nodes in a V2X network. The results presented in this paper can be used to form an adaptive transmission strategy that is able to select appropriate transmission schemes in a changing environment to maintain the best QoS performance in a dynamic way, in terms of achieving the highest throughput with a fixed energy budget or the lowest energy cost for a given throughput target.

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