Adaptive cooperative communications for enhancing QoS in vehicular networks

Radwa Ahmed Osman[a,b], Xiao-Hong Peng[a], M. A. Omar[b]

[a] *School of Engineering & Applied Science, Aston University, Birmingham B4 7ET, UK*
[b] *College of Engineering & Technology Arab Academy for Science, Technology & Maritime Transport P.O. Box 1029, Alexandria, Egypt*

Abstract

In a vehicular network with high mobility, it is challenging to ensure reliable and efficient connections among vehicles and between vehicles and roadside communication units (or infrastructure) such as base stations or WiFi hot spots. In this paper, we propose a method that utilizes cooperative communications for a combined vehicle-to-infrastructure (V2I) with vehicle-to-vehicle (V2V) approach to improving quality of service (QoS) across the vehicular network. In this approach, we have obtained the closed-form expressions of key QoS performances such as outage probability, throughput, energy efficiency, packet delivery ratio, packet loss rate and average end-to-end-delay for different investigated transmission schemes. These performances can be optimized by adaptively selecting appropriate transmission schemes and, as a results, good trade-offs between system reliability and efficiency can also be achieved under various environmental conditions.

Keywords: QoS, V2V, V2I, cooperative communications.

---

1. Introduction

Recently vehicular communications technologies in the form of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), or V2X as a whole, have attracted huge attention from researchers due to their varied applications in connected and autonomous vehicles and the intelligent transportation system (ITS) [1]. 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. Most research in this area has been focused on the vehicular ad-hoc network (VANET) [2, 3], including its connection to the Fourth-Generation or Long-Term Evolution (LTE and LTE-Advance) cellular networks and solutions for ensuring low latency and high reliability communications [4, 5, 6].

IEEE 802.11p is one of the commonly used standards for V2I and V2V to support communications in highly mobile, often densely populated, and frequently non-line-of-sight environments [7, 8]. In addition, the IEEE 802.15.4 standard, comprising a simple physical (PHY) layer and energy efficient medium

---

Email addresses: osmanmra@aston.ac.uk, radwa.ahmed@aast.edu (Radwa Ahmed Osman), x-h.peng@aston.ac.uk (Xiao-Hong Peng), mabd_elhamid@aast.edu (M. A. Omar)

access control layer, is also designed to support both real-time and contention-based services and has been considered as a promising candidate for Internet of vehicles (IoV) and vehicular sensor networks [9]. To tackle the problems encountered when improving QoS, cooperative communications techniques can be applied to enhance transmission reliability by creating diversity [10]. In this case, mobile nodes (vehicles) can help each other through relaying other node's data and sharing their resources to improve loss performance and increase transmission coverage. However, the performance enhancement by using relays is constrained by the power (energy) budget imposed and high mobility in the vehicular network [11]. This issue can potentially impede the delivery of QoS in V2I and V2V communications.

In this work, we investigate both cooperative and non-cooperative transmission schemes, and reveal how these schemes perform in the context of a vehicular network, in terms of energy consumption, throughput, packet delivery ratio, packet loss rate and average end-to-end-delay under different conditions, such as transmission distance, relaying method and channel quality (path loss exponent). These findings are used to identify proper transmission schemes that can optimize the system performance for the whole network in a changing environment. The proposed approach is unique in the sense that it provides an efficient way to find the best transmission method for V2I links, which is assisted by proper V2V communications when needed. This method is evaluated based on the performance models we derive. The remainder of this paper is organized as follows. Section 2 discusses the relevance of this research with other work reported. The system models for both cooperative and non-cooperative transmission schemes for V2I communications are presented in Section 3. Simulation results produced by Matlab and NS-2 and discussions are presented in Section 4. Finally, the paper is concluded in Section 5.

2. Related Work

Technologies that support cooperative communications have been studied extensively for VANETs and two of the most common protocols are Amplify-and-Forward (AF) and Decode-and-Forward (DF) [12]. Cooperative or polarization diversity is created by applying these protocols which exploit the broadcast nature of wireless channels and use relays to improve link reliability and throughput in a vehicular network [13]. In addition, the use of graph theory to formulate the problem of cooperative communications scheduling in vehicular networks is proposed in [14], in order to improve the throughput and spectral efficiency of the system concerned. Furthermore, a novel cooperative V2V communication method has been proposed by [15] for enhancing QoS and quality-of-experience (QoE) in V2V communications. Also, [16] showed that the cooperative multiple-input–single-output (MISO) and multiple-input–multiple-output (MIMO) techniques are more energy-efficient than the traditional multi-hop SISO techniques for medium and long range transmissions.

Enhancing system efficiency is a key issue in applying cooperative communications in V2I approaches, depending on the connectivity in V2I and V2V communication scenarios in one-way and two-way platoon based VANETs [17]. The smart antenna technology can also contribute to the increment of the service coverage and system throughput of V2I [18]. The capacity of V2I communications can be maximized by an iterative resource-allocation method [19] and the efficiency of V2I communications can be improved by applying a scheme called Distributed Sorting Mechanism (DSM) [20]. To improve power efficiency in V2I communication networks, [21] 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 an energy efficient distributed routing method [22].

Although there have been many reports demonstrating the possibility of improving the system performance of vehicular networks by using proper communication protocols or data processing algorithms, there is a lack of information regarding how to choose specific transmission schemes under different conditions that can ensure the best QoS in changing environments. In this paper, 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 V2X communications. Our approach is based on the development of analytical models for these transmission schemes and the assessment of their performances in reliability, energy efficiency and throughput. It also reveals the trade-offs between cooperative and non-cooperative transmission schemes and shows how to utilize this property to achieve the optimized performance through adaptive cooperative communications.

3. System Model

In this section, the analytical models of the required transmitting power, outage probability, energy efficiency, throughput and packet loss rate in the context of a vehicular 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 $V \in \{1, \ldots, L\}$, the goal of the optimization proposed in this work scheme in connection to the QoS requirement 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.,

$$\begin{aligned} Min\sum E_{bi} \quad s.t.\{p_{outVI}\} \quad or \\ Max\sum S_{thi} \quad s.t.\{d_{VI}\}. \end{aligned} \tag{1}$$

where E_{bi} and S_{thi} are the energy consumed per bit and the throughput, respectively, of the *i-th* path between a vehicle *(V)* and the infrastructure *(I)*, p_{outVI} and d_{VI} are the fixed outage probability target and the total transmission distance between V and I.

Four transmission schemes in the context of V2X are identified in Figure 1, including single-hop direct V2I (1a), multi-hop V2I via V2V (1b), cooperative V2I with a single relay (1c), and cooperative V2I with multiple relays (1d). In this work, we intend to examine and compare their performance in energy efficiency, throughput, packet delivery ratio, packet loss, average end-to-end delay and to optimize the transmission scheme in different environmental conditions.

We consider a vehicular network in which the transmission links are subject to narrowband Rayleigh fading with additive white Gaussian noise (AWGN) and resulting 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 IEEE801.11p [3], thus no mutual interference is considered in this system model. These channels can be reused by other vehicles away from a certain distance.

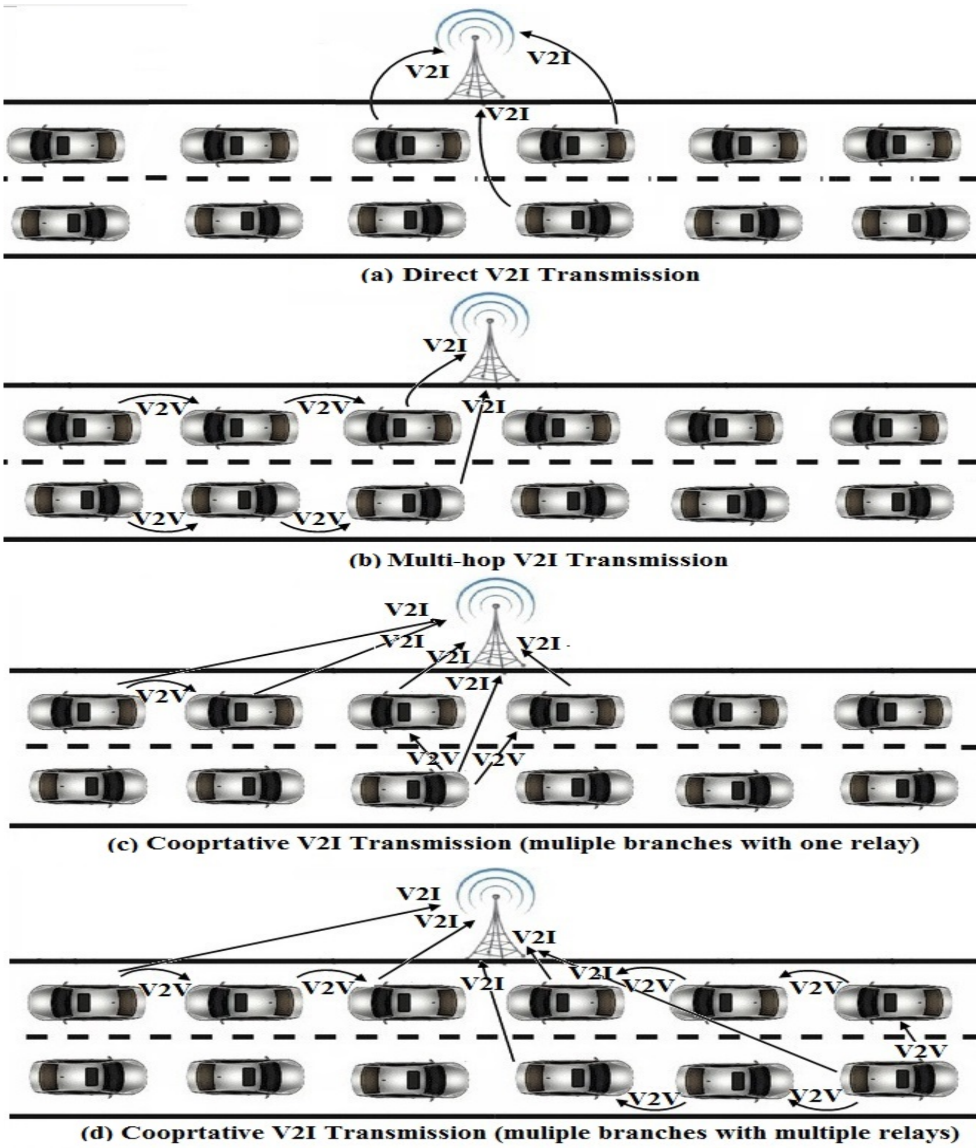

Figure 1: Different V2X transmission schemes.

3.1. Non-Cooperative Transmission Schemes

Consider the transmission scheme for a direct link *(V, I)* as shown Figure (1a) where no relaying paths are involved. We use P_{SDir} to denote the source transmission power for this case. For the direct transmission in the *V-I* link, the received symbol r_{VI} and the spectral efficiency R_S *(bits/s/Hz)* can be modelled as [23, 24]:

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

$$R_S = log_2\left(1+SNR_{VI}\right). \tag{3}$$

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 $N_o/2$ per dimension, where N_o is the thermal noise power spectral density per Hertz. The log-normal environment shadowing path loss model at a distance d_{ij} between node i and node j is given by [25]:

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

where X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ and with some time correlation which is zero if no shadowing effect exists. $PL(d_o)$ is the path loss at a reference distance d_o in dB. The Signal-to-Noise Ratio (SNR) of the $V-I$ link is [23]:

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

where N =N_o.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 β=2^{2Rs}-1, where R_s is the required system spectral efficiency. The outage probability of the single-hop transmission is given by [23, 24]:

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

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:

$$p_{out} \le 1-U. \tag{7}$$

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

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

The main objective for the performance optimization of a V2X network is to minimize the total energy consumption under different environmental conditions.

$$Min\sum E_{bDir} \quad s.t.\left\{p_{outDir} \le 1-U\right\}. \tag{9}$$

Thus, the transmit power required to satisfy the reliability requirement or be constrained by the outage probability for the direct transmission must be:

$$P_{SDir} \geq \left(2^{2Rs}-1\right)\frac{N}{|h_{VI}|^2\gamma_{ij}}\left(ln\left(U^{-1}\right)\right)^{-1}. \tag{10}$$

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

$$E_{bDir} = \frac{P_{AM,Dir}+P_C}{R_b}. \tag{11}$$

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

$$P_{AM,Dir} = \frac{\xi}{\eta}P_{SDir}. \tag{12}$$

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_sB is the data rate in bits/s, B is the system bandwidth, P_C is the power consumed by the internal circuitry for transmitting (P_{Tx}) and receiving(P_{Rx}). The throughput S_{th}, the packet delivery ratio *PDR*, packet loss rate *PLR* and end-to-end delay $E2E$ can simply be defined, i.e.:

$$S_{th} = \frac{Total\,Received\,Payload}{Total\,Transmitted\,Time}. \tag{13}$$

$$PDR = \frac{Total\,Received\,Packets}{Total\,Sent\,Packets}. \tag{14}$$

$$PLR = \frac{Total\,Sent\,Packets - Total\,Received\,Packets}{Total\,Sent\,Packets}. \tag{15}$$

$$E2E = \frac{\sum_{received\,packets} time\,spent\,to\,deliver\,packets}{\#received\_packets}. \tag{16}$$

In Figure (1b), a non-cooperative transmission scheme is used with multi-hop relays. We assume that we have *R* relays, *R* ϵ *{1, n}*, and each of them is able to forward the original information received to the next relay or the destination only when the packet is received correctly by them. Otherwise, the packet is considered lost. In this case the received signal at each time slot can be expressed as:

$$r_{ij} = \sqrt{P_{SMH}d_{ij}^{-\alpha}}h_{ij}s + n_{ij}. \tag{17}$$

where *i* ϵ *{V,R}*, *j* ϵ *{R,I}*, P_{SMH} is the transmit power required by the multi-hop transmission, which must be lower than the direct transmitted power as in this condition the distance between two consecutive nodes will be smaller than the total distance between the source and the destination. We can conclude that for multi-hop transmission schemes the total outage probability is given by:

$$p_{outMH} = 1 - \left(1 - p_{outVR_1}\right)\left(1 - p_{outR_1R_2}\right)\cdots\cdots\cdots\cdots\left(1 - p_{outR_nI}\right). \tag{18}$$

After some mathematical manipulation, the outage probability for direct transmission with a single and multi-hop relays can be expressed as:

$$P_{outMH} = 1 - e^{-\left(2^{2Rs}-1\right)NA}. \tag{19}$$

where $A = \left(\frac{1}{P_{VR_1}\left|h_{VR_1}\right|^2\gamma_{VR_1}} + \sum_{i=2}^{n} \frac{1}{P_{R_{i-1}R_i}\left|h_{R_{i-1}R_i}\right|^2\gamma_{R_{i-1}R_i}} + \frac{1}{P_{R_nI}\left|h_{R_nI}\right|^2\gamma_{R_nI}} \right)$.

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. So, the power between two communicating nodes is given by:

$$P_{ij} = \nu_{ij}^{\alpha} P_{VI} = X P_{VI}. \tag{20}$$

where ν_{ij} denotes the power coefficient between node i and node j and X=${\nu_{ij}}^{\alpha}$. In our model, we assume that the value of ν_{ij} depends on the distance of the source-destination, relay-relay or relay-destination link. For example, the transmit power for the relay-destination link is:

$$P_{RI} = \nu_{RI}^{\alpha} P_{VI} = \left(\frac{d_{RI}}{d_{VI}}\right)^{\alpha} P_{VI}. \tag{21}$$

so Equation (19) can be rewritten as:

$$P_{outMH} \approx \frac{\left(2^{2Rs}-1\right)NA}{P_{SMH}}. \tag{22}$$

We can formulate the power minimization problem for the non-cooperative transmission scheme with multi-hop relays by specifying a required reliability level, in a similar way to the method expressed in (7). The optimization problem can be stated as follows:

$$Min \sum E_{bMH} \quad s.t. \left\{p_{outMH} \leq 1 - U\right\}. \tag{23}$$

and the power P_{SMH} is bounded by:

$$P_{SMH} \geq \left(2^{2Rs}-1\right)NA\left(ln\left(U^{-1}\right)\right)^{-1}. \tag{24}$$

Therefore, the total consumed energy per bit for the direct transmission with multi-hop relays can be expressed as:

$$E_{bMH} = \left(p_{outVR}\right)\frac{P_{AM,MH}+P_C}{R_b} + \left(1-p_{outVR}\right)\frac{\left(\sum_{i=2}^{n} X_{R_{i-1}R_i} + X_{R_nI} + 1\right)P_{AM,MH} + (n+1)P_C}{R_b}. \tag{25}$$

The first term on the right-hand side 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. The total consumed power can be expressed as:

$$P_{totMH} = (p_{outVR})(P_{AM,MH} + P_C) + (1 - p_{outVR})\left(\left(\sum_{i=2}^{n} X_{R_{i-1}R_i} + X_{R_nI} + 1\right) P_{AM,MH} + (n+1) P_C\right). \quad (26)$$

P_{totMH} can be minimized with one constraint variable through:

$$\frac{\partial P_{totMH}}{\partial P_{SMH}} + \lambda_{MH} \frac{(\partial p_{outMH} - 1 + U)}{\partial P_{SMH}} = 0. \quad (27)$$

where λ_{MH} represents the Lagrangian optimization factor for the multi-hop transmission scheme. Then, the derivatives of the total power consumption P_{totMH} and the outage probability p_{outMH} with respect to the transmit power P_{SMH} are given by:

$$\frac{\partial P_{totMH}}{\partial P_{SMH}} = \frac{\xi}{\eta} + Q\frac{\xi}{\eta} e^{-\frac{b_{VR_1}}{P_{SMH}}} + Q\frac{\xi}{\eta} \frac{b_{VR_1} e^{-\frac{b_{VR_1}}{P_{SMH}}}}{{P_{SMH}}^2} + n * P_C \frac{b_{VR_1} e^{-\frac{b_{VR_1}}{P_{SMH}}}}{{P_{SMH}}^2}. \quad (28)$$

$$\frac{(\partial p_{outMH} - 1 + U)}{\partial P_{SMH}} = -\frac{T_1 e^{-\frac{T_1}{P_{SMH}}}}{{P_{SMH}}^2}. \quad (29)$$

where $Q = \sum_{i=2}^{n} X_{R_{i-1}R_i} + X_{R_nI}$, $T_1 = b_{VR_1} + b_{R_{i-1}R_i} + b_{R_nI}$.

$$b_{VR_1} = \frac{\left(2^{2Rs} - 1\right) N}{v_{VR_1}^{\alpha} \left|h_{VR_1}\right|^2 \gamma_{VR_1}}, \; b_{R_{i-1}R_i} = \frac{\left(2^{2Rs} - 1\right) N}{v_{R_{i-1}R_i}^{\alpha} \left|h_{R_{i-1}R_i}\right|^2 \gamma_{R_{i-1}R_i}}, \; b_{R_nI} = \frac{\left(2^{2Rs} - 1\right) N}{v_{R_nI}^{\alpha} \left|h_{R_nI}\right|^2 \gamma_{R_nI}}.$$

Substituting the previous formulas in Equation (26) by (27), the Lagrangian can be written in the following simple form:

$$\lambda_{MH} = \frac{\frac{\xi}{\eta} + Q\frac{\xi}{\eta} e^{-\frac{b_{VR_1}}{P_{SMH}}} + Q\frac{\xi}{\eta} \frac{b_{VR_1} e^{-\frac{b_{VR_1}}{P_{SMH}}}}{{P_{SMH}}^2} + n * P_C \frac{b_{VR_1} e^{-\frac{b_{VR_1}}{P_{SMH}}}}{{P_{SMH}}^2}}{\frac{T_1 e^{-\frac{T_1}{P_{SMH}}}}{{P_{SMH}}^2}}. \quad (30)$$

3.2. Cooperative Transmission Schemes

In cooperative transmission, the sender V broadcasts its symbol to all potential receivers including the destination I and relays in the current time slot. Both the destination and relays receive noisy versions of the transmitted symbol. Then the relays transmit the received symbol after some processing to the relay that follows or the destination. The received symbol by relays, r_{VR}, and by the destination from relays, r_{RI}, and the spectral efficiency R_S of the V2I link involved can be expressed as:

$$r_{VR} = \sqrt{P_V d_{VR}^{-\alpha}} h_{VR} s + n_{VR}. \quad (31)$$

$$r_{RI} = \sqrt{P_{CC} d_{RI}^{-\alpha}} h_{RI} s + n_{RI}. \quad (32)$$

$$R_S = log_2\left(1 + SNR_{VR} + SNR_{RI}\right). \tag{33}$$

where P_V is the transmitting power of the source and P_{CC} is the transmitting power of relays, h_{VR} and h_{RI} are the channel coefficients of the vehicle-relay link and the relay-infrastructure link, respectively. In this paper we present two types of cooperative transmission schemes: 1) using multiple cooperative relaying branches with one relay in each branch-shown in Figure (1c), and 2) using multiple cooperative relaying branches with multiple relays in each branch-shown in 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. We assume that the selection combining technique is used at the destination on the received packets. 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.

$$p_{outMB} = p_{outVI}\left(1 - \left(1 - p_{outVR}\right)\left(1 - p_{outRI}\right)\right). \tag{34}$$

When we have multiple (K) branches Equation (34) becomes:

$$p_{outMB} = p_{outVI}\left(1 - \left(1 - p_{outVR}\right)\left(1 - p_{outRI}\right)\right)^K. \tag{35}$$

So Equation (35) can be rewritten as:

$$p_{outMB} \approx \left(2^{2Rs} - 1\right)^{K+1} N^{K+1} B. \tag{36}$$

$$\text{where } B = \left(\frac{1}{P_{VI}|h_{VI}|^2\gamma_{VI}}\left(\frac{1}{P_{VI}|h_{VR}|^2\gamma_{VR}} + \frac{1}{P_{RI}|h_{RI}|^2\gamma_{RI}}\right)^K\right).$$

We can formulate the power minimization problem by specifying a required reliability level, in a similar way to the method expressed in (7), which can be stated as:

$$Min\sum E_{bMB} \quad s.t.\left\{p_{outMB} \leq 1 - U\right\}. \tag{37}$$

Here there are two variables involved in the optimization (contained in p_{outMB}) for the cooperative transmission mode, namely, the transmit powers P_{VI} and P_{RI} at the vehicle and relay nodes, respectively. And the power of the selective decode-and-forward scheme with multiple relays is bounded by:

$$P_{SMB} \geq \left(2^{2Rs} - 1\right) N B^{\frac{1}{K+1}} \left(ln\left(U^{-1}\right)\right)^{-\left(\frac{1}{K+1}\right)}. \tag{38}$$

Therefore, the total consumed energy per bit for this transmission scheme can be expressed as:

$$E_{bMB} = \left(p_{outVR}\right)^K \frac{P_{AM,MB} + P_{C1}}{R_b} + \left(1 - \left(p_{outVR}\right)^K\right) \frac{\left(\sum_{l=1}^{K} X_{R_l I} + 1\right) P_{AM,MB} + P_{C2}}{R_b}. \tag{39}$$

$$\text{where } P_{C1} = \left(P_{Tx} + \left(K * P_{Rx}\right)\right), P_{C2} = \left(\left(K+1\right) P_{Tx} + \left(2 * K + 1\right) P_{Rx}\right).$$

Hence the relay's transmitting and processing power, and the extra receiving power at the destination are involved. The total consumed power can be expressed as:

$$P_{totMB} = p_{outVR}^{K}\left(P_{AM,MB}+P_{C1}\right)+\left(1-p_{outVR}^{K}\right)\left(\left(\sum_{l=1}^{K} X_{R_l I}+1\right)P_{AM,MB}+P_{C2}\right). \tag{40}$$

Again, P_{totMB} can be minimized with one constraint variable via the Lagrangian:

$$\frac{\partial P_{totMB}}{\partial P_{SMB}}+\lambda_{MB}\frac{\left(\partial p_{outMB}-1+U\right)}{\partial P_{SMB}}=0. \tag{41}$$

where λ_{MB} represents the Lagrangian optimization factor for the cooperative transmission scheme using multiple branches each with one relay. Then, the derivatives of the total power consumption P_{totMB} and the outage probability p_{outMB} with respect to the transmit power are given by:

$$\begin{aligned}\frac{\partial P_{totMB}}{\partial P_{SMB}} &= K\left(p_{outVR}\right)^{K-1}\left(\frac{1-p_{outVR}}{P_{SMB}{}^{2}}b_{VR}\right)\left(P_{C2}-P_{C1}\right)\\ &+\frac{\xi}{\eta}\left(1+E\left(1-\left(p_{outVR}\right)^{K}+KP_{SMB}\left(p_{outVR}\right)^{K-1}\left(\frac{1-p_{outVR}}{P_{SMB}{}^{2}}b_{VR}\right)\right)\right).\end{aligned} \tag{42}$$

$$\frac{\left(\partial p_{outMB}-1+U\right)}{\partial P_{SMB}}=-\frac{T_2 e^{-\frac{T_2}{P_{SMB}}}}{P_{SMB}{}^{2}}\left(1-e^{-\frac{T_3}{P_{SMB}}}\right)^{K}+K\left(1-e^{-\frac{T_3}{P_{SMB}}}\right)^{K-1}\left(\frac{-e^{-\frac{T_3}{P_{SMB}}}T_3}{P_{SMB}{}^{2}}\right)\left(1-e^{-\frac{T_2}{P_{SMB}}}\right). \tag{43}$$

where $E=\sum_{l=1}^{K} X_{R_l I}$, $T_2=b_{VI}, T_3=b_{VR}+b_{RI}$.

$$b_{VI}=\frac{\left(2^{2Rs}-1\right)N}{\left|h_{VI}\right|^{2}\gamma_{VI}}, b_{VR}=\frac{\left(2^{2Rs}-1\right)N}{\left|h_{VR}\right|^{2}\gamma_{VR}}, b_{R_n I}=\frac{\left(2^{2Rs}-1\right)N}{v_{RI}^{\alpha}\left|h_{RI}\right|^{2}\gamma_{RI}}.$$

.

Substituting the previous formulas in Equation (41), the Lagrangian can be written in the following simple form:

$$\lambda_{MB}=\frac{\frac{K\left(p_{outVR}\right)^{K-1}\left(1-p_{outVR}\right)b_{VR}}{P_{SMB}{}^{2}}\left(P_{C2}-P_{C1}\right)+\frac{\xi}{\eta}\left(1+E\left(1-K\left(p_{outVR}\right)^{K}+\frac{K\left(p_{outVR}\right)^{K-1}\left(1-p_{outVR}\right)b_{VR}}{P_{SMB}}\right)\right)}{\left(\frac{T_2 e^{-\frac{T_2}{P_{SMB}}}}{P_{SMB}{}^{2}}\left(1-e^{-\frac{T_3}{P_{SMB}}}\right)^{K}+K\left(1-e^{-\frac{T_3}{P_{SMB}}}\right)^{K-1}\left(\frac{e^{-\frac{T_3}{P_{SMB}}}T_3}{P_{SMB}{}^{2}}\right)\left(1-e^{-\frac{T_2}{P_{SMB}}}\right)\right)}. \tag{44}$$

In Figure (1d), multiple relays are used in each cooperation branch. The transmit power at relays can be reduced and the energy efficiency is improved as a result. This scheme is particularly suitable for long-range transmission and the related results will be shown in Section 4. In this case, the outage probability of this transmission scheme p_{outMHB} is:

$$p_{outMHB} \approx \left(2^{2Rs}-1\right)^{K+1}\left(\frac{N}{P_{SMHB}}\right)^{K+1}\left(\frac{1}{\left|h_{VI}\right|^{2}\gamma_{VI}}C\right). \tag{45}$$

$$\text{where } C=\left(\frac{1}{\left|h_{VR_1}\right|^{2}\gamma_{VR_1}}+\sum_{i=2}^{n}\frac{1}{\nu_{R_{i-1}R_i}^{\alpha}\left|h_{R_{i-1}R_i}\right|^{2}\gamma_{R_{i-1}R_i}}+\frac{1}{\nu_{R_nI}^{\alpha}\left|h_{R_nI}\right|^{2}\gamma_{R_nI}}\right)^{K}.$$

We can formulate the power minimization problem for cooperative transmission scheme using multiple branches each with multiple relay by specifying a required reliability level, in a similar way to the method expressed in (7). The optimization problem can be stated as follows:

$$Min\sum E_{bMHB} \quad s.t.\left\{p_{outMHB}\leq 1-U\right\}. \tag{46}$$

Thus, the power minimization problem is specified in a similar way to Equation (37) and the power P_{SMHB} is bounded by:

$$P_{SMHB}\geq\left(2^{2Rs}-1\right)N\left(\frac{1}{\left|h_{VI}\right|^{2}\gamma_{VI}}C\right)^{\frac{1}{K+1}}\left(ln\left(U^{-1}\right)\right)^{-\left(\frac{1}{K+1}\right)}. \tag{47}$$

The total energy consumed per bit and the total power consumption for this transmission scheme can be expressed as:

$$E_{bMHB}=p_{outVR_1}^{K}\frac{P_{AM,MHB}+P_{C3}}{R_b}+\left(1-p_{outVR_1}^{K}\right)\frac{\left(\sum_{l=1}^{K}\left(\sum_{i=2}^{n}X_{(R_{i-1}R_i)l}+X_{(R_nI)l}\right)+1\right)P_{AM,MHB}+P_{C4}}{R_b}. \tag{48}$$

where $P_{C3}=\left(P_{Tx}+\left(K*P_{Rx}\right)\right)$, $P_{C4}=\left(\left(K*n+1\right)P_{Tx}+\left(K*\left(n+1\right)+1\right)P_{Rx}\right)$.

$$P_{totMHB}=p_{outVR_1}^{K}\left(P_{AM,MHB}+P_{C3}\right)+\left(1-p_{outVR_1}^{K}\right)\left(\left(\sum_{l=1}^{K}\left(\sum_{i=2}^{n}X_{(R_{i-1}R_i)l}+X_{(R_nI)l}\right)+1\right)P_{AM,MHB}+P_{C4}\right). \tag{49}$$

Again, P_{totMHB} can be minimized with one constraint variable via the Lagrangian:

$$\frac{\partial P_{totMHB}}{\partial P_{SMHB}}+\lambda_{MHB}\frac{\left(\partial p_{outMHB}-1+U\right)}{\partial P_{SMHB}}=0. \tag{50}$$

where λ_{MHB} represents the Lagrangian optimization factor for the cooperative transmission scheme using multiple branches with multiple relays. Then, the derivatives of the total power consumption P_{totMHB} and the outage probability p_{outMHB} with respect to the transmit power P_{SMHB} are given by:

$$\frac{\partial P_{totMHB}}{\partial P_{SMHB}}=K\left(p_{outVR_1}\right)^{K-1}\left(\frac{1-p_{outVR_1}}{P_{SMHB}{}^{2}}b_{VR_1}\right)\left(P_{C4}-P_{C3}\right)$$

$$+\frac{\xi}{\eta}\left(1+F\left(1-\left(p_{outVR_1}\right)^K+K\left(p_{outVR_1}\right)^{K-1}\left(\frac{1-p_{outVR_1}}{P_{SMHB}}b_{VR_1}\right)\right)\right). \tag{51}$$

$$\frac{\left(\partial p_{outMHB}-1+U\right)}{\partial P_{SMHB}}=-\frac{T_2 e^{-\frac{T_2}{P_{SMB}}}}{P_{SMHB}{}^2}\left(1-e^{-\frac{T_4}{P_{SMHB}}}\right)^K-K\left(1-e^{-\frac{T_4}{P_{SMHB}}}\right)^{K-1}\left(\frac{e^{-\frac{T_4}{P_{SMHB}}}T_4}{P_{SMHB}{}^2}\right)\left(1-e^{-\frac{T_2}{P_{SMHB}}}\right). \tag{52}$$

where $F=\sum_{l=1}^{K}\left(\sum_{i=2}^{n}X_{(R_{i-1}R_i)l}+X_{(R_nI)l}\right)$ $T_4=b_{VR_1}+b_{R_{i-1}R_i}+b_{R_nI}$.

$$b_{VR_1}=\frac{\left(2^{2R_s}-1\right)N}{\left|h_{VR_1}\right|^2\gamma_{VR_1}},\, b_{R_{i-1}R_i}=\frac{\left(2^{2R_s}-1\right)N}{\nu^{\alpha}_{R_{i-1}R_i}\left|h_{R_{i-1}R_i}\right|^2\gamma_{R_{i-1}R_i}},\, b_{R_nI}=\frac{\left(2^{2R_s}-1\right)N}{\nu^{\alpha}_{R_nI}\left|h_{R_nI}\right|^2\gamma_{R_nI}}.$$

.

So the Lagrangian for this transmission scheme can be written in the following simple form:

$$\lambda_{MHB}=\frac{\frac{K\left(p_{outVR_1}\right)^{K-1}\left(1-p_{outVR_1}\right)b_{VR_1}}{P_{SMHB}{}^2}\left(P_{C4}-P_{C3}\right)+\frac{\xi}{\eta}\left(1+F\left(1-\left(p_{outVR_1}\right)^K+\frac{K\left(p_{outVR_1}\right)^{K-1}\left(1-p_{outVR_1}\right)b_{VR_1}}{P_{SMHB}}\right)\right)}{\left(\frac{T_2 e^{-\frac{T_2}{P_{SMB}}}}{P_{SMHB}{}^2}\left(1-e^{-\frac{T_4}{P_{SMHB}}}\right)^K+K\left(1-e^{-\frac{T_4}{P_{SMHB}}}\right)^{K-1}\left(\frac{e^{-\frac{4}{P_{SMHB}}}T_4}{P_{SMHB}{}^2}\right)\left(1-e^{-\frac{T_2}{P_{SMHB}}}\right)\right)}. \tag{53}$$

The related results of the proposed transmission schemes will be shown in Section 4.

4. 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 and packet loss rate. We then reveal the conditions for selecting the optimal transmission schemes through the analysis of the results obtained. The network settings for the simulation are listed in Table 1. Assume the spectral efficiency R_s in this scenario to be 2 bit/sec/Hz, and the required system reliability level to be 0.999. Mobility files are created in NS-2 simulation. In addition, it is assumed 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}<33m); the non-cooperative transmission using multi-hop relays outperforms the direct transmission for the range 33m<d_{VI}<43m and, in particular, the transmission using two intermediate relays (n=2) nodes has the lowest energy consumption for this range. 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 the distance continuously increases, the lowest energy consumption is achieved by the transmission using two branches with one relay (K=2, n=1) for 58<d_{VI}< 80m, and by the transmission using two branches with two relays (K=2, n=2) for d_{VI}>80m. The optimum transmission scheme for each transmission distance can be found in Table 2.

Table 1: SIMULATION PARAMETERS

Parameters	Values
N_o	-174 dBm
B	10 kHz
R_s	2 bit/sec/Hz[20]
P_{Tx}	97.9 mW[20]
P_{Rx}	112.2 mW [20]
ξ	0.5
η	0.35
Packet Size	512 bytes
fc	5.9 GHz
α	3
Simulation time	1000
Nodes	10/20/30/40/50/60/70/80/90/100
Velocity	5 km/h, 20 km/h, 60km/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

Table 2: RECOMENDED TRANSMISSION SCHEMES VS TRANSMISSION DISTANCES

Schemes	Distance
Direct Transmission	<33m
Multi-hop Transmission scheme (n=2)	Between 33m and 43m
Cooperative one branch with two relay nodes(K=1, n=2)	Between 43m and 58m
Cooperative two branches with one relay node (K=2, n=1)	Between 58m and 80m
Cooperative two branches with two relay nodes (K=2, n=2)	>80m

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.

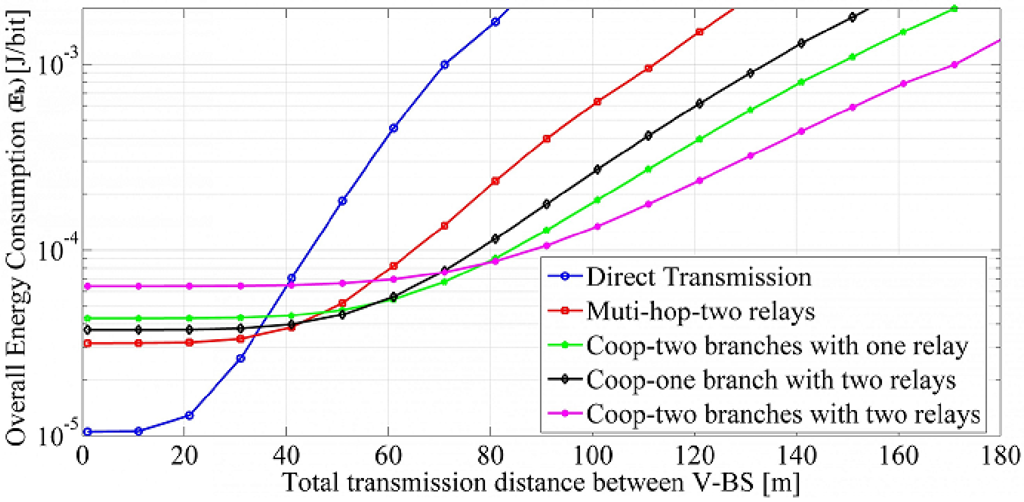

Figure 2: Overall energy consumption vs total transmitted distance.

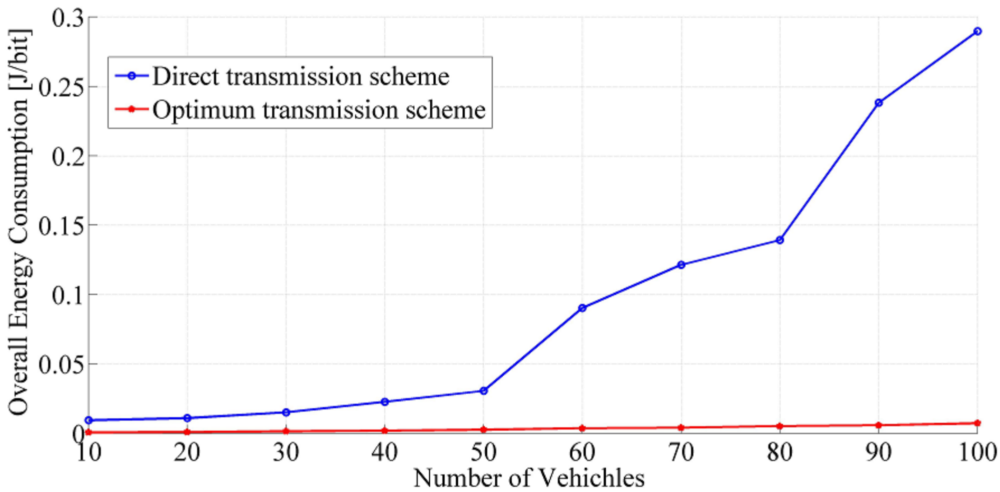

Figure 3: Overall energy consumption vs number of vehicles.

The average system throughput is shown in Figure 4 for three different vehicle velocities where the source-destination pairs are chosen randomly within the network, with an arbitrary distance between them. The optimum transmission scheme which is chosen based on the transmission distance as demonstrated in Table 2 clearly outperforms the direct transmission scheme 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 the increased operation overhead at the nodes that act as the source, as well as the relay at the same time. In addition, Figure 5 demonstrates the throughput against the simulation time for different vehicle densities and at a constant speed of 60 km/h. This figure shows that the optimum transmission scheme outperforms the direct transmission scheme throughout the simulation time.

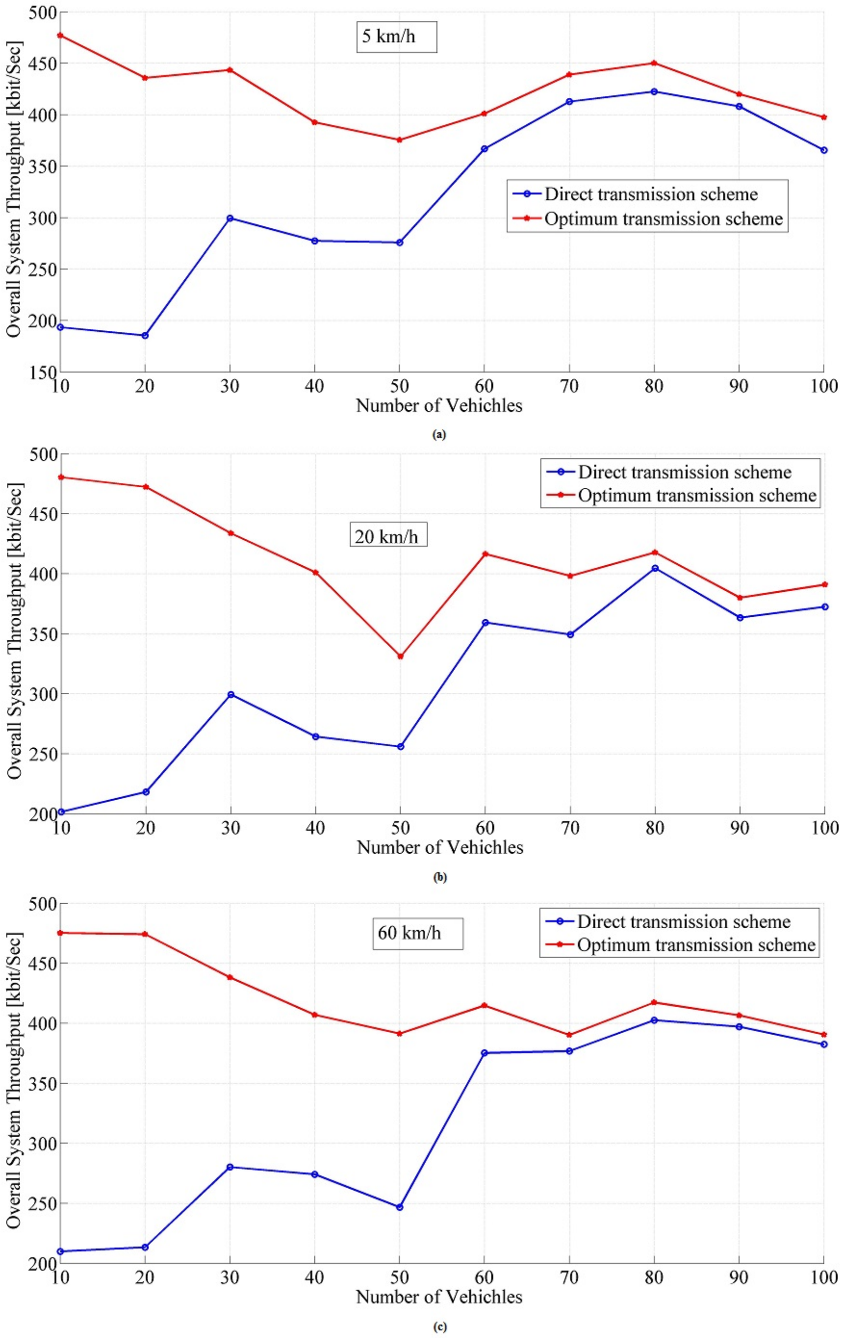

Figure 4: Overall system throughput vs number of vehicles.

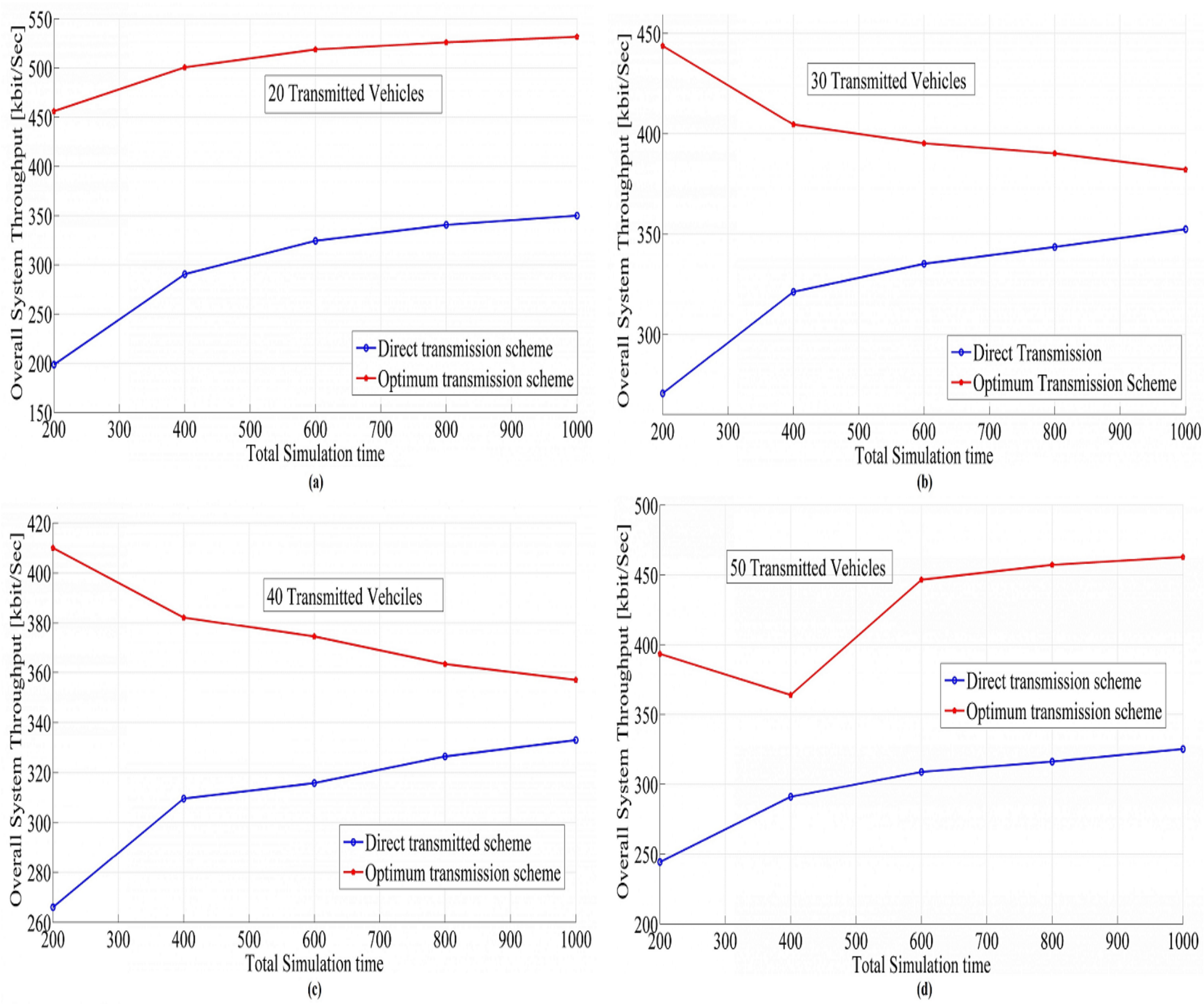

Figure 5: Overall system throughput vs total simulation time.

The packet delivery ratio (PDR) is evaluated for all the transmission schemes, showing, in Figure 6, that the data packet efficiency of the optimum transmission scheme has an increasing tendency when comparing it with the direct transmission scheme regardless of the selected speed. It is also shown that the change in vehicle's density has a significant effect on PDR. Especially in the direct transmission schemes, PDR decreases gradually when the vehicle density increases, which is mainly due to the increased congestion in the network and processing overhead as the density increases. When using the cooperative transmission scheme, the distance between vehicles decreases and connectivity for vehicles is improved. In this case, the added intermediate nodes promote easy and effective route selections for transmissions between vehicles and the destination and consequently the PDR is increased in comparison with direct transmission schemes. These results also conform to those in Figure 4, i.e. the higher the throughput, the higher the PDR.

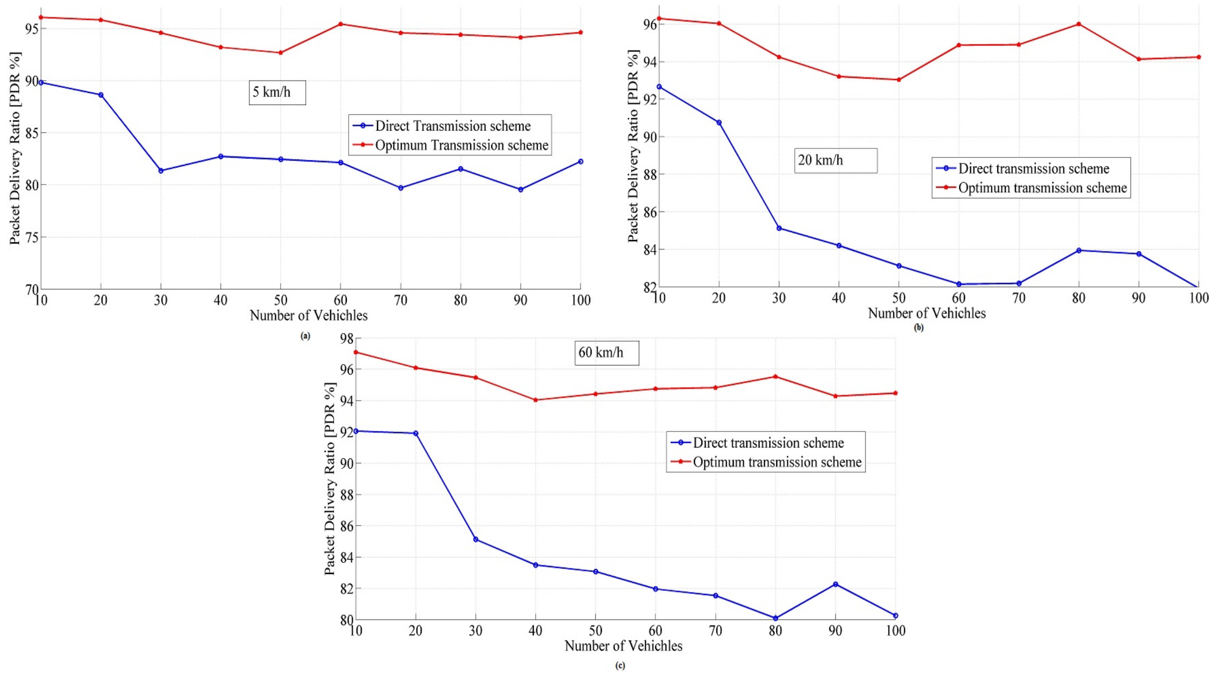

Figure 6: Packet delivery Ratio vs number of vehicles.

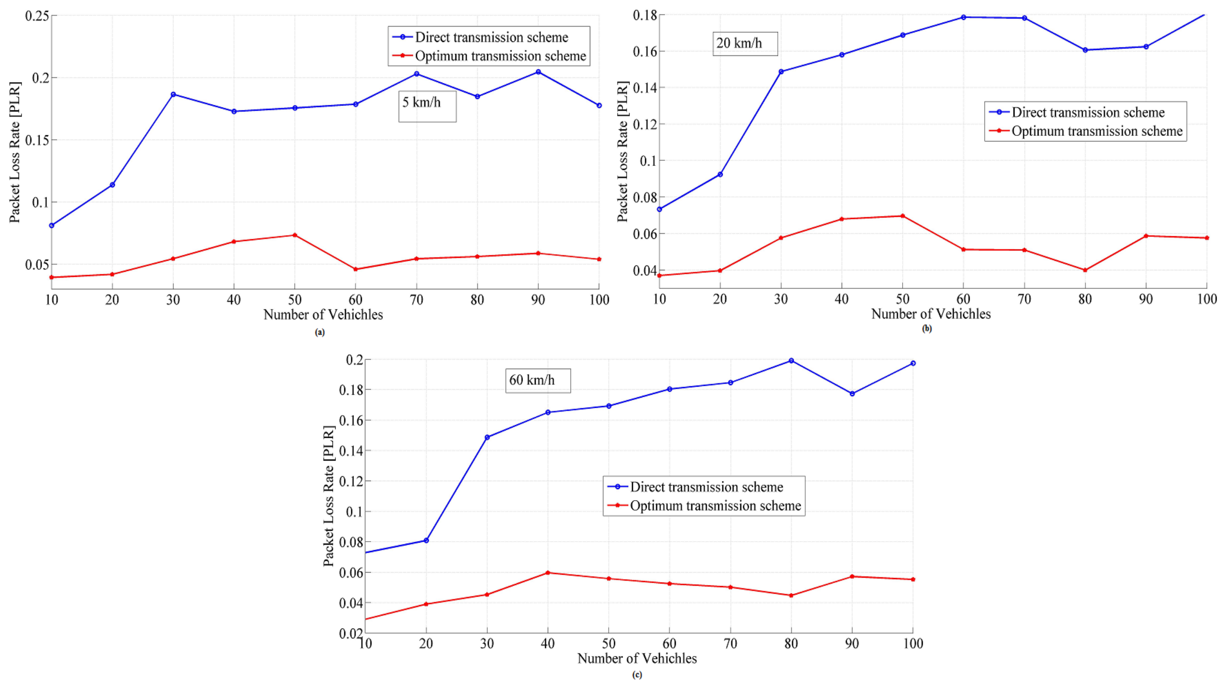

Figure 7: Packet loss rate vs number of vehicles.

Figure 7 depicts the overall system packet loss rate for direct transmission and optimum transmission scheme 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 for throughput as shown in Figure 4. It is worth mentioning that the optimum transmission schemes have much lower packet loss rates than the direct transmission scheme. This is because 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 in cooperative communications.

Finally, we evaluate the average end-to-end delay of both direct transmission and the optimum transmission schemes by counting on all possible transmission distances at a vehicle velocity 60 km/h. As illustrated in Figure 8 the direct transmission scheme has lower end-to-end delay than the optimum transmission schemes, due to the processing and retransmission time taken by relays. In addition, it shows that when the number of vehicles increases (more then 40) the longer delays are experienced in the optimum transmission scheme due to the network congestion.

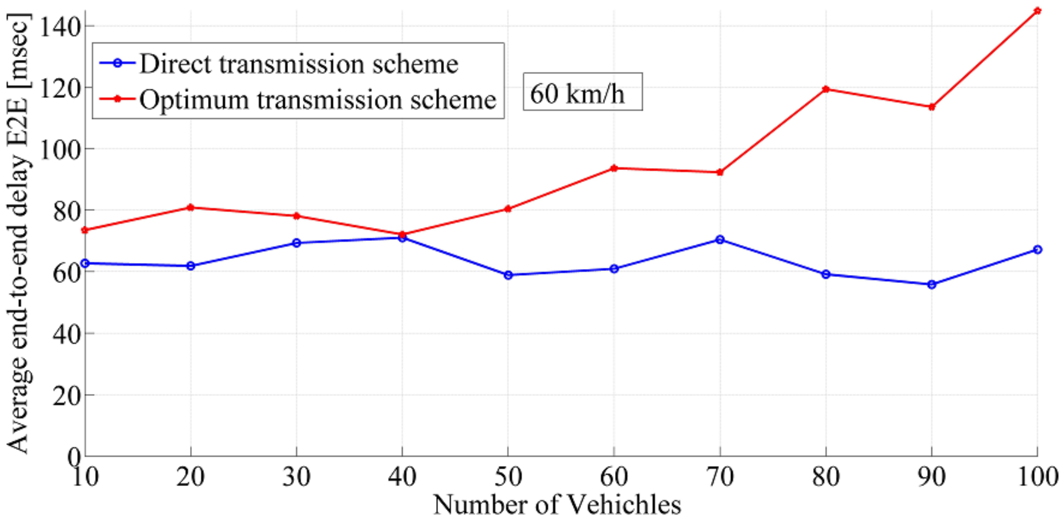

Figure 8: Average end-to-end delay vs number of vehicles.

Based on the above discussions the results presented in Figures 2-8, we give a summarized analysis for the performance of both direct and cooperative transmission schemes. First of all, there are a number of factors affecting energy consumption, throughput, packet delivery ratio and packet loss in V2I. Cooperative transmission uses additional paths and nodes (relays) compared to direct transmission, which seems to cost more energy, but the diversity it creates can save energy by reducing the probability of link failure and consequently reducing the number of retransmissions. Diversity increases with the number of relay branches used but this increase could be marginal when the number of branches is large as it is difficult to ensure all the branches are uncorrelated. In addition, increasing the number of relays in each branch reduces the transmission distance for each relaying hop, which results in lower transmit power for relays as it is proportional to d^{α} where d is either d_{RI} or d_{RR}. But when the number of relays increases, the total circuitry power will accumulate as it depends on the number of transmitting nodes and is independent from the transmission distance. This implies that the total energy consumption will increase when more branches and relaying nodes are used to some extent.

Secondly, on the evaluation of the QoS performance of different transmission schemes, we demonstrate a clear advantage of cooperative transmission over direct transmission. Specifically, as an importance performance for QoS, throughput is affected by both the packet lose rate and end-to-end (E2E) delay. Although the E2E delay of cooperative transmission is higher than that of direct transmission and the gaps increases when the number of vehicles is more than 40 as shown in Figure 8, the packet loss rate of cooperative transmission is much lower than that of direct transmission when number of vehicles increases as shown in Figure 7. As a result of an overall impact of these two factors on throughput, Figure 4 shows that cooperative transmission can always outperform direct transmission on throughput for a wide range of the vehicle density.

Clearly, based on the requirement of a particular application, to achieve the best energy performance, proper transmission schemes should be selected for the given transmission conditions, such as overall distance, d_{SD}, and channel quality in terms of α. Our work provide an effective guidance for deciding when and how the cooperative or non-cooperative transmission scheme should be employed. For achieving high throughput as a main QoS requirement, cooperative transmission schemes are recommended and the number of relaying branches and the number of relays in each branch should be determined appropriately for the given transmission conditions. Therefore, based on our results, an energy-efficient or QoS ensured transmission strategy can be formed in a V2X network by adaptively choosing cooperative or non-cooperative transmission schemes under different network and transmission conditions, which may involve determining the number of relaying branches and the number of relays if the cooperative scheme is to be used.

5. Conclusion

We have investigated different transmission schemes for their energy and QoS performance in a vehicular network, including the strengths and limitations of the cooperative transmission schemes in comparison with non-cooperative schemes. Based on the outage probability, energy efficiency, throughput, packet delivery ratio, packet losses and average end-to-end delay models, we have shown that both cooperative and non-cooperative transmission schemes can exhibit the best performance under a certain environmental condition. The optimal transmission scheme can be identified on judging the distance between the source node and the destination node in a V2X link. The results presented in this paper can be used to form an adaptive transmission strategy that is able to select appropriate transmission schemes to achieve the best QoS performance for any source-destination pair selected. In this way, we can attain either the highest throughput with a fixed energy consumption, or the lowest energy cost for the given throughput target.

References

[1] P. Papadimitratos, A. De La Fortelle, K. Evenssen, R. Brignolo, and S. Cosenza, "Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation," *IEEE communications magazine*, vol. 47, no. 11, 2009.

[2] S.-H. Wu, C.-M. Chen, and M.-S. Chen, “An asymmetric and asynchronous energy conservation protocol for vehicular networks,” *IEEE Transactions on Mobile Computing*, vol. 9, no. 1, pp. 98–111, 2010.

[3] M. J. Booysen, S. Zeadally, and G.-J. Van Rooyen, “Survey of media access control protocols for vehicular ad hoc networks,” *IET communications*, vol. 5, no. 11, pp. 1619–1631, 2011.

[4] S. Chen, J. Hu, Y. Shi, and L. Zhao, “Lte-v: A td-lte-based v2x solution for future vehicular network,” *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 997–1005, 2016.

[5] A. Bazzi, B. M. Masini, and A. Zanella, “Performance analysis of v2v beaconing using lte in direct mode with full duplex radios,” *IEEE Wireless Communications Letters*, vol. 4, no. 6, pp. 685–688, 2015.

[6] G. El Mouna Zhioua, N. Tabbane, H. Labiod, and S. Tabbane, “A fuzzy multi-metric qos-balancing gateway selection algorithm in a clustered vanet to lte advanced hybrid cellular network,” *IEEE Transactions on Vehicular Technology*, vol. 64, no. 2, pp. 804–817, 2015.

[7] O. Goubet, G. Baudic, F. Gabry, and T. J. Oechtering, “Low-complexity scalable iterative algorithms for ieee 802.11 p receivers,” *IEEE Transactions on Vehicular Technology*, vol. 64, no. 9, pp. 3944–3956, 2015.

[8] X. Wu, S. Subramanian, R. Guha, R. G. White, J. Li, K. W. Lu, A. Bucceri, and T. Zhang, “Vehicular communications using dsrc: challenges, enhancements, and evolution,” *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, pp. 399–408, 2013.

[9] C.-H. Wang, C.-T. Chou, P. Lin, and M. Guizani, “Performance evaluation of ieee 802.15. 4 nonbeacon-enabled mode for internet of vehicles,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 6, pp. 3150–3159, 2015.

[10] A. Nasri, R. Schober, and I. F. Blake, “Performance and optimization of amplify-and-forward cooperative diversity systems in generic noise and interference,” *IEEE Transactions on Wireless Communications*, vol. 10, no. 4, pp. 1132–1143, 2011.

[11] D. Xie, W. Wei, Y. Wang, and H. Zhu, “Tradeoff between throughput and energy consumption in multirate wireless sensor networks,” *IEEE Sensors Journal*, vol. 13, no. 10, pp. 3667–3676, 2013.

[12] H. Hakim, H. Boujemaa, and W. Ajib, “Single relay selection schemes for broadcast networks,” *IEEE Transactions on Wireless Communications*, vol. 12, no. 6, pp. 2646–2657, 2013.

[13] S. Sohaib and D. K. So, “Asynchronous cooperative relaying for vehicle-to-vehicle communications,” *IEEE Transactions on Communications*, vol. 61, no. 5, pp. 1732–1738, 2013.

[14] K. Zheng, F. Liu, Q. Zheng, W. Xiang, and W. Wang, “A graph-based cooperative scheduling scheme for vehicular networks,” *IEEE Transactions on Vehicular Technology*, vol. 62, no. 4, pp. 1450–1458, 2013.

[15] E. Yaacoub, F. Filali, and A. Abu-Dayya, “Qoe enhancement of svc video streaming over vehicular networks using cooperative lte/802.11 p communications,” *IEEE Journal of Selected Topics in Signal Processing*, vol. 9, no. 1, pp. 37–49, 2015.

[16] T.-D. Nguyen, O. Berder, and O. Sentieys, “Energy-efficient cooperative techniques for infrastructure-to-vehicle communications,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 659–668, 2011.

[17] C. Shao, S. Leng, Y. Zhang, A. Vinel, and M. Jonsson, “Performance analysis of connectivity probability and connectivity-aware mac protocol design for platoon-based vanets,” *IEEE Transactions on Vehicular Technology*, vol. 64, no. 12, pp. 5596–5609, 2015.

[18] S.-Y. Pyun, H. Widiarti, Y.-J. Kwon, J.-W. Son, and D.-H. Cho, “Group-based channel access scheme for a v2i communication system using smart antenna,” *IEEE Communications Letters*, vol. 15, no. 8, pp. 804–806, 2011.

[19] S.-Y. Pyun, W. Lee, and D.-H. Cho, “Resource allocation for vehicle-to-infrastructure communication using directional transmission,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 4, pp. 1183–1188, 2016.

[20] T.-Y. Wu, S. Guizani, W.-T. Lee, and K.-H. Liao, “Improving rsu service time by distributed sorting mechanism,” *Ad Hoc Networks*, vol. 10, no. 2, pp. 212–221, 2012.

[21] H. Zhang, Y. Ma, D. Yuan, and H.-H. Chen, “Quality-of-service driven power and sub-carrier allocation policy for vehicular communication networks,” *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 1, pp. 197–206, 2011.

[22] L. Azpilicueta, C. Vargas-Rosales, and F. Falcone, “Intelligent vehicle communication: Deterministic propagation prediction in transportation systems,” *IEEE Vehicular Technology Magazine*, vol. 11, no. 3, pp. 29–37, 2016.

[23] G. G. de Oliveira Brante, M. T. Kakitani, and R. D. Souza, “Energy efficiency analysis of some cooperative and non-cooperative transmission schemes in wireless sensor networks,” *IEEE Transactions on Communications*, vol. 59, no. 10, pp. 2671–2677, 2011.

[24] A. S. Ibrahim, Z. Han, and K. R. Liu, “Distributed energy-efficient cooperative routing in wireless networks,” *IEEE Transactions on Wireless Communications*, vol. 7, no. 10, pp. 3930–3941, 2008.

[25] A. Goldsmith, *Wireless communications*. Cambridge university press, 2005.