CROSS LAYER DESIGN APPROACH FOR EFFICIENT DATA DELIVERY BASED ON IEEE 802.11$_p$ IN VEHICULAR AD-HOC NETWORKS (VANETS) FOR CITY SCENARIOS

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ABSTRACT

Intelligent Transportation Systems (ITS) have been one of the promising technology that has a great interest attention from many researchers over the world. Vehicular Ad-hoc Network (VANET) communications environment as a part of ITS opens the way for a wide range of applications such as safety applications, mobility and connectivity for both driver and passengers to exploit the transport systems in a smoothly, efficiently and safer way. Several challenging tasks facing adopting VANET functionality for ITS such as modelling of wireless transmission and routing issues. These research issues have become more critical due to the high mobility of vehicles nodes (transmitters and receivers) and unexpected network topology due to the high speed of nodes. In fact, modelling radio propagation channel in VANET environment which considers as one of a stringent communications environment is a challenging task. The selection of a suitable transmission model plays a key role in the routing decisions for VANET. Different propagation models allow calculating the Received Signal Strength (RSS) based on key environmental properties such as the distance between transmitter vehicle and a receiver vehicle, the gain and antenna height of transmitter and a receiver vehicles. Hence, it is useful to calculate RSS and SNR values for a specific propagation model and then these values can be used later for routing decision in order to find the best path with high SNR. This paper evaluates the performance of different transmission models (free-space, two-ray and log-normal) in terms of Receive Signal Strength (RSS). In addition, the performance of such wireless transmission models for vehicular communication in terms of PDR, throughput and delay is evaluated by applying the proposed cross layer routing approach based on IEEE 802.11p. By using MATLAB, the obtained results confirm the best packet delivery ratio for our proposed approach, where it indicates poor quality of DSSS PHY with high number vehicles. The minimum delay achieved when traffic density is decreased.

KEYWORDS

VANET, Radio Propagation Model, RSS, Cross-layer, FHSS, DSSS, IEEE 802.11p.

1. INTRODUCTION

In recent years, Intelligent Transportation Systems (ITS) have been receiving significant interest and attention from various stakeholders over the world. Indeed, automotive companies, ITS designers, and even the industry academic research communities are all looking forward to design and deploy different ITS applications and systems. The main goal of ITS is to introduce improvements in terms of efficiency and safety level of the road and the transportation system via new applications, protocols and standard. Besides that, increasing number of vehicles gives the motivations for improving road safety and inter-vehicle entertainment via Vehicular Ad-hoc Networks (VANET) systems as part of ITS [1-3].

In the past few years, further developments in Mobile Ad-hoc Networks (MANETs) have led to the emergence of Vehicular Ad-hoc Networks (VANETs). The concept is to create an ‘ad-hoc

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network' of moving vehicles with ever-present connectivity. Each vehicle acts like a mobile node and moves along predetermined paths (roads). The connectivity is established when a vehicle tries to look for a nearby vehicle or infrastructure within the communication range to establish desired communication. Since vehicles can communicate with each other, it has opened a totally new communication paradigm that can be used to provide new services to stakeholders [4, 5]. Emerging Vehicular networks will provide both driver and passengers with a variety of applications for safety, traffic efficiency, driver assistance, as well as infotainment to be incorporated into modern automobile designs [6].

One of the big challenges facing VANET system is a high traveling speed situation of vehicles. A key problem in such environment is the data exchange between neighbour vehicles must be supported with high level of QoS. A major problem with VANET systems is the effect of different propagation models in addition with multipath fading. The Received Signal Strength (RSS) is position dependent and time varying. The received power is determined by the radiating characteristics and the vehicle antenna as well as statistically distributed reflectors. Before designing a new routing scheme that becomes more suitable with dynamic VANET environment, modelling of different wireless transmission methods must be studied as pointed out in [7, 8]. The selection of a proper transmission model plays a key role in the routing decisions for VANET. Main challenges to model the wireless channel for VANET are physical constraints inherent to such networks such as high speed, lack of permanent infrastructure, limited knowledge in relation to the position of vehicles as well as various interfering obstacles that affects the strength of received signal at each communicating vehicle and can be provided by as a main information from a wireless channel model at the receiver vehicle. This value of Received Signal Strength (RRS) can be exploited in the routing decisions. In general, there are two ways to model the wireless radio channel for VANET. The first approach is to develop mathematical models while the second method is to practically take the measurements and use these measurements to fit a certain mathematical model [9-11].

For VANET communication environment, two types of propagation models are defined for wireless systems. The first model is named by deterministic propagation model which allows calculating the Received Signal Strength (RSS) based on key environmental properties such as the distance between transmitter vehicle and a receiver vehicle. These models have a wide range from basic to very complex where they also account for multipath propagation in the environment modeled exactly as the area of deployment. The second propagation model is called probabilistic propagation model allow a more realistic modelling of radio wave propagation to predict the received power at the destination vehicle for dynamic wireless channel. In these models an average received power at a distance d is calculated by predetermining the value of a reference received power Po as a mean value. This value of P_o is obtained using deterministic models [12].

In general form, when designing VANET system that provides safety applications, it is important to take into account the particular requirements and constraints to obtain high level of QoS. The main requirements are low delay, high throughput and low packet loss rate. Thus, some additional design metrics including the strength of received power P_r according to specific propagation model that gives an indication of Signal to Noise Ratio (SNR) can be used in routing protocol. Those route metrics comes from a cross layer design (CLD) that enable sharing of information between physical and MAC layers. In fact, cross layer design (CLD) has enormous potential in ad-hoc communications environment to define a good level of link quality for a specific type of applications [7, 9].

IEEE 802.11p is an IEEE recommended MAC and PHY layer standard for VANET environment [10, 13]. It uses dedicated frequency band of 5.85 GHz to 5.925 GHz and supports 10 MHz bandwidth and provide performance and power transmission mask improvement in Wireless Access for Vehicular Environment (WAVE) compliant receiver [14, 15].

In this paper, the performance of urban city VANET environment under two different types of propagation models in terms of PDR, average throughput and delay by using cross layer design (CLD) based on IEEE 802.11p is evaluated. The reminder of this paper is organized as follows: Section II reviews several studies about cross layer design (CLD) cross layer design (CLD) under specific transmission model. In Section III, the proposed system model is discussed and the simulation environment is explained in details. Section IV presents the results and analysis for different scenarios. Section V concludes the contribution of this paper.

2. RELATED WORKS

In conventional and traditional networks, channel modelling has shown a significant impact on the performance of routing design [16, 17]. In addition, authors in [18] introduced a detailed study in relation to the modelling of channel conditions for vehicular communication and a comparison of different propagation models based on the propagation mechanism and the modelling technique was presented. More efforts in terms of VANET channel architecture was presented in [19] where the researchers presented the limitations of unit-disk and Log-Normal models in order to achieve realistic VANET topology characteristics. In this work, a mechanisms to tune the parameters of Log-Normal model according to vehicle density, and verified the applicability by using real-time data of four different highways has been proposed. The authors in [20] introduced a method for channel modelling in VANETs based on discrete time by utilizing Markov Chain modelling (MVCM).

Many efforts have been done by researchers for finding the best MAC layer protocols for the problematic VANET aspects. Different standards of IEEE 802.11 are evaluated in terms of different parameters in order to find the best standard that can be compatible with the dynamic environment of VANET system. In addition, several different routing protocols have been studied and proposed in the literature to improve the communication performance of VANETs that affects by routing issues. Cross layer design (CLD) Cross layer design (CLD) based on IEEE 802.11p is one of the proposed technique that aims to minimize delay and increase both the throughput and PDR [21].

Recently work was done in [7], the authors proposed an Enhanced version of AODV (En-AODV) protocol to deal with routes instability issue in multimedia applications. En-AODV leverages cross-layer information on the link quality state combined with the knowledge of the final vehicle destination to estimate more stable route. In their work, minimum lifetime and destination region is proposed to reduce the communication overhead as a two additional fields were added to the Route REQuest (RREQ) packets in order to estimate more stable and reliable route. The obtained simulation results by using NS-3 confirmed the efficiency of En-AODV and highlight its supremacy over AODV under various metrics and scenarios.

Several routing protocols have been defined by many researchers for VANET. Author in [22] evaluated various proposed routing techniques for VANET in terms of throughput and PDR for city and highway scenarios. His paper concluded the importance to propose a new routing protocol in order to improve the performance of VANET transmission to provide reliable QoS for safety applications in VANET.
In [9] a survey of recent work on cross-layer communication solutions for VANETs is presented. Major approaches to cross-layer protocol design is introduced, followed by an overview of corresponding cross-layer protocols. Finally, open research problems in developing efficient cross-layer protocols for next generation transportation systems are discussed.

Authors in [23] evaluate the performance of the 802.11p MAC protocol with various vehicle densities (0.01-0.5 vehicles/m). The 802.11p MAC protocol is evaluated in terms of collision, reliability, delay and throughput in the OMNeT++ network simulator. The evaluation results indicate that 802.11p MAC protocol can be improved via extending the Control Channel (CCH) interval and proves that the IEEE 802.11p MAC protocol can satisfy the latency requirement in VANET safety applications. Similarly, the main aim of the study in [24] is to examine the MAC of the vehicular communication standard IEEE 802.11p CSMA through simulation. The obtained results indicate severe performance degradation for high density loaded system, both for individual nodes and for the system. The simulations show that 802.11p is not suitable for periodic location messages in a Mumbai-Pune highway road scenario. Also, the main idea of [25] is to evaluate IEEE 802.11p MAC standard by creating a vehicular ad-hoc network scenario using MATLAB simulations. A highway scenario with periodic broadcast of time critical packets in a V2V architecture is considered. The evaluation was done in terms of channel access delay and probability of channel access. The results show that, when the number of vehicles is increased from 100 to 200, channel access delay increases by approximately 20ms and probability of channel access decreases by approximately 5%.

On the other hand, in [13] authors conducted an experimental research analysis to measure the performance through off-the-shell IEEE 802.11p devices to evaluate the standards' performance in a real scenario in terms of delay, jitter, bit rate and loss rate, where UDP protocol was used. The achieved results indicate the best performance of this standard for VANET environment.

As a summary from the recent related works and with the passage of time, cross layer design (CLD) has been proposed in recent works and it refers to a protocol design that exploits the dependency between protocol layers to achieve desirable performance gains. On the other hand, the research and application development in VANETs are driven by the IEEE 802.11p technology which is intended to enhance the IEEE 802.11 to support ITS applications where reliability and low latency are crucial factors. Therefore, it is important to test and evaluate cross layer design (CLD) based on IEEE 802.11p for VANET system by using the actual radio propagation models such as shadowing model. Before that, different propagation models need to be evaluated in terms of RSS. The majority of VANET simulators such as NS-2 works only under two-ray models.

3. Simulation Environment

3.1 Models Of Radio Propagation Channel

In this section, the system model that is used in this work to evaluate various propagation conditions is defined. The first assumption is each transmitting vehicle has transmitted power P_t = 0.2 W. A VANET model has a specific topology which defined by a size of urban city area equals to $x_{max} \times y_{max}$ that contains n number of nodes (vehicles) which are moving with a constant velocity υ which depends on the simulation scenario (highway or city). Here, a speed of 50 Km/s for a urban city scenario was considered. The positioning of the vehicles are defined according to the homogeneous Poisson point process. It is assumed that the source vehicle s randomly selects a destination vehicle d to communicate with. Here, position-update.m as function in MATLAB was created. Moreover, Random Waypoint model was used in order to model the mobility of vehicles. In order to evaluate the effects of different transmission models on the communication, the received power (RSS) is calculated according to specific mathematical equation which defined the transmission model in terms of varied distance between transmitter and receiver as shown later in this section. Here, the main aim is to determine the value of the received power of signal (RSS) in terms of the channel propagation model and the distance between source and destination vehicles. Finally, cross-layer design routing approach for different traffic density based on maximum SNR path is evaluated for city scenario and compared by using two-ray and log-normal shadowing models.

Free-space Propagation Model

The simplest deterministic propagation models is the free-space model which defined by line of sight (LOS) path between transmitter and receiver separated by distance d. Sometimes referred to as Friis model. This model is based on the Friss-transmission equation [12]. The model can also be applied to a vehicular communication scenario with relatively simple assumptions. The received power using Free-space model can be calculated according to the following formula:

$$\mathbf{P_r = P_t\, G_t\, G_r\, (\frac{\lambda}{4\, \pi\, d})^2} \qquad (1)$$

Where: P_r = the strength of received power, P_t = the transmitted power, G_t = the transmitter antenna gain, G_r = the receiver antenna gain, λ = the wavelength, and d = the distance between transmitter and receiver vehicles.

Two-Ray Propagation Model

As it is known, line of sight not always exist between transmitter and receiver. To take into the account non line of sight path, a Two-Ray propagation model was developed [12]. In literature, few variants of this model have been described with different assumptions. Some implementations of this model in the context of VANETs are described in this section. In one of the implementations, practical parameters of the transmitter and receiver such as antenna heights are considered. The strength of received power using this model can be calculated based on the value of cross-over distance which is determined from the following equation:

$$\mathbf{d_{cross} = \frac{4\ \pi\ h_t\ h_r}{\lambda}} \qquad (2)$$

Where: h_t = the transmitted antenna height, h_r = the received antenna height, and λ = the wavelength.

The following formula shows the relationship between the strength of received power (Pr) and the distance between two communicating vehicles nodes (d) based on the value of d_{cross} :

$$\mathbf{P_r} = \begin{cases} \mathbf{P_t\, G_t\, G_r\, (\frac{\lambda}{4\, \pi\, d})^2} & d \le d_{cross} \\ \frac{\mathbf{P_t\, G_t\, G_r}\, h_t^2 h_r^2}{d^4} & d > d_{cross} \end{cases} \qquad (3)$$

Log-Normal Shadowing Model

The Log-Normal Shadowing propagation model is one of the basic probabilistic propagation models uses a normal distribution with variance σ to distribute reception power in the logarithmic domain. As compared to the deterministic models where received power is estimated as a function of distance, in this model the received power is classified as a random variable following the Log-Normal distribution. This model states that for any particular distance d between transmit and receive vehicles, the received power is decreased by a factor that resembles a random variable having normal distribution at the mean distance dependent value [12]. The strength of received power in dB unit can be calculated based on the value of cross-over distance which is determined as:

$$\mathbf{P_r\, [dB] = P_{ro} - 10\, n\, \log\left(\frac{d}{d_0}\right) + X_0} \qquad (4)$$

The value of P_{r0} refers to the strength of the received power when the propagation model in free space and can be calculated using the following formula [9]:

$$\mathbf{P_{r0}} = \mathbf{P_t\, G_t\, G_r} \left(\frac{\boldsymbol{\lambda}}{\mathbf{4\,\pi\, d}}\right)^2 \qquad (5)$$

Where: P_r = the strength of received power, P_t = the transmitted power, G_t = the transmitter antenna gain, G_r = the receiver antenna gain, λ = the wavelength, and d = the distance between transmitter and receiver vehicles.

In fact, the log-normal shadowing model is defined according to two parameters as presented in equation (4) the exponential value of path loss n and X_0 which represent the Gaussian random variable with zero mean and one variance.

3.2 Simulation Scenarios And Parameters

In this work, the simulation parameters were defined according to the VANET standard which is IEEE 802.11p. The standard in [26, 27] defined the main parameters as shown in Table I. In this simulation, Direct Sequence Spread Spectrum (DSSS) as one of the simplest PHY techniques was used in order to simulate highway scenario for VANET. IEEE 802.11p DSSS/PHY characteristics and Physical Layer Convergence Protocol (PLCP) frame formats as shown in Table II were obtained from IEEE standard in [28, 29].

Table I **:** The Simulation Parameters

Parameter	**Value**
Frequency	5.9 GHz
# of Vehicles	100-300
Speed Limit	50 Km/h
Packet size	18496
Network size	1200 x 500
Gt	10
Gr	10
$\mathbf{h_t}$	1
$\mathbf{h_r}$	1
Physical Layer	IEEE 802.11p
Contention Window Min (CW_{Min})	31 slots
Contention Window Max (CW_{Max})	1023 slots
Mobility	Random Way Point

Table 2 **:** DSSS PHY Parameters

Parameter	**DSSS**
Slot Time [µs]	20
Turnaround Time [µs]	5
Preamble [bits]	144
PLCP header [bits]	48
Data Rate [Mbps]	1
SIFS interval [µs]	10

Moreover, the topology and road network were defined with a specific number of vehicles nodes. The total simulation area of 1200x500 is used in our simulation by using topo.m function as shown in Figure 1.

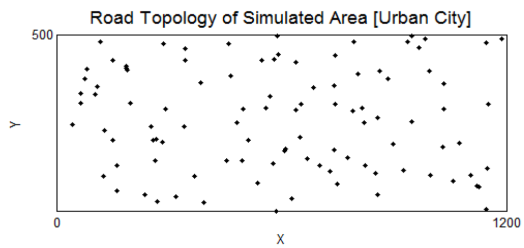

Figure 1. Road Topology of Simulated Area in MATLAB (Urban City Scenario)

3.3 THE PROPOSED CROSS LAYER PHY/MAC FRAMEWORK

In VANET communication, each two communicating vehicles can send an information through one route (the best available path) which contains several vehicles (hops). Each link defines by several metrics such as the available bandwidth (BW), the received signal strength (P_r) and then the value of SNR that are used to select the route with best channel quality with a specific number of hops. In this work, a cross layer design (CLD) which aims to exploit the SNR of the route based on RSS has been proposed. According to this method, each link has its calculated received power that based on specific wireless transmission propagation model. In cross layer design (CLD), the physical lower layer information is forwarded to MAC layer in order to enhance the overall performance of routing mechanism.

In this work, both two-ray as deterministic propagation model and log-normal shadowing as a probabilistic propagation model are evaluated. These characteristics need to be represented in computer simulations. The loss coefficient value that is equals to 1. On the other hand, Cross layer Design (CLD) aims to form a stable routes and improve the application performance in terms of PDR and delay. The channel quality is defined according to SNR values which are passed to neighbour during route discovery phase. By capturing SNR information from the PHY layer, the network layer can provide a better route that improves link connectivity through defining an interface which can communicate directly between the layer-1 and layer-2 bypassing the layer-2.

3.4 ROUTE DISCOVERY PHASE

The phase of route discovery is one of the most important phases of any protocol in wireless environment to enable communications between two nodes. In routing protocol, when there is an information to send from sender to receiver vehicles, a valid path (route) must be checked in the vehicle routing table. If this route exit in this routing table, there is no need to send a Route REQuest (RREQ) in order to find a route, otherwise it is mandatory to start a new route by broadcasting a new RREQ to all its vehicles in the neighbors from the source node. The RREQ packet contains source and destination nodes addresses. In addition, it contains source and destination nodes sequence numbers and broadcast ID and a counter in order to count the number of RREQ generation. Each packet has a defined sequence number to avoid duplication. Any RREQ packet with the same sequence number is discarded in the receiver node. Two additional fields (RSS and SNR). Finally, the RREQ arrives some nodes with a route to that destination and hence, a Route REPly (RREP) packet is generated which is then sent back to the source node. Both new two design metrics RSS and SNR are added to the RREP packet. A summary of route discovery phase is presented in Algorithm 1.

```
Algorithm 1:  Route Discovery Algorithm
---------------------------------------------------------------
Step 1  Check the routing table (contains destination IP address
        and sequence number)
if      (there is no route) then
        Go to step 2
else
         Discard the RREQ
End
---------------------------------------------------------------
Step 2  RREQ packet is generated by a source vehicle with ID (i)
      ✓  Set the destination IP address in dest. ID field
      ✓  Initialize the Pr and SNR fields to zero
      ✓  Broadcast the RREQ packet
---------------------------------------------------------------
Step 3  Upon reception of a RREQ an intermediate vehicle Vec
        does the following:
if      (Vec is the destination vehicle) then
         Go to Step 5
else
         If  (Vec is currently in or going to the same region) then
               record in their routing tables the address of neighbours
               Go to Step 4
         else
               Discard the RREQ
         end
end
---------------------------------------------------------------
Step 4  Compute the Pr and SNR with the sender vehicle (neighbor)
      ✓  Compute the Pr0 using equation (2)
      ✓  Compute Pr by using propagation model equation
if       (SNR > TH_value) then
           Update the SNR value in the RREQ
           Broadcast the updated RREQ
else
           Broadcast the received RREQ
End
---------------------------------------------------------------
Step 5  Wait an arbitrary time to receive more RREQs
      ✓  Select the route with max SNR value
      ✓  Send a RREP to the source vehicle using the reverse
         direction of the discovered route
---------------------------------------------------------------
Step 6
if      (The RREQ is not acknowledged yet by an RREP) then
              timeout_rreq ++
              if  (timeout_rreq  <  # of tries) then
                    Go to step 2 (retransmit the RREQ)
              else
                    Drop RREQ retransmit packet
              end
end
```

4. SIMULATION RESULTS

In this section, VANET simulation for urban city scenario was carried out to evaluate the performance of the proposed routing approach by applying two-ray and log-normal shadowing propagation models. In addition, PHY DSSS technique was used in this simulation. By using MATLAB environment, the performance in terms of average throughput, delay and PDR is evaluated. Here, cross layer design based on IEEE 802.11p is used. The main simulation parameters of both physical and MAC layers are defined in IEEE 802.11p standard as given in [27, 29]. In this work, two additional design metrics were added to RREQ packets (P_r and SNR). The results showed the effect of increasing the number of vehicles on these three performance metrics as discussed in the coming sections.

4.1 PROBABILISTIC VS DETERMINISTIC MODELS

A comparison between deterministic models and the Log-normal probabilistic model is shown in Figure 2 .This figure shows that the received signal determined using the probabilistic model (log-normal shadowing) has lower values compared to its counterparts. Therefore, log-normal can be considered to be more realistic VANET propagation model.

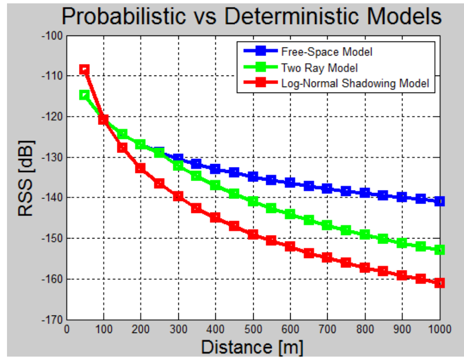

Figure 2. Different Radio Propagation Models

4.2 Packet Delivery Ratio (PDR)

The first performance evaluation was done and measured in term of PDR. This value is calculated by dividing the overall number of packet arrived at destination node (R^p) by the overall packet sent from source nodes (S^p) according to:

$$\mathbf{PDR} = \frac{\sum_{\mathbf{i=no.des}} \mathbf{R_i^p}}{\sum_{\mathbf{i=no.sou}} \mathbf{S_i^p}} \qquad (6)$$

Figure 3 shows the effect of increasing the number of vehicles on PDR for city scenario by applying both propagation models (two-ray and log-normal shadowing). In general view, the PDR values shows unstable behaviour. Firstly, by increasing number of vehicle nodes the PDR is decreased which is normal situation. Secondly, when number of vehicles becomes more than 70, the PDR is decreased due to link failure. After that, when number of nodes becomes 130 the routing path is more stable to deliver information which gives enhancement in PDR. The maximum value of PDR for both models was achieved when number of vehicles was 200 and equals to 99.42%. It can be clearly seen that, the value of PDR is decreased and has influence behaviour due to traffic congestion in city area and the number of collision.

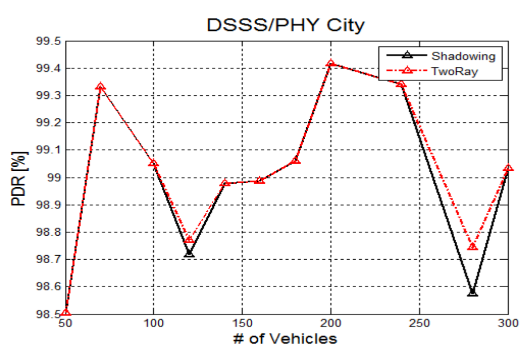

Figure 3. Packet delivery ratio in VANET network for city scenario

4.3 Average Throughput And Delay

This is one of the important and critical parameters that measures the overall network performance. The average throughput $\bar{\gamma}$ in kbps can be calculated as [7]:

$$\bar{\gamma} = \frac{K \sum_{m=1}^{n} R_m^p}{D} \qquad (7)$$

where k is the packet size, R_p no. of received packets and D is the delay. Figure 4 presents the average throughput Mbps versus m number of vehicles nodes for city scenario. It can be clearly seen that, by increasing the traffic density, the throughput is decreased rapidly. Both two propagation models present almost the same behaviour.

The delay represents the time period that needs to route a packet from the source to the desired destination. The delay can be defined as the packets per unit time interval length which depends on PDR value in the network and can be calculated from equation (7).

Similarly as introduced in Figure 5 which shows poor effect is obtained from log-normal shadowing model when traffic density becomes high with maximum value equals to 926.39ms. It can be clearly realized that, the minimum delay values were achieved when number of vehicles is decreased.

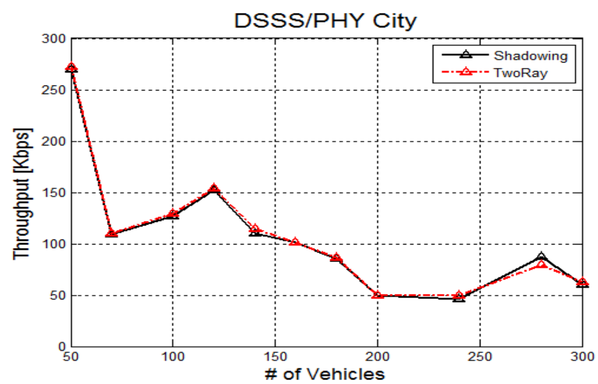

Figure 4. Average Throughput $\bar{\gamma}$ in VANET network for city scenarios

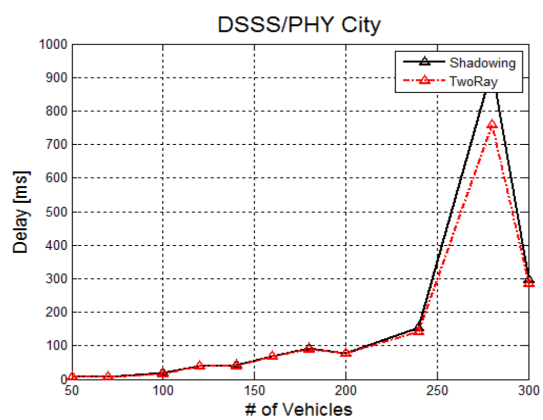

Figure 5. Delay in VANET network for city scenario

5. CONCLUSIONS

Nowadays, ITS industries and academic research communities are interesting to find a solution for many problematic issues in VANET environment applications, technologies and systems. It is crucial to find the suitable approach for routing that can adapt the dynamic topology of VANET environment. The objective of this work is to analyse and evaluate the performance of the proposed cross layer design (CLD) based on IEEE 802.11p by using MATLAB simulation tool. The performance is evaluated and compared in terms of PDR, average throughput and delay. Our goal is to estimate the performance of cross layer routing model for city scenario by using DSSS PYH technique under both two-ray and log-normal shadowing models. The obtained results confirm the best packet delivery ratio for our proposed approach, where it indicates poor quality of DSSS PHY with high number vehicles. The minimum delay achieved when traffic density is decreased.

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