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A Novel Approach: Routing Metric Using Level Crossing Rate for Device-to-Device Communication in a Multipath Fading Environment

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Abstract: In the real world, device-to-device (D2D) communications in ad hoc networks often experience changes in signal quality. The change in path characteristics is caused by the distance and multipath fading between the transmitter and receiver, so that the amplitude and phase of the received signal vary over time. Consequently, the performance of the routing algorithm in determining uncertain communication paths causes a significant decrease in throughput. Therefore, calculating the fading rate and the fading signal frequency, which are below a threshold, becomes imperative. This mechanism is known as the level crossing rate (LCR). Here, we propose LCR as a novel metric model approach for routing in multipath fading environments to determine the communication path. Also, we created a model for estimating throughput based on the LCR. We evaluated and compared the performance of our proposed method to that of a routing model that uses the shortest path algorithm (SPA) and channel quality (CQ) aware routing that employs average signal-to-noise ratio (ASNR) and average power connection (APC) as the metric. The simulation results show that the proposed LCR routing model outperforms another routing model that applies SPA, ASNR, and APC.

Keywords: routing metric, level crossing rate, device-to-device communication, multipath fading.

一种新方法：在多径衰落环境中使用电平交叉速率进行设备到设备通信的路由度量

摘要：在现实世界中，自组织网络中的设备到设备 (D2D) 通信经常会经历信号质量的变化。路径特性的变化是由发射机和接收机之间的距离和多径衰落引起的，从而使接收信号的幅度和相位随时间变化。因此，路由算法在确定不确定通信路径方面的性能会导致吞吐量的显着下降。因此，计算低于阈值的衰落率和衰落信号频率变得势在必行。这种机制被称为水平交叉率 (LCR)。在这里，我们提出 LCR 作为一种新颖的度量模型方法，用于在多径衰落环境中进行路由以确定通信路径。此外，我们创建了一个基于 LCR 估算吞吐量的模型。我们评估并比较了我们提出的方法的性能与使用最短路径算法 (温泉) 和信道质量 (重庆) 感知路由的路由模型的性能，该路由采用平均信噪比 (ASNR) 和平均功率连接（ APC ）作为度量。仿真结果表明，所提出的 LCR 路由模型优于另一个应用温泉、ASNR 和 APC 的路由模型。

关键词：路由度量、平交率、设备到设备通信、多径衰落。

1. Introduction

The device-to-device (D2D) communication link experiences shifting to its link quality due to fading and mobility when it is deployed in a multipath environment. It will worsen the routing performance that uses the shortest path algorithm (SPA), where the selected path with the fewest hops concerns how far the distance between the transmitter and the receiver is. The fading existence will severe the connection and lead the established link to be disconnected. To enhance network performance, a work that used unified analysis has been studied on a fluctuated channel for D2D communication [1]. Another research has

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investigated the analytical approach based on the average probability of outage to estimate the Rayleigh and Nakagami-m propagation model due to the fading period [2]. Following [3] that has studied the D2D communication outage expression, the impact of path loss, co-channel interference, and channel fading parameters are its basis. Under general fading conditions, [4] presented the trade-off and evaluated the D2D network based on spectral efficiency and outage probability. Research in [5] proposed κ - μ fading model as human body shadowing to seek opportunities to improve network capacity and spectral efficiency in cellular D2D communications.

The routing process to find a communication path between the sender and the receiver in D2D communication faces uncertainty in channel quality (CQ), especially in fading channel environments. Therefore, several studies have been conducted to improve routing performance in this matter. In [6], the authors improved the QoS on MANET using a distributed acceptance control protocol quality of service (DACP-QoS) based on a per-hop flow. Another study investigated the performance of routing protocols comprising dynamic MANET on demand (DYMO), dynamic source routing (DSR), and ad hoc on demand distance vector (AODV) routing protocols in a real environment against fading following Rayleigh and Rician propagation with scenario movement and number of users [7]. In the study [8], the performance of DSR was explored using various propagation methods in a severe interference environment. A study of a routing metric based on contention-based forwarding (CBF) that quantifies link stability while considering multipath fading statistics was done in [9]. The performance of the routing protocol applied to the unmanned aerial vehicles Ad Hoc Network, optimizing the parameters of link quality and traffic load by selecting a routing path, was proposed in [10]. The level crossing rate (LCR) indicates how many times the fading level is above a certain threshold. It can be used to characterize the fading severity level in a channel. The average LCR of a received signal enveloped is used to select the diversity of the input signal in the Rayleigh, Rician, and Nakagami-m models [11]. An investigation on a multiple-input multiple-output (MIMO) channel fading output keyhole with the LCR applied in the Nakagami-m model has been explored [12]. Although the development of routing using SPA and CQ metrics, such as signal-to-noise ratio (SNR) and energy or power, can improve network performance in multipath fading environments, there are uncertainties faced in connection quality changes. This will induce the result of packet errors, connection breaks, and degradation of throughput gain. Therefore, in this study, the direct correlation between the LCR effect and the performance of the routing model scheme for D2D communication is examined. A set of formulas to calculate the throughput model following the multipath fading LCR is developed. We also propose a new routing model that uses LCR as the metric to find a communication path and compare its performance with another routing metric model. This will be the basis of a new proposed method that measures the LCR effect as a new parameter for routing path decisions in D2D communication.

This study's structure is as follows. Section 2 describes this research's related works. Section 3 describes the multipath fading environment. Section 4 describes the LCR. Section 5 describes the proposed method. Section 6 presents the results and discussion, and finally, Section 7 concludes with a discussion on future research.

2. Related Work

Proactive and reactive routing protocols that apply SPA face degradation network performance in a multipath fading environment [12]. The CQ aware routing is a method that uses channel quality parameters as routing metrics to improve network performance in D2D communication. [6, 7] used SNR and channel characterization as metrics to manage uncertainty communication path quality. Using the outage probability and the average nonfading as routing metrics by [8, 10] to maintain network performance in fading environments was proposed. The outage probability p_o is the probability that the connection's *SNR* (γ) falls below the reference *SNR* (γ_{th}), $p_o = p(\gamma < \gamma_{th}) = 1 - p(\gamma \geq \gamma_{th})$. Another strategy that uses channel state information for the optimal path selection that reaches the highest trusted-connectivity probability (T-CP) from the D2D transmitter to the receiver by using multiple D2D was examined in [13]. According to [14, 15, 16], spectrum aware routing that uses channel quality, energy or power, and throughput as the metric parameters for considering the in-path search process can improve the network performance.

In [17], a protocol for joint full duplex-aware channel assignment and route selection was introduced; using a dedicated control channel, broadcast route request (RREQ) packets are used to discover a collection of feasible free loop pathways *P* between the communication nodes *S* and *D*, adding its achievable SINRs along with the route information. A routing metric model that evaluates the energy consumption of the links transmitted with or without simultaneous wireless information and power transfer (SWIPT) was introduced in [18]. A link reliability-based adaptive routing algorithm (LRAR) was proposed by [19] to increase the efficiency of transmission; these models select the link with the maximum utility function value of $maxU_i(S)^{w_s^i}xU_i(a)^{w_a^i}xU_i(q)^{w_q^i}$ under the premise of satisfying the constraints of the data transmission links. However, when using channel quality metrics, such as average SNR (ASNR) and average energy or power connection (APC), a routing metric model will still experience uncertainty in each connection quality in a multipath fading environment. Therefore, in this research, we propose using LCR as a routing metric that can dynamically represent the change in the connection quality. The LCR metric is used to route the decision to find a communication path in a multipath fading environment.

3. Multipath Fading

Multipath fading is a propagation model that is utilized to examine the radio transmission channel. It resembles the real signal propagation situation, which contains multiple paths. To observe this event, a few propagation models—the Rician and Rayleigh propagation models—are used to study the distribution occurring at that moment. These models can provide an actual condition for D2D communication, where several factors such as channel fading, topology change, and mobility will affect the network routing performance. We can express the Rician distribution as (1) [20]:

$$p(z)\begin{cases}\frac{z}{\sigma^2}exp\left[-\frac{z^2+A^2}{2\sigma^2}\right]I_0\left(\frac{zA}{\sigma^2}\right) & z \geq 0, A \geq 0 \\ 0 & z < 0\end{cases} \quad (1)$$

The z is the received signal's envelope amplitude, while A^2 is the line of sight (LOS) peak amplitude. The $2\sigma^2$ describes the average multipath power. By applying the 0th order of Bessel function as I_0, in a distribution, the average acceptability can be computed by (2).

$$P_r = \int_0^{\infty} Z^2 p(z)dx = A^2 + 2\sigma^2 \quad (2)$$

The ratio of signal power and non-LOS multipath describes the Rician distribution parameter in fading environment K, as described by (3).

$$K = \frac{A^2}{2\sigma^2} \quad (3)$$

The other model, the Rayleigh propagation model, is addressed to observe radio wave propagation when it encounters an environment that contains multipath only, without LOS condition. It combines received signal level fluctuation due to multipath that can severe or enhance the received signal. Its probability is modeled by (4) [21].

$$p(z)\begin{cases}\frac{z}{\sigma^2}exp\left[\frac{-z^2}{2\sigma^2}\right] & 0 \leq z \leq \infty \\ 0 & z < 0\end{cases} \quad (4)$$

The receiver combines all the received signals from all incoming paths, LOS or non-LOS signals. It produces an agile variation of the received signal, which usually happens on the device-to-device communication link.

4. The Level Crossing Rate

The LCR in lower fade level has a significant effect in multipath fading and is expected to be useful in D2D communication design [22], [23] and the main second-order statistics to deepen the characteristics of wireless communication channels [24], [25]. The crossing rate level is utilized to monitor the channel quality from any changes due to mobility and fading in a certain value. It is used to count how much of the received signal power passes the reference or threshold level. When mobile devices communicate to each other, the frequency of the signal peak level passes the threshold level R defined by the LCR, N_R [26].

$$\text{NR} = .\int_0^{\infty} \dot{r}\, p(R,\dot{r})d\dot{r} \quad (5)$$

The density function of r's joint is described by $p(R,\dot{r})$. Equation (5) can be illustrated as (6) for the Gaussian channel condition.

$$N_R = \sqrt{\frac{\mu_2}{2\pi}}.\frac{R}{\sigma_1^2}\ exp\left(-\frac{R^2}{2\sigma_1^2}\right) \quad (6)$$

Equation (7) is the level of crossover for p, which compares R and the rms point.

$$N_\rho = \sqrt{\frac{\mu_2}{\pi\sigma_1^2}}.\rho\ e^{-\rho^2} \quad (7)$$

where p is calculated by (8).

$$\rho = \frac{R}{\sqrt{2\sigma_1^2}} \quad (8)$$

If μ_2 is the second event of the channel spectrum $S(f)$, it follows the expression as (9).

$$\mu_2 = (2\pi)^2.\frac{\sigma_1^2}{2}\ f_{T1}^2(1+\alpha^2) \quad (9)$$

In addition, the level crossing rate is obtained by using (10) [25].

$$N_\rho = f_T\ \sqrt{2\pi}\ \rho\ e^{-\rho^2}\sqrt{1+\alpha^2} \quad (10)$$

The $\alpha = V_R / V_T$ is the velocity rate comparison element, while V_R describes the receiver velocity rate and V_T describes the transmitter velocity rate. The average signal level comparison between the threshold (r_{tr}) and the received (r_{rms}) is $\rho = r_{tr}/r_{rms}$. The maximum frequency due to the Doppler shift of the sender is $f_T = f_0\, V_T / c$, where f_o represents the transmitting frequency, and c indicates the speed of wave propagation.

5. Proposed Method

To investigate the routing metric using LCR to find the communication path, we proposed throughput and routing algorithm models using CLR.

5.1. Throughput Model based on the LCR

In this section, we developed a throughput model based on LCR. For the D2D network model with 2D of side length, with N uniformly dispersed devices, we can calculate the node density as $\delta = N/(2D)^2$. It is assumed that transmission range T of all the devices is equal to the number of connections and the average number of neighbors, which is $G = \varepsilon\pi T^2 - 1$, then the number of hops per connection that is expected can be obtained by (11).

$$W_c = \frac{D(\sqrt{2}) + ln(\sqrt{2}+1)}{3T} \quad (11)$$

Throughput can be calculated based on the average number of data transmitted during some average interval time. Denote B as the throughput, the duration of time required to transmit the data is $E[T]$, and the average data transmitted is $E[D]$, then,

$$B = \frac{E[D]}{E[T]}. \quad (12)$$

If k is the average of data transferred, and the transmission rate is R, then the total time to send k is k/R. Average propagation time and process time at all devices are t_p and t_a, respectively. We can calculate $E[T]$ by

$$E[T] = \frac{k}{R} + 2\,(t_a + t_p). \quad (13)$$

Routing connection in device-to-device communication consists of several hop connections with an average probability of success transmitting the data P_r. We can rewrite $E[D] = k.P_r$, then we can express the average throughput as

$$B = \frac{k\,P_r}{k + 2\,R\,(t_a + t_p)}\,R. \quad (14)$$

We can use the probability of packet error p to calculate P_r. Based on [27, 28], the packet error in the AWGN channel can be expressed by (15).

$$p = 1 - \left(1 - Q\left(\sqrt{\frac{S}{N}}\right)\right)^n. \quad (15)$$

Finally, from Equations (8), (10), and (15), we can find the correlation between crossing level rate and signal to noise ratio to calculate the throughput performance when the noise is assumed constant as

$$B(N_p) = \frac{\bar{K}\,\prod_{i=1}^{N}\left(1 - Q\left(\frac{\sqrt{2\sigma_1^2}}{N}\right)_i\right)^n}{\bar{K} + 2\,R\,(t_a + t_p)}\,R. \quad (16)$$

and throughput as crossing level rate function is

$$B(N_p) = \frac{\bar{K}\,\prod_{i=1}^{N}\left(1\text{-}Q\left(\left(\sqrt[3]{-\left(R^3/\ln\frac{N_p}{x}\right)}\right)/N_o\right)_i\right)^n}{\bar{K} + 2\,R\,(t_a + t_p)}\,R \quad (17)$$

Based on this throughput model in Equation (17), we proposed a new metric model for the routing process that uses the level crossing rate as a new metric to find the route in D2D communication, especially in a fading environment.

5.2. Routing Algorithm Model Using Level Crossing Rate

In this research, we propose a routing mechanism model using LCR to find the data communication path between the source and destination nodes. This method improves routing performance in D2D communication, especially in a multipath fading environment.

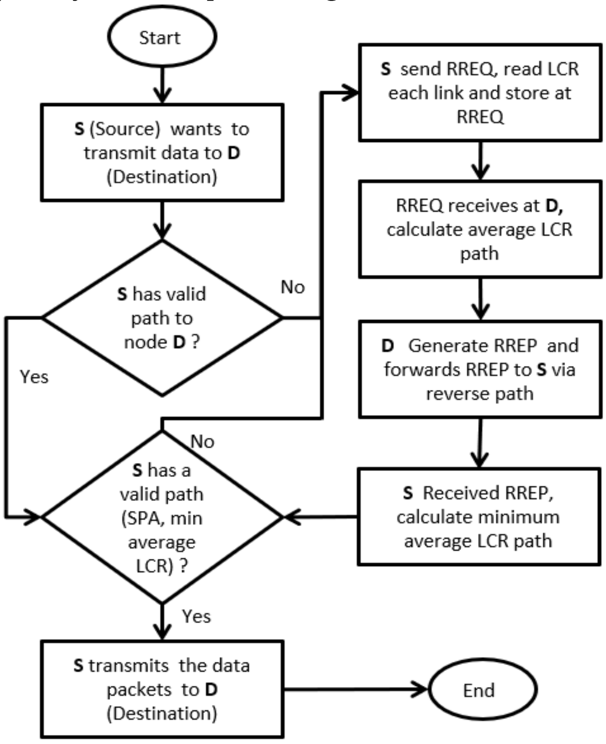

Fig. 1 The proposed routing model with the LCR discovery process

Fig. 1 shows the mechanism routing with the LCR discovery process to find a communication path. When the source wants to transmit the data and does not have valid routes, the route request (RREQ) is generated and broadcast to all available neighbors. Along the way to the destination, the link between the nodes will calculate the LCR and store it in RREQ. After RREQ receives at the destination route reply (RREP) is generated. The node destination will calculate the average LCR path, store it in RREP, and send it to the sender through the reverse path. The source will calculate the minimum average LCR path after receiving RREP. The source could receive multiple RREP from the node destination. The source will transmit the data through the path that has the minimum average CLR and the shortest path. The RREQ and RREP handling in the routing algorithm model with CLR is shown below:

RREQ, RREP routing handling with CLR metric

// RREQ message broadcasting method
Send_RREQ (NodeX)
{SET Sqn#=1, LCR= LCRNode X, Hop_count = 0
BROADCAST RREQ to all Neighbors}

//The RREQ message handling method
Receive_RREQ (RREQ, LCR, NodeX){
IF (NodeX == Destination) UPDATE the Route,
Send_RREP (NodeX, AverageLCR, RREQ)
IF (NodeX ! = Destination) {
*IF (Seq#_req > Seq#_tbl) OR ((Seq#_req==Seq#_tbl) AND (Hop_Count<Hop_*

Count_tbl)) UPDATE, READ LCR, INPUT LCR, FORWARD RREQ, CREATE REVERSE ROUTE (dest=source, nexthop=NodeX, hopcount=X)
ELSE FORWARD RREQ, UPDATE LCR, UPDATE RREQ: Seq#_tbl=Seq#_req,
Hop_Count_tbl=Hop_Count +1}
UPDATE Route, Seq#_tbl = Seq#_req, Hop_Count_tbl= Hop_Count }

// Method for unicast the RREP messages
Send_RREP(NodeX, AverageLCR, RREQ)
{SET Sqn#_rpy = Seq#, LCR=averageLCR, Hop_count_rpy = 0
UNICAST RREP to Neighbors}

// Method for handling the RREP messages
Receive_RREP (RREP, averageLCR, NodeX)
{IF (NodeX == Source) UPDATE Route, COUNT Avrg LCR, DATA
IF RREP > 1, min Avrg LCR, DATA
IF (Node X ! = Destination) {
IF (Seq#_rpy > Seq#_tbl) OR ((Seq#_rpy==Seq#_tbl) AND (Hop_Count_rpy < Hop_Count_tbl) UPDATE, READ LCR, INPUT LCR, FORWARD the RREP
ELSE FORWARD the RREP, UPDATE the RREP: Seq#_tbl = Seq#_rpy, Hop_Count_tbl = Hop_Count +1}
UPDATE the Route, Seq#_tbl = Seq#_rpy, Hop_Count_tbl= Hop_Count_rpy}

The LCR will be calculated at the physical layer and read when a node receives an RREQ. If the recipient of the RREQ is an intermediate node, the LCR value will be stored in the RREQ; then, it will create a reverse path and rebroadcasts to the next node until it arrives at the destination. The reverse path that is formed will be used for sending RREP from the destination.

6. Results and Discussion

In this paper, the simulations have investigated the proposed method and the influence of the level crossing rate on D2D communication network performance. Thus, the node density is expressed as $\delta = N/(2D)^2$. Network devices obtain the same transmission length of T. The number of hops targeted at each connection is calculated according to equation (11).

According to [29-30], the WIFI coverage capability is up to 200 m, so that it strongly supports D2D network coverage. In this study, we determined the transmission length of T to be 200 m and the side area of D to be 1000 m. 512-byte data packets are used, with 40 packets per second for the transmission rate. The Doppler frequency is set at $f_0 = 2.4$ GHz with $c = 3 \times 10^8$. All nodes in the network are given constant additive white Gaussian noise (AWGN). The effect of the difference in the number of hops representing the path length in a D2D connection is analyzed in the routing scheme. In addition, we also simulate different transmission rate, such as $R1 = 3000$ packet/s, $R2 = 5000$ packets/s, and $R3 = 7000$ packet/s and the source device velocity include: $V_{t1} = 10$ m/s, $V_{t2} = 15$ m/s, and $V_{t3} = 20$ m/s. We simulated SNR thresholds at 5 dB, 10 dB, and 15 dB for the LCR scenario.

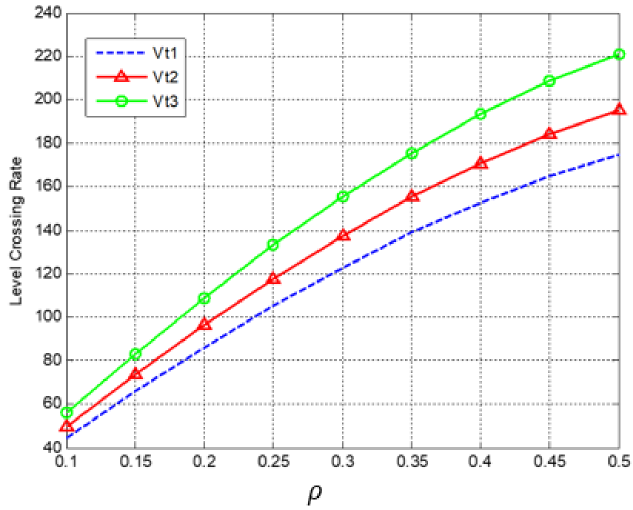

Fig. 2 The LCR with ρ connection and node velocity $V_{t1} = 10$ m/s, $V_{t2} = 15$ m/s, $V_{t3} = 20$ m/s

Fig. 2 shows the correlation level crossing rate ρ between (r_{tr}) and (r_{trrms}). The connection quality will deteriorate when the ρ value increases along with LCR. The node velocity movement will increase the LCR and make the connection face quality channel degradation. The value of LCR shows the dynamical channel quality connection.

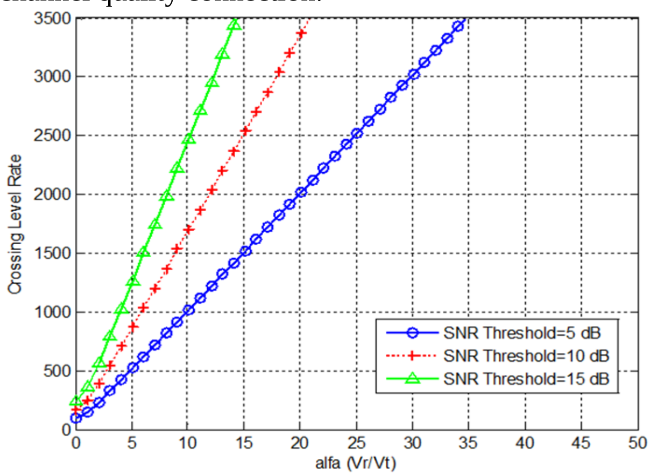

Fig. 3 Crossing level rate with speed ratio and SNR threshold

In D2D mobile communication, the velocity ratio between the moving receiver and the sender causes the doppler effect and influences the level crossing rate number, as shown in Fig. 3. Lower SNR threshold can reduce the level crossing rate in a higher ratio of velocity between the moving receiver and the sender. In [31], the level crossing rate has correlation with outage probability P_{out_k}. The expression of LCR and the outage probability is given by (18).

$$N(\sigma_{th}, s_{th}) = \sum_{l=1}^{L} N_l(\sigma_{th}, s_{th}) x \prod_{\substack{k=1 \\ K\neq l}}^{L} [1 - P_{out_k}(\sigma_{th}, s_{th})] \quad (18)$$

where $N(\sigma_{th}, s_{th})$ is the LCR of the lth hop link in fading environment. The outage probability is the probability that the connection's SNR drops under the reference SNR signal or SNR threshold. When the outage occurs, the connection is disconnected. We can see that small LCR will produce higher SNR connections with less outage probability. However, a lower SNR threshold can reduce the standard requirement for the quality of device connection. Higher SNR threshold for high standard quality connection need leads to a higher power level in the device connection. The higher-level crossing rate indicates the reduction of the quality of connection with higher probability of error. The connection with low level crossing rate can gain a more stable connection.

The result of the throughput with level crossing rate and transmission rate is present in Fig. 4. The simulation result shows the impact of the number of LCR to the routing connection performance. Increasing the number of LCR in device connection will decrease the network throughput. The results of this simulation are in accordance with equation (17) and shows that LCR as a routing metric is an important factor in improving network performance.

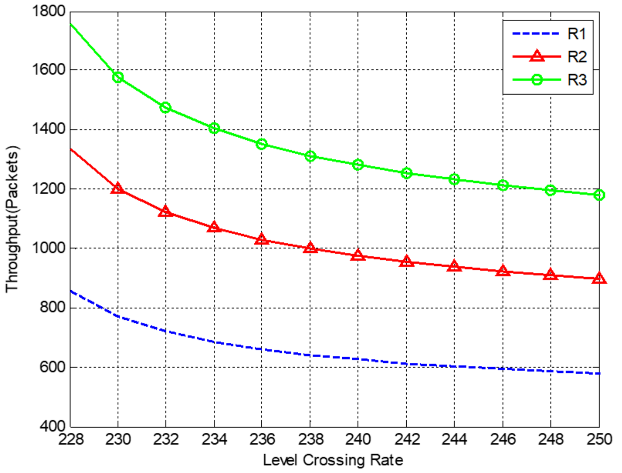

Fig. 4 Throughput with level crossing rate and transmission rate

Based on equation (17) we can increase throughput performance if we maintain the path that has an average minimum level crossing rate. In this research we propose the routing process that uses the LCR as the new metric routing model. The proposed method combines the shortest path algorithm that chooses the path based on the minimum hop and the average minimum LCR as the metric to select the route. We have simulated and compared our proposed routing method model, which used LCR as the routing metric, with SPA routing models and channel quality routing models that apply ASNR and average power connection (APC) as the parameter routing metric.

Fig. 5 shows the throughput of the proposed routing model with the LCR metric, SPA model, ASNR and APC models. With higher throughput performance, the proposed routing model with the LCR metric outperforms and can gain advantages over the other models. With a lower LCR the connection is more stable and the probability of error and path breaks is decreased. The number of hops represents the length of the path and, based on (17) and (18), the probability of error, path break and outage probability will increase as the number of hops increases. The results of this simulation are in line with the mathematical model of the effect of node speed on the length of a path connection formed by [32]. In this model, the length of the path connection duration (μ) depends on the transmission distance (τ), the number of hops (h) and the node speed (V). If the node mobilization model parameter is used, then the average path connection duration can be modeled as:

$$\mu = \frac{1}{\sigma} = \frac{\tau}{\sigma_0 hV},$$

where σ_0 is proportionally constant and independent of the values of h and V. Increasing the number of hops will reduce the length of the path connection duration.

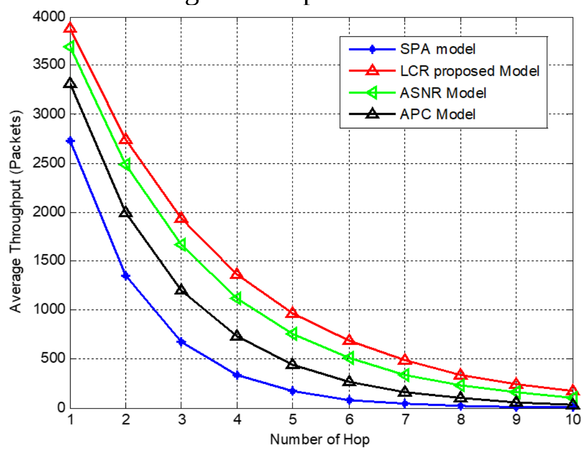

Fig. 5 Throughput of LCR proposed model, SPA model, ASNR, and APC model in the number of hops scenarios

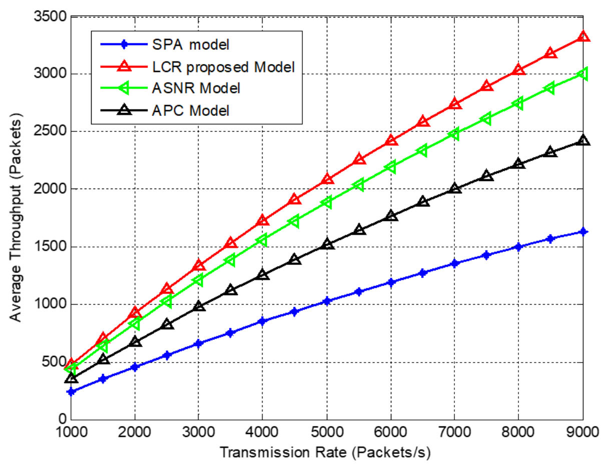

Fig. 6 Throughput of LCR proposed model, SPA model, ASNR, and APC model in the transmission rate scenarios

Fig. 6 shows the throughput of the proposed LCR routing model, SPA routing model, ASNR and APC routing models in transmission rate scenarios. The proposed routing model outperforms the other models and can gain advantages with higher throughput performance. The results of this simulation are in accordance with equations (14) and (16).

7. Conclusion

The impact of the LCR on the quality and performance of D2D communication routing connections has been investigated. The low-level routing connection can be indicated with their LCR that reaches a high value. It may decrease the performance of the network as well. The factors causing such a network to occur are the existence of the multipath fading, and the mobility of the object in the observed environment. The LCR is determined by two notable keys: The threshold signal level and the SNR connection distribution. In this paper, a new parameter for D2D communication routing is proposed. Through use of the throughput model, we show the correlation between the LCR and the throughput network performance. We proposed the LCR as the new metric approach model to find routes in D2D communication. The simulation results show that our proposed model outperforms the routing model that used SPA, ASNR and APC as routing metrics. The investigation of the LCR routing metric complexity and the influence of various propagation models in a broad environment (such as in 5G, outer space, underwater, etc.) can be considered for future research.

Acknowledgments

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