Reliable Collaborative Semi-infrastructure Vehicle-to-Vehicle Communication for Local File Sharing

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Abstract. Recently, Vehicular Cloud Communication (VCC) has been gaining momentum targeting intelligent and efficient data transmission. VCC is a type of mobile ad-hoc network comprising heterogeneous vehicles sharing their resources to perform collaborative activities. In this paper, we propose a new semi-infrastructure file-browsing in order to provide Network as a service (NaaS) enabling internet-independent browsing. In our scenario, a central management platform plays the role of controlling and managing the selection of relaying vehicles supporting the source to destination file transmission procedure. Nagel-Schreckenberg rules for traffic cellular automata (CA) are used as the basis for our scenario simulation. Nagel-Schreckenberg rules simulate the behavior of a group of hypothetical vehicles moving across a highway. We study the reliability and efficiency of file transfer in such settings. Simulation results show that the number of selected relays required to establish the network highly impacts the probability of successfully sending the requested files. In addition, the distances between the selected relays influence the network throughput and the probability of network failure. Moreover, the density of relays strongly affects the overall delay that occurs due to the continuous re-transmission of the selected files among different hops.

Keywords: Vehicular Cloud Communication (VCC) · Nagel-Schreckenberg rules · Network as a service (NaaS) · Collaborative file sharing

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1 Introduction

In the last few decades, substantial resources have been added to vehicles, including computational power, sensing capabilities, and data storage and analytics [1]. Currently, vehicle resources are underutilized, due, in part, to limited service and resource management models [2]. Recently, Vehicular Cloud Communications (VCC) has received significant attention as a host for various infotainment services [3]. Vehicles can communicate with other vehicles directly forming vehicle-to-vehicle communication (V2V) model, or communicate with fixed equipment next to the road, referred to as Road Side Unit (RSU) forming vehicle to infrastructure communication (V2I) model [4, 5]. Nowadays, there are many vehicle-to-vehicle (V2V) applications such as emergency braking, velocity adjustment to avoid accidents, effective transportation to avoid passage congestion, hazardous location notifications transmitted to the road/side station [6–8].

Apparently, the growth of population and the increase of traffic issues made people spend more time on the road. Browsing new files, videos, do some research, or even read articles might be a good way to expend the time on the road. However, the continuous usage of the mobile internet for browsing purposes might cost a lot, and sometimes cause higher data congestion which influences the speed of data transfer. From this context, we propose a novel local-communication-based browsing as a service for enabling internet-independent browsing among moving vehicles.

The paper is proposing an idea for Network as a Service (NaaS), that utilizes the VANETs concept to provide an entertainment services for the passengers on highways that may stay on the road for several hours with limited access to the cellular network like (4G). For simplicity the proposed scenario and the presented results, we consider a hypothetical idea using emulator. In the future extensions we will address the same scenario with real data representing actual traffic.

In this scenario, we assume a group of vehicles are moving across a long highway and have plenty of time for browsing files. The proposed approach depends on constructing network via a hierarchical management framework in order to provide data routing for multi-hops V2V communications. Our approach adopts the concept of data Storage for browsing as a Service, where the mobile communicating networked vehicles maintain different types of data that might be requested by other vehicles at real time. Therefore, there is a tremendous need in such networking environment to locate and construct reliable paths to fulfil the requests in a timely manner.

For simulation purposes, we assume a group of vehicles moving across a two lanes highway. Nagel-Schreckenberg traffic flow model for Cellular Automata (CA) is used. Nagel-Schreckenberg model is a well-known model investigates some features commonly found in real traffic problems, such as the transition between free flow and a jammed state, and shocks (due to driver overreaction) [10, 11]. By applying Nagel-Schreckenberg rules, velocities and positions of these hypothetical vehicles are calculated and updated frequently without any crashing across the simulated highway.

The proposed scenario exploits a cloud management platform, which plays the role of establishing a multi-hop network from the surrounding vehicles that act as communication relays/hops. These vehicular relays are responsible for delivering the requested file from the source vehicle to the destination of the requester vehicle.

The numbers and positions of theses selected relays are highly influencing the network and the probability of successfully receiving the requested files. Consequently, the cloud management platform should determine carefully which relays could be used for establishing the vehicular network. The appropriate selection of these relays reduces the number of hops, which definitely minimizes the chance of networking failure.

Therefore, our main contributions in this paper can be summarized as follows:

- A novel localized file sharing model on a vehicular cloud management platform exploiting semi-infrastructure V2V communication and vehicular resources; and
- Autonomous Cellular Automata (CA) model based on ad-hoc multi-hop V2V network guided by real-time dynamic vehicle location updates.

The paper organization is as follows. Section 2 illustrates the proposed semi-infrastructure system model and the networking strategy for the local offline browsing scenario. Section 3 describes the vehicular traffic flow model and the suggested methods for selecting the routing path. Section 4 presents the obtained numerical results that illustrate the influence of relay selection on the system. Finally, the paper concludes in Sect. 5.

2 V2V Communication Framework for Local WiFi-Based File-Sharing

The proposed system is composed of a user side mobile application, a cloud backend or management cloud platform, and the vehicle computational and storage device, which is assumed to be raspberry PIs controllers. In the presented scenario, we implement a mobile application to enable users traveling on the road to access the proposed offline browsing VCC service. The proposed system aims to limit the internet access for cost reduction purposes. Therefore, the internet access would be for management purposes only which are sending the request to browse and receiving the list of available file only. All heavy computations and data transfer are done locally over WiFi under the control of a cloud management platform. The aforementioned application continuously registers the user GPS location, and the available list of files for sharing. The expected amount of traffic involved in such updates is no more than a few bytes and can be neglected if compared to the heavy file transfer traffic conducted over WiFi.

We assume that all travelling vehicles are capable of bidirectional transmission and will participate in the proposed network. Further, we assume a semi-infrastructure less network, so relying on the RSU is only considered for network construction only. Cloud connection are established through RSUs to handle network management traffic only. Heavy traffic is transmitted directly between travelling cars.

Our scenario starts when one of the registered users requests to browse the list of available files on the road. The requester application sends a notification to the cloud management application on the backend. Once received, the management system selects all files available for sharing only from the vehicles within reasonable communication range to the requester. Once received, the requester will have a fixed amount of time to select the files to be downloaded. Once selected, the management system starts to select the list of vehicles that will participate as relays to construct the network between the requester and the source file vehicles. This process is depicted in details in Fig. 1. Each of these vehicles will receive a directed connection establishment instruction defining his role in the connection process between source file and the requester vehicles. The management system will monitor the connection for any interruptions or connection termination signal. In the case of connection interruption, the entire process will be repeated.

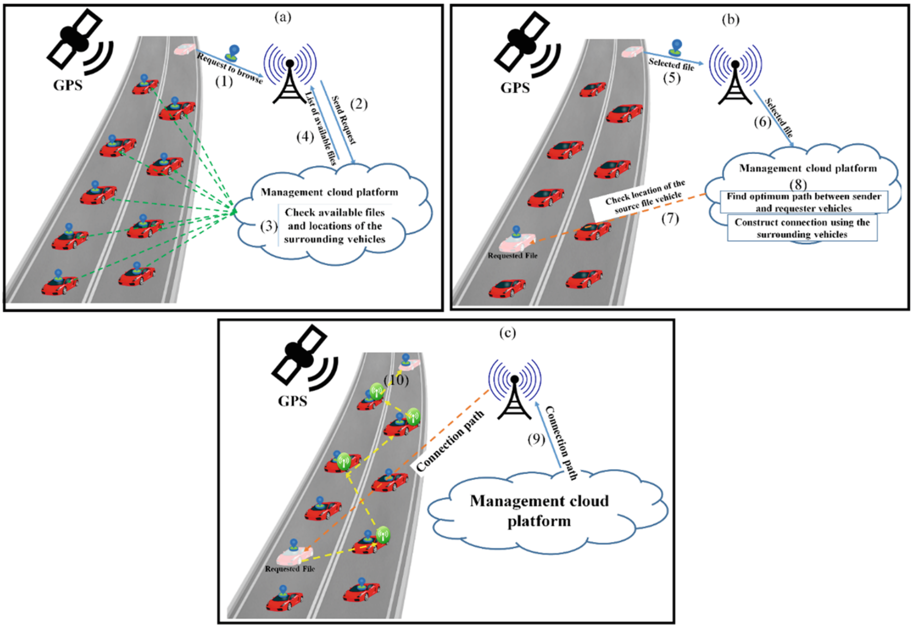

Fig. 1. Communication Network Architecture for Reliable V2V Communication

2.1 Networking Strategy

As mentioned before, the proposed system consists of a set of vehicles equipped with Raspberry PIs controllers with WiFi 802.11p modules enabling wireless communication. The hierarchical management framework in our approach consists of two main levels, which are a set of Road Side Units (RSUs) or cellular service providers and the management cloud platform. Each RSU serves a certain number of vehicles at a section of the highway. The storage capacity and the types of stored data are two related attributes defined at the cloud management side. The data communication in the proposed scenario depends on bidirectional wireless communication technologies. For communication between vehicles and RSUs and between RSUs and the cloud platform, WiFi protocols are used. While, the network topology in this scenario is defined as a linear multi-hop network that comprises a set of vehicles to form a multi-hop V2V data communication path between the sender (S) and requester (R) vehicles. The communication between vehicles can be established within the communication range defined by the IEEE 802.11p.

At the beginning, all of the online vehicles on the road send their information including their positions, velocities, and any of the required data to the cloud platform through the nearby RSUs. For the browsing process, users desire to browse send requests to browse via their mobile application to the nearby RSUs, which directly forward these notifications to the cloud management platform. After that, the cloud replies with the available files during the requested time slot. After that users send the cloud again when they choose the data files according to their preferences within the available list of files. Then, the cloud performs some calculations to determine the possible paths to fulfill all the requests sent by the vehicles. Accordingly, the cloud will send RSUs all of these recommended paths to begin establishing and monitoring the file-sharing network.

3 System Model

3.1 Vehicular Traffic Flow Cellular Automata Model

The used simulation model describes a group of vehicles moving on a highway, composed of two crossable lanes. Vehicles behavior across the road including their updated velocities and positions are calculated using a modified version of Nagel-Schreckenberg traffic flow model. The simulated road is assumed to be with length (L) cells. Each cell in that hypothetical road is equivalent to 2 m length, and is occupied by either zero, or one that represents the vehicle existence at different time instants. The model constrains that the vehicles velocity can't exceed a specified maximum velocity (Vmax). During the simulation, any vehicle (i) in the road is defined by its position (Xi) and current velocity (Vi). The empty sites in front of the ith vehicle; i.e. gap between any two consecutive vehicles is denoted by di (t) = Xi + 1 − Xi – 1 [10]. The movement of vehicle (i) from time step t to t + 1 is then defined by Nagel-Schreckenberg model four rules as follow:

$$\textbf{Acceleration: } V_i(t) = \min(V_i(t) + 1, V_{max}) \tag{1}$$

$$\textbf{Deceleration: } V_i(t) = \min(d_i(t), V_i(t)) \tag{2}$$

$$\textbf{Randomized barking probability (p): } V_i(t+1) = \max(V_i(t) - 1, 0) \tag{3}$$

$$\textbf{Movement: } X_i(t+1) = X_i(t) + V_i(t+1) \tag{4}$$

At each discrete time step t → t + 1, both the position, and velocities of all the vehicles must be updated.

During the vehicles journey across the road, they might change their location from one lane to the other. The rules for updating the vehicles location with respect to the road lanes is as follows [12]:

$$\textbf{Incentive criterion: } d_i < \min(V_i + 1, V_{max}) \tag{5}$$

$$\textbf{Safety constraints: } d_{pred} > d_i \tag{6}$$

$$d_{succ} > d_{safe} \tag{7}$$

where dpred and dsucc are the gaps between the targeted vehicle (i) and the preceding vehicle and the succeeding vehicle in the target lane respectively; and dsafe is the maximum possible gap of the preceding and succeeding vehicles in the target lane. Figure 2, shows a detailed flow chart of the described traffic flow model.

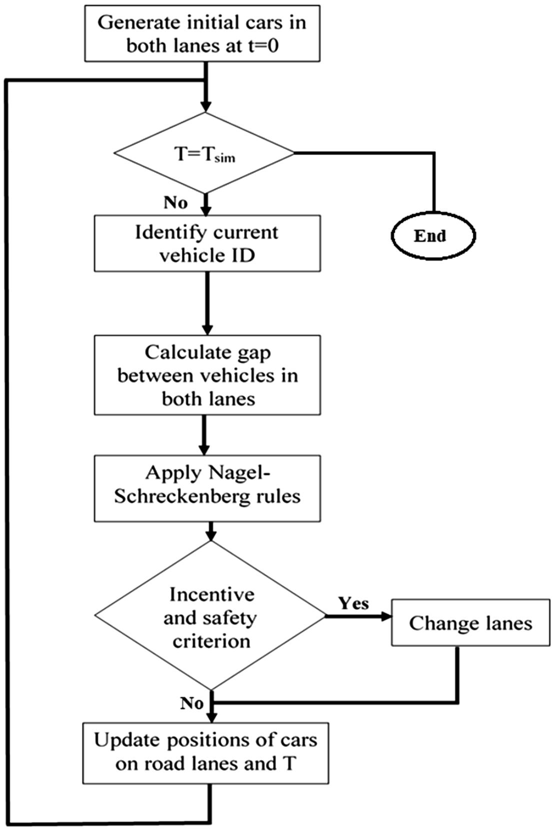

Fig. 2. Proposed traffic flow model flow chart

3.2 Path Selection Mechanism

When a certain vehicle sends a request to browse to the cloud, it starts connecting the requester vehicle (R) to the source-file vehicle (S). In case of the long distances between S and R, the network will use the surrounding vehicles to act as vehicular communication relays/hops. In our simulation model, we assume that all the surrounding vehicles around both S and R are valid online vehicles and can act as communication relays at any time.

Nevertheless, the main issue depends on what is the most appropriate vehicle to act as a communication relay/hop. The main factor affects selecting the best relay is the position of those vehicles from each other. If the selection process depends on minimizing the distance link between each relay, this might result in the usage of several communication hops, leading to increase the overall system transfer delay with slow communication.

On the other hand, selecting the vehicles positions that lead to maximize the communication link between each hop, leads to increase the Signal-Noise Ratio SNR which causes a huge reduction in the total received power and increases significantly the probabilities of occurring errors. This concludes that there must be a tradeoff between number of communication hops and the distance between every hop for successfully files transfer. Therefore, selecting the best positioned vehicles acting as relays could help in strengthen the communication between both sender and requester vehicles while using few number of hops.

In this paper we propose an initial scenario that illustrates a simple mechanism for selecting the most appropriate vehicles that can act as communication vehicular relays. All the possible relays surrounding the one that contains the file at this time instance are assumed to be valid candidates. The constrain in this assumption is related to the distance of the link between the current relay that received the file and all of the suggested valid candidates for the next transmission hop. This distance must be within the acceptable wireless communication range; i.e. cannot exceed 150 m. The relay that exists in an average distance relative to the others will be considered as the best selected one for the current transmission hop (event).

4 Evaluation

This section demonstrates our simulation results. The numerical calculations focus on the selection of most appropriate paths to ensure reliable communication between vehicles during sharing the requested files. Tables 1 shows the detailed parameters used in the Nagel-Schreckenberg model.

Table 1. Table captions should be placed above the tables.

Parameters	Value
Road length (L)	1000 cells
Maximum car velocity (Vmax)	~6 cells/iteration
Probability of parking (P)	0.6
Simulation total time	500 iteration

Our numerical results obtained for the vehicles moving across a two lanes road. The cloud start selecting all the possible paths between the source and requester vehicles, then determine the optimal routing path between them. As per the number of lanes increase, the number of existing vehicle increase leading to increase the possibilities of finding paths.

The proposed model estimates the total road capacity per each iteration. From this information, we can determine the expected computational power within the whole road at any time instant as shown in Fig. 3. As mentioned before, we assume that every vehicle on the road to be equipped with a low power controller like Raspberry Pi that is responsible for controlling the network. Therefore, in this scenario we can exploit such controllers for performing small tasks or controlling the traffic among the vehicles.

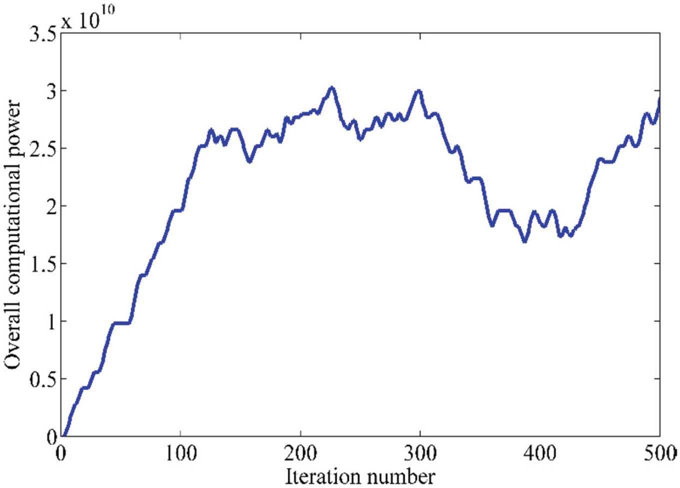

Fig. 3. Total computational power per iteration

Generally, it is well known that wireless transmission across different distances highly influences the received signal power. In fact, the relation between the received power and the transmission distance link is inversely proportional as shown in Fig. 4. The received power is exponentially reduced with increasing the transmission link between the sender and receiver. This depicts that reducing the transmission distances is better for power constrained devices.

Figure 5 depicts the influence of increasing the communication hops on the probability of successful file reception in our assumed model. This figure shows that under different circumstances of the transmission media which increases the probability of error per each link, the probability of successful transmission is highly reduced with the increase of number of hops. This concludes constructing a network using high number of hops increases the probability of networking failure, thus losing the communication between vehicles.

Moving to our proposed scenario, as mentioned previously, there is a cloud management platform, which is responsible for managing the networking between the source file vehicle S and requester vehicle R using the surrounding relays. We assume that the request to browse signal is sent to the cloud management platform from the first vehicle in the road at a certain iteration. In order to study the effect of sending files over large distances, we assume that the source file vehicle is located at end of this road.

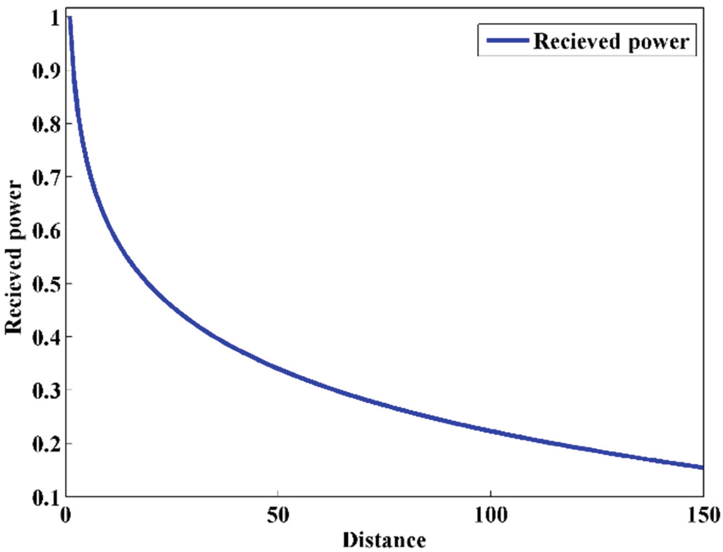

Fig. 4. General received power over different distances

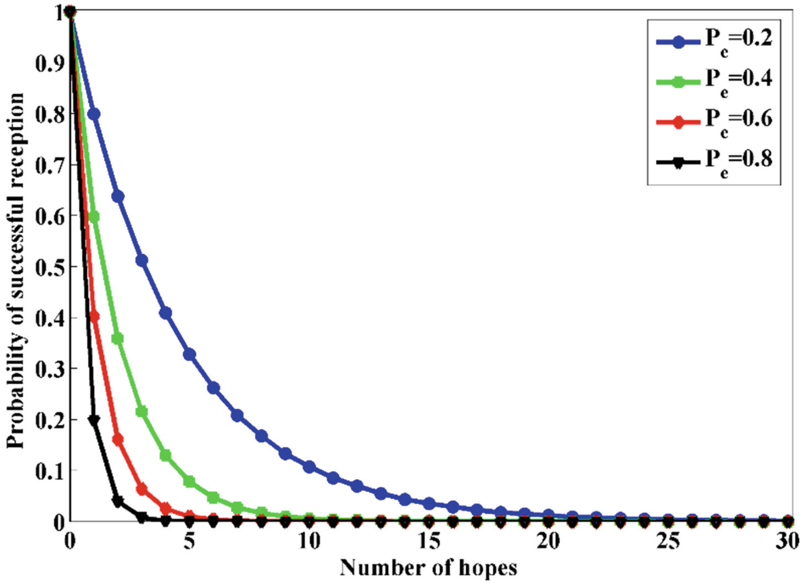

Fig. 5. Probability of successful reception versus number of communication hops

Using the previous assumption, the distance between both vehicles is found to be very long that the file cannot be sent directly. Therefore, the cloud management platform starts selecting the communication relays from the surrounding vehicles to establish the multi-hop network. Figure 6 shows three cases for the relay selection between both the requester R and sender S vehicles.

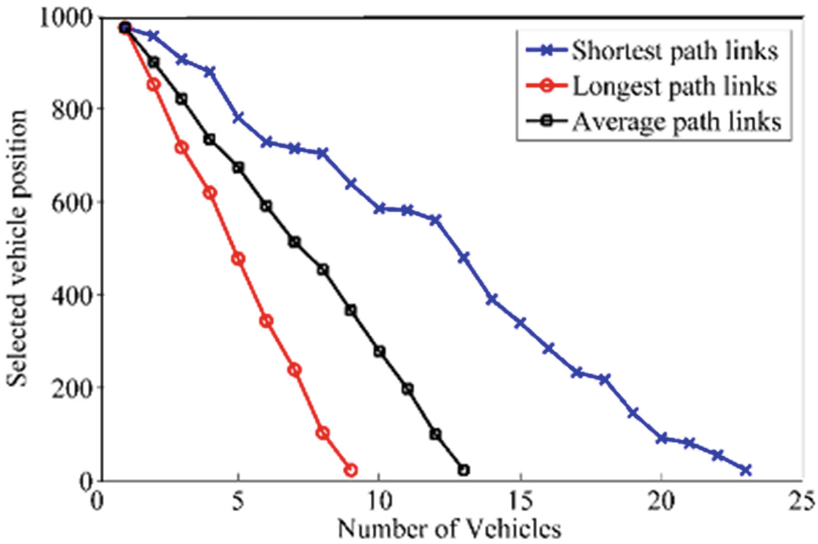

Fig. 6. Selected paths between S and R vehicles

The first case studies selecting the nearest relays from each other to reach the shortest possible link between every two consecutive relays. Minimizing the distance between the selected relays guarantees transferring higher signal power, therefore a reliable communication. However, the simulation results in this case, shows that it requires around 21 relay at different iterations to establish the required network between S and R. Despite the high throughput that can be reached in this case, the probability of transmitting the sharable file between S and R successfully is reduced as discussed before in Fig. 5.

Meanwhile, using few vehicles to share the file between the same S and R may lead to send the file at relatively longer distances. In the second case study, the selected relays between S and R are picked based on the maximum achievable distance link between the relays without exceeding 150 m before the received signal power depletes. As shown in Fig. 6, selecting relays between R and S located at relatively long distances from each other results in reducing the number of the needed hops to be only 7 relays. Reducing number of relays results in increasing the distance link between each relay, therefore the average received power of the file is highly reduced leading to increase the probability of error, as illustrated before in Fig. 5.

The above studied cases show that there is a tradeoff between number of selected relays and their positions from each other. For the best relays selection, the aforementioned algorithm in Sect. 3 is used. Selecting vehicles located in average distances from each other, achieves constructing the required network using less number of relays located in moderated distance from each relay. Figure 6, shows that about 11 relays could be used for establishing this optimum path between the same R and S studied in the other two cases. Table 2, shows number of required vehicles and average distance between relays for the mentioned three cases which are shortest, longest, and optimum paths. Moreover, it is found that the total delay added to the original file transferring time between both S and R, depends highly on the number of used relays in the network as shown in Table 2. We assume that every relay selected required a delayed time for re-transmitting the received file to the next node. Based on the simulation results, it's found that the first case which is the shortest link path required around 44 ms extra delay added to the overall transmission time due to the usage of large numbers of vehicles as relays. While this delay time is reduced in case of using less relays for constructing the network between both S and R vehicles.

Table 2. Comparison between the studied three cases for selecting the communication relays between S and R vehicles.

Case	Number of hops	Overall delay (ms)
Shortest path	21	44
Longest path	7	8.4
Optimal path	11	14.4

Projecting the mentioned issues across the network, Figs. 8 and 9 show how the variation of the relays number affects both the throughput and increases the probability of error per links. Throughput or network throughput is the rate of successful message delivery over a communication channel. These messages belong to be delivered over a physical or logical link, or it can pass through a certain network node. Throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second (p/s or pps) or data packets per time slot.

Simply, throughput is the average rate of successful message delivery over a communication channel. It is a measure of how many units of information a system can process in a given amount of time. It is applied broadly to systems ranging from various aspects of computer and network systems to organizations. The system throughput or aggregate throughput is the calculated by adding the data rates that are delivered to all nodes in a network. However, the throughput of a communication system may be affected by various factors, including the available processing power of the system components the speed with which some specific workload can be completed, and response time between a single interactive user request, receipt of the response, and the distance between the transmitter nodes.

Figure 7 presents the throughput in case of differently selected relays of our system model with respect to the signal to noise ratio (SNR). It is clearly shown that the throughput of the short selected path is the highest one compared with either the long or the optimal paths. As shown in Fig. 6, the shortest link path includes multi-vehicle relays, thereof the link reliability increased which guarantee that the data arrived correctly to the destination. On the other hand, the long path includes less number of vehicles, which means that the distance between each node is higher than the distances between nodes in the shortest one. As the distance increase the throughput decrease and the probability of error increased too. Consequently, optimizing the number of the used vehicles with respect to the distances between each relay results in aggregating the maximum achievable throughput.

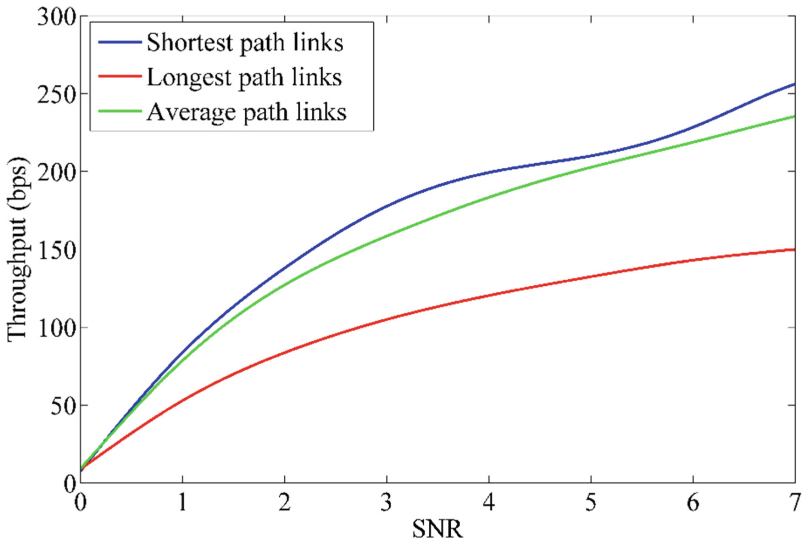

Fig. 7. Throughput Vs SNR

As mentioned in the previous section, if the actual throughput was less than the expected amount, therefore the network is effected and there is higher probability that the requested file fail to reach the destination correctly. Figure 8 shows the probability of error for the available three paths with respect to different hops invariant signal to noise ratio values. As the number of hops increases the reliability of the system increase, then the immunity to prevent errors occurrence increase too, therefore the probability of error decreases. That's why, the longest path suffers from the highest probability of error and the shortest path have an advantage of increasing the ratio of the corrected data reach to its destination node. From this context, our optimized path has an acceptable probability of error with low complexity of multi-vehicle relays.

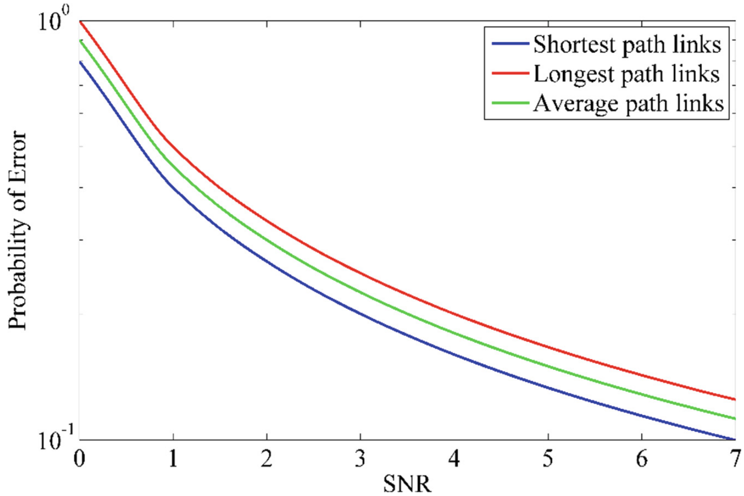

Fig. 8. Probability of error per each link for the three studied cases

5 Conclusion

This paper proposed a browsing as a service scenario for localized offline file sharing using V2V communication. The purpose of this novel service is to provide the users quick and reliable local file browsing using vehicular cloud communication. We assumed that the vehicles are passing across a highway, sharing files using multi-hop networks. The communication between the requester and source file vehicles is controlled by a cloud management platform. The cloud management platform manages the network establishment using the surrounding vehicles as communication relays.

Nagel-Schreckenberg rules for traffic cellular automata (CA) models were used to calculate the location and the velocity of a group of hypothetical simulated vehicles across a two-lane highway. The numerical results show that there is a tradeoff between the number of the selected communication relays and distance between relays. Using a moderated number of relays located in suitable positions on the road enhances the process of the file transmission. A simple technique is used to optimize the number of used communication hops to ensure reliable communication with lower probability of network failure, higher throughput and acceptable file transmission delay.

The recommendation for future work is to use machine learning techniques for predicting the best relays for the “near” optimum paths to reduce cloud management overhead.

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