# Performance estimation of direct and indirect transmission in V2X communications

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*Abstract*—**In this paper, we evaluate the performance of a vehicular ad hoc network that enables Vehicle-to-Everything (V2X) communication considering direct and indirect packet transmission. As a performance indicator, we use the blocking probability due to the unavailability of resources. For the blocking probability calculation, we utilize two loss models from the teletraffic theory. The results demonstrate that both the capacity of the V2X links and the number of hops in the multi-hop transmission significantly affect the blocking probability of a request for service and consequently the QoS.**

***Keywords—V2X, VANET, loss models, single-hop transmission, multi-hop transmission***

## I. INTRODUCTION

The standardization and implementation of the 5th generation (5G) of wireless networks has set the ground for providing higher data rates, lower latency, improved reliability and higher connectivity between the mobile users and the network infrastructure. In the next decade, the evolution of telecommunication networks towards the 6th generation (6G) will bring a new era of services in which the majority of humans will interact with a massive number of connected devices by processing and communicating information [1],[2]. The automotive industry will be majorly impacted by 6G, and it is expected to revolutionize vehicular technologies and improve the users' safety and quality of experience (QoE) [3].

The integration of the advances in vehicular technologies with the corresponding progress in the field of telecommunication systems has paved the way for Intelligent Transportation Systems (ITSs) and for realizing the concept of vehicular communications and autonomous driving. In particular, recent telecommunication research aims to evolve vehicular systems into smart and autonomous systems by giving them the capability to communicate and intelligently exchange useful information with other entities about their surrounding environment. Towards this direction, the field of the Vehicle-to-Everything (V2X) communication technologies has been developed. V2X technologies aim to interconnect vehicles with other entities, e.g. traffic lights, in order to provide improved safety, higher levels of vehicle automation, and to reduce traffic congestion and emissions in an eco-friendly way [4].

Fifth Generation Automotive Association (5GAA) and the Third Generation Partnership Project (3GPP) have distinguished various categories that the V2X applications and use cases belong and that could be supported by 5G: Safety, Convenience, Vehicles operations management, Autonomous driving, Traffic efficiency and environmental friendliness, Platooning, Society and community [4]. These V2X use cases have different requirements like bandwidth, security, latency, etc., and for this reason, accurate performance evaluation is mandated to ensure a sufficient quality of service (QoS) management design in each use case. The performance evaluation of a vehicular network that enables V2X communication constitutes an issue that concerns academia [5]-[10]. At greater length, the authors of [5]-[8] utilize queueing models from the teletraffic theory in order to evaluate the performance of a vehicular ad hoc network (VANET) where V2X communication is enabled and the requests for service are generated by a huge number of sources. In the same manner, in [9], [10] queueing models from the teletraffic theory are employed in order to assess the performance of a VANET that supports requests generated by a finite number of users. However, the abovementioned works focus on evaluating vehicular systems that serve applications and services with similar features and requirements.

In this work, to address this issue, we aim to evaluate the performance of a VANET that enables V2X communication and supports different types of applications and services. For this reason, we exploit multi-rate models from the teletraffic theory in order to calculate the probability that a request for service gets rejected due to the unavailability of resources.

## II. SYSTEM UNDER STUDY

The different kinds of V2X communications that are enabled by a VANET are vehicle-to-vehicle (V2V) communication, vehicle-to-network (V2N) communication, vehicle-to-infrastructure (V2I) communication and vehicle-to-pedestrian (V2P) communication [3]. V2V communication enables the information exchange between the vehicles while V2P communication is conducted between the vehicles and the smart devices belonging to pedestrians. On the other hand, the V2N and the V2I types of communication focus on the information exchange between the vehicles and the system fixed infrastructure such as e.g. the core network in the V2N communication or e.g. the traffic lights in the V2I communication.

In this work, we emphasize on the most common communication types, which are the V2V and V2N accommodating the requests of the majority of vehicular-

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related applications and services. In more detail, the V2N communication is conducted between a vehicle and the gNB, and it is used for serving applications that request to access the Internet, e.g., for the users' infotainment. In addition, V2N communication is important in V2X use cases that are relevant to efficient and eco-friendly traffic management since they transmit necessary information, such as the road traffic volume of specific regions to the servers over the 5G network. On the other hand, V2V communication is especially used for exchanging necessary information between vehicles, such as location, speed, accident prevention/detection etc. This kind of information is of vital importance for safety-related services and V2X use cases, such as platooning or cooperative driving [4].

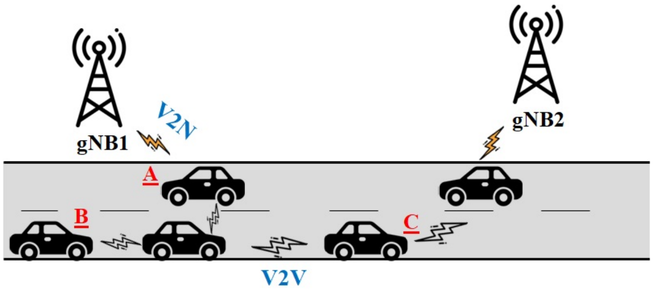

Fig. 1. The system under study

To estimate the performance of the abovementioned system, we define a VANET as a directed and connected graph $G(V,E)$, where the gNBs and the vehicles are represented by the graph's nodes $V$ and the wireless links between them constitute the graph's edges $E$. Each edge $l$ is defined by two specific features [5]: a) the edge's capacity $C_l$ and b) the cost $w_l$ of sending a packet over the edge. In our case, due to the fact that a node can be either a gNB or a vehicle and we study two different types of communications, we denote the capacity of an edge $l$ as $C_{ml}$ where $m = 1,2$ while $m = 1$ stands for the V2N communication and $m = 2$ for the V2V communication. For simplification purposes, we assume that all the edges have the same cost $w_l$.

In the system under study, the applications and services hosted by the vehicles require access to the Internet; thus, their requests should be transmitted to the gNBs in order to be served. In more detail, the requests for service are generated by the vehicles and then they are conveyed by the wireless links to the gNBs in order to be served. A request for service can be transmitted to the gNB either via single-hop or via multi-hops. In the single-hop transmission, the vehicle requesting for service communicates directly with the gNB conducting V2N communication (e.g. the V2N link between vehicle "A" and gNB1 in Fig.1). However, when the destination gNB is not within the vehicle's coverage area, it exploits the vehicles located within its coverage area to transmit indirectly via them the request for service to the gNB. In particular, the vehicle-sender transmits its request through its V2V link to the neighboring vehicle in order to forward it to the gNB. If the neighboring vehicle does not communicate directly with the gNB, it transmits the request to its neighboring vehicle and this process continues until the request is transmitted to the gNB. Therefore, in the multi-hop transmission, the intervening vehicles between the sender (i.e., the vehicle) and the receiver (i.e., the gNB) are leveraged as relays, and they do not have an active role in the transmission.

In the direction of avoiding the requested multi-hop transmission being a very long process due to unnecessary hops, the least costly route between the vehicle-sender and the gNB-receiver should be chosen. As the system under study is described as a graph, the most suitable path between the sender and the receiver can be determined by finding the route (combination of links) with the minimum cost. Since all links have the same cost $w_l$, finding the best route can be dealt with as a shortest path problem (SPP) whose objective is to find the path with the minimum number of possible hops. However, the links that constitute the path between the vehicle-sender and the gNB-receiver have a finite capacity thus their bandwidth resources may not suffice to transmit the request. Hence, even though the available path between the vehicle-sender and the gNB-receiver may exist, the necessary resources should be also available in order for a transmission to be considered as successful.

## III. DESCRIPTION OF THE ADOPTED MODELS

We consider the V2X system presented in Fig.1. Each gNB communicates with a moving vehicle through a V2N link that has a fixed capacity equal to $C_{1l}$ bandwidth units (b.u.) and it accommodates requests for service from the moving vehicles. In addition, the bandwidth resources of the V2V links are fixed and equal to $C_{2l}$ b.u. and they are utilized in order to forward the vehicles' request to the gNB when the option of the multi-hop transmission is available. The applications and services hosted by the moving vehicles can be categorized into $K$ different service-classes where each service-class $k$ ($k = 1,. . . K$) has its specific features and resource requirement. In particular, a request for service arrives at the system according to a Poisson process and the arrival rate has a mean value $\lambda_k$. The time that a request of a service-class $k$ spends in the system after its acceptance is exponentially distributed with mean value $\mu_k^{-1}$ and therefore the traffic load of this service-class is $a_k = \lambda_k/\mu_k$ erl [11]. An arriving request of a service-class $k$ needs $b_k$ b.u. in order to be served; otherwise, the request is rejected.

### A. Single-hop transmission

As it is illustrated in Fig.1, we consider a single-hop transmission where a vehicle communicates directly with the gNB forming a V2N communication. To evaluate system's performance, we calculate the probability that a request for service from a service-class $k$ is denied due to resource unavailability. To this end, we calculate the unnormalized values of the system's resource occupancy distribution $q(j)$ by utilizing the classical Kaufman-Roberts recursive formula [11]-[12] as follows:

$$q(j)=\begin{cases}1, & \text{for } j=0\\ \frac{1}{j}\sum_{k=1}^{K}a_k b_k q(j-b_k), & j=1,\ldots,C_{ml}\\ 0, & \text{otherwise}\end{cases} \tag{1}$$

where $l = 1,\ldots,L$, and $m = 1$ since in the system under study the communication in the single-hop transmission is always V2N.

The probability that a request for service generated by a service-class $k$ is blocked, $Pb_k$, is given by:

$$Pb_k=\sum_{j=C_{ml}-b_k+1}^{C_{ml}}\frac{q(j)}{G} \tag{2}$$

where $G$ is the normalization constant determined as $G = \sum_{j=0}^{C_{ml}} q(j)$.

### B. Multi-hop transmission

In the multi-hop transmission, the connection establishment between the transmitting vehicle and the receiving gNB does not depend solely on the available resources of the V2N link. Since the capacity of a V2V link is finite, the necessary bandwidth resources may not be available to transmit the vehicle's request to its destination i.e. to the gNB. For this reason, in the multi-hop transmission, we consider a path of at least one V2V and one V2N link where the required resources should be available in order to transmit the vehicle's request to the gNB.

The system illustrated in Fig. 1 can be modeled as a routing network of $L$ links and each link supports $K$ service-classes. When a request for service of a service-class $k$ generated by a vehicle is transmitted to a gNB through multi-hop transmission, then a path of links $L_k$ is created, so $L_k \subseteq \{1,...,L\}$. In this path $L_k$, the bandwidth resources of $b_k$ b.u. must be available in each link in order for the transmission to be regarded as successful; otherwise, the request is rejected. To estimate the performance of this use case, we utilize the reduced load approximation (RLA) method [11], [13] in the direction of calculating the probability that a request of a service-class $k$ is rejected due to the unavailability of resources. According to the RLA method, the blocking probability of a request of a service-class $k$ at a certain link $l$ is given by:

$$B_{lk}[C_{ml}; a_k, k \in K] = \sum_{j=C_{ml}-b_k+1}^{C_{ml}} G^{-1} q(j) \tag{3}$$

where $C_{ml}$ denotes the capacity of link $l$ for $l = 1,...,L$ and $m = 1, 2$ while $G$ is the normalization constant and $q(j)$ is the resource occupancy distribution of link $l$ determined via the Kaufman-Roberts formula of (1).

Due to the fact that the links belonging to path $L_k$ may have different capacities or serve requests of other service-classes, calculating the blocking probability of a request of a service-class $k$ in link $l$ is not representative of the performance of the whole path. Therefore, the blocking probability expression should be updated in the direction of including the entire set of links of the path $L_k$. According to the RLA method, the offered traffic load of a service-class $k$ to a link $l$ is actually reduced when it traverses through the sequence of links. Therefore, with respect to a service-class $k$, the offered traffic-load $a_k$ is reduced to $a_k \prod_{i \in L_k - \{l\}} (1 - V_{ik})$ and the emerging approximated blocking probability of a request of this service-class in a specific link $l$ is defined as:

$$V_{lk} = B_{lk}[\mathrm{C}_{ml}; a_k \prod_{i \in L_k - \{l\}} (1 - V_{ik}), k \in K] \tag{4}$$

Hence, the total blocking probability of a service-class $k$ in the path $L_k$ due to lack of resources is determined by:

$$Pb_k \approx 1 - \prod_{l \in L_k} (1 - V_{lk}), k = 1...K \tag{5}$$

## IV. SYSTEM PERFORMANCE EVALUATION

In this section, we consider the system of Fig.1 which consists of two gNBs and moving vehicles requiring service from the gNBs. The vehicles transmit their requests for service to the gNBs either via single-hop over one V2N link or via multi-hops over one V2N link and at least one V2V link. All V2N links are identical with a capacity equal to $C_1$ = 40 b.u. In accordance, all V2V links are identical with capacity equal to $C_2$ b.u. Both the V2N and V2V links accommodate requests of $K = 2$ service-classes generated by the moving vehicles. In respect to the requests of the 1st service-class, they arrive at the system with an arrival rate $\lambda_1$ = 1 packet/s, the service rate is equal to $\mu_1$ = 1 packet/s and they require $b_1$ = 3 b.u. in order to be served. Apropos the requests of the 2nd service-class, the requests' arrival rate is $\lambda_2$ = 2 packets/s, the service-rate is $\mu_2$ = 1 packet/s and $b_2$ = 4 b.u. should be allocated in order to serve this request. For the performance evaluation, we distinguish three different cases: In the first case, we consider a vehicle (i.e. vehicle "A" in Fig. 1) that requests direct service from the gNB (i.e. the gNB1). In the second case, we consider the vehicle "B" that cannot communicate directly with a gNB so it leverages the option of the multi-hop transmission to transmit its request to the nearest gNB. By utilizing the SPP algorithm, it is shown that the requests of vehicle "B" are transmitted to gNB1, and $N$ = 2 neighboring vehicles are exploited for the transmission. Finally, in the third case, we consider a vehicle "C" that cannot request direct service from a gNB, as no gNB is located within the vehicle's coverage area; thus, it exploits the multi-hop transmission to send its request to the nearest gNB too. However, contrary to the second case, in the third case the number of intervening vehicles equals $N$ = 1 vehicle. In addition, with a view to investigate the impact of the multi-hop transmission on the system's performance, we evaluate these three cases by considering three different V2V link capacities: $C_2$ = 30, 40, 100. The V2V links are identical in each case study and their capacity is not affected by the number of intervening vehicles.

Next, we employ the method described in Section III to calculate the probability that a vehicle's request for service is rejected due to the unavailability of resources, and the results are presented in Figs. 2-3 for the 1st and the 2nd service-class, respectively. In more detail, for the first case under study we utilize the method for the performance evaluation of the single-hop transmission, described in Section III.A (denoted as S-H in Figs. 2-3) because the vehicle communicates directly with the gNB in order to be served. On the other hand, as in the last two cases under study the vehicle-sender exploits its V2V connections to forward its request to the gNB-receiver, we implement the method of Section III.B, (denoted as M-H in Figs. 2-3). However, the number of the exploited vehicles is different in the two cases, thus we use the notion of the number of the intervening vehicles $N$ in order to differentiate them (i.e. $N$ = 2 stands for the second case and $N$ = 1 denotes the third case). The abovementioned three cases are studied for an increasing number of offered traffic load expressed in Figs.2-3 by traffic points that are increased by 0.5 erl for both service-classes. Hence, point 1 represents the values $a_1$ = 1 erl and $a_2$ = 2 erl while point 10 corresponds to the traffic load values: $a_1$ = 5.5 erl and $a_2$ = 6.5 erl.

The numerical results in Figs.2-3 show that both the V2V link capacity and the number of intervening vehicles significantly affect the system's performance. In particular, the highest blocking probability values are observed during the multi-hop transmission when the V2V link capacity equals $C_2 = 30$ and the number of hops is $N = 2$. The blocking probability is slightly improved when the number of intervening vehicles is reduced (i.e. when $N = 1$). However, the blocking probability is mainly improved in both cases when the $C_2$ value increases i.e. when $C_2 = 40$ and $C_2 = 100$. This outcome is reasonable because when the $C_2$ value is low then the arriving request cannot find the necessary resources to be forwarded to the gNB. This gets even worse as the number of intervening vehicles increases since the required resources should be available in all V2V links in order for the request to be forwarded to the gNB.

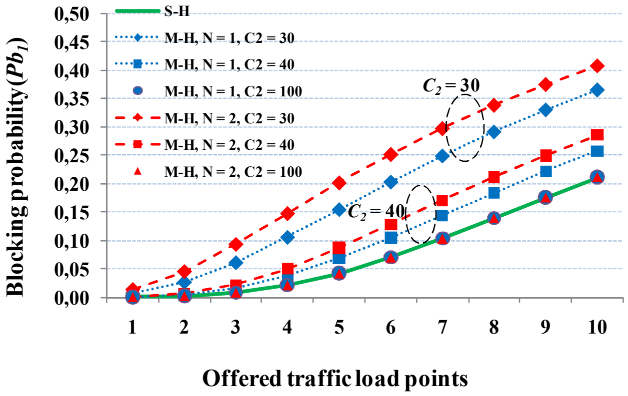

Fig. 2. The impact of the traffic load increase on the request blocking probability of the 1st service-class ($Pb_1$)

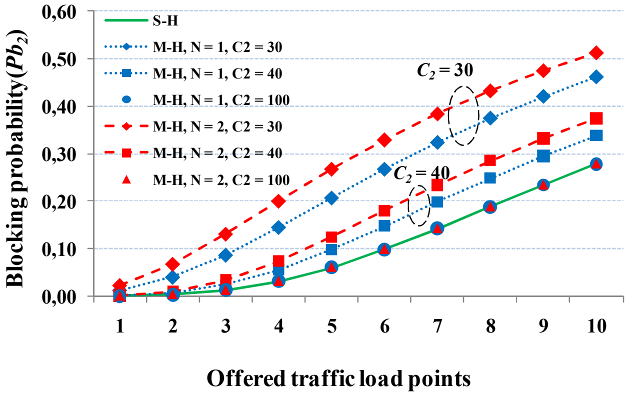

Fig. 3. The impact of the traffic load increase on the request blocking probability of the 2nd service-class ($Pb_2$)

On the opposite, it is shown that the lowest blocking probability for both service-classes is observed either in the single-hop transmission or when the V2V link capacity in the multi-hop transmission is high. In more detail, it is shown that when the V2V link capacity is high, then the multi-hop transmission does not affect the system's service provision to the users since the bandwidth resources are sufficient to serve the arriving requests. Contrary to the cases when $C_2 = 30$ and $C_2 = 40$, when $C_2 = 100$, the number of intervening vehicles does not affect the request blocking probability since the required resources do exist in all hops in order to forward the request to the gNB. Therefore, when $C_2$ is high, the multi-hop transmission system operates the same way as in the single-hop transmission. In addition, it is shown that an increase in the traffic load causes an increase in the blocking probability values of both service-classes. This is justified by the fact that an increase in the traffic load is interpreted as more arriving requests for service that compete for the same resources so the probability that the needed resources may not be available increases. As a general remark, it is shown that both the links' capacity and the number of hops have an impact on the blocking probability and consequently the overall QoS. This outcome gets even more significant for services that are very stringent to loss of packets such as safety-related services. Towards the same direction, the optimal number of vehicles participating in V2X use cases, such as platooning or cooperative driving, should be carefully chosen since the number of hops affects the service provisioned to the applications and services.

## V. CONCLUSION

In this work, we utilized two multi-rate loss models from the teletraffic theory in order to evaluate the performance of a VANET that enables V2X communication. The system under study consists of moving vehicles that request service from the gNBs and the request transmission to the gNB can be either via single-hop or via multi-hops. It is shown that the links' capacity and the number of hops in the multi-hop transmission have a significant impact on the QoS provided to the services hosted by the vehicles. In future work, we aim to apply resource management strategies that favor applications and services that are sensitive to packet losses.

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