Traffic Modeling and Performance Evaluation in Vehicle to Infrastructure 802.11p Network

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Abstract. In Intelligent Transportation Systems new applications based on cooperative approach are being created. These applications are characterized by the real time reconstruction of the driver environment used in combination of on-board sensors and cooperative system information. In this paper, we propose a traffic modeling and 802.11p access categories mapping of three main ITS services: warning to a foggy zone, inter-distance measurement and road warning event. Then, we elaborate an ETSI layer modeling at large scale (facilities/network layer) and burst scale (MAC layer) in order to evaluate the performance of the three ITS services in a vehicular environment and prove ETSI architecture reliability to transport ITS applications. Analytical results match simulation results; this proves the accuracy of our mathematical modeling. Moreover, in traffic jam situation, we computed average packet loss rate and delay and identified the vehicles number range that leads to significant increase of QoS metrics. Performance analysis confirms that the service differentiation is well achieved with EDCA mechanism.

Keywords: ITS, quality of service, V2I, access categories, EDCA, queuing system.

1. INTRODUCTION

The growing mobility of people and goods has a very high societal cost in terms of fatalities, injured people and traffic congestion. In this context, Intelligent Transportation System (ITS) is identified as a key technology to increase safety, enhance transportation infrastructures and improve driver comfort. Therefore, ITS is currently the center of attention of car manufacturers as well as transportation authorities. The basic idea is to broaden the range of perception of the driver beyond his/her field of vision and further on to assist the driver with autonomous assistance applications. ITS systems rely mainly on three components: smart vehicles equipped with onboard units (OBUs), road-side units (RSUs) and vehicular communication. The RSU is a wireless stationary access device mounted along the road transport network that supports information exchange with OBUs. We mainly distinguish between two types of wireless communications in vehicular networks: Vehicle-to-Vehicle (V2V) communications consist of data exchange and communication between different onboard units. Whereas Vehicle-to-Infrastructure (V2I) communications consist of data exchange between an OBU and RSUs.

A key challenging issue that should be addressed in wireless vehicular mobile networks carried by IEEE 802.11p standard is Quality of Service (QoS) provisioning. In fact, safety applications have critical-delay requirements. The timing requirements can be observed from the fact that it is only relevant to communicate about an upcoming dangerous situation before the situation becomes a fact and perhaps can be avoided. Consequently, special QoS mechanisms should be applied in order to prioritize safety applications.
In the literature, researchers oriented their effort towards studying the quality of service in ITS. Many authors proposed different analytical modeling techniques and simulation in the purpose of evaluating the performance of different ITS scenarios. Nevertheless, the various studies focus solely on the physical and Mac layers, without taking into account source traffic models. As a matter of fact, resource allocation and wireless scheduling are highly impacted by traffic variations and traffic statistical distribution. Therefore, a special attention should be devoted to source traffic modeling when evaluating a quality of service mechanism in wireless vehicular networks. In this paper, we strive at focusing on traffic flow characteristics while evaluating the performance of a V2I network. The performance evaluation is conducted through accurate simulation runs and mathematical modeling in order to assess the EDCA performance. Our contribution is two-fold:

1. We define the characteristics of three ITS services: warning to a foggy zone, inter-distance measurement and road warning event and provide a source traffic modeling for each service.
2. We provide a mathematical modeling of the V2I scenario performance at a large scale and burst scale.

The paper is organized as follows. The following section details the literature survey on quality of service in 802.11p networks. In section 3 we present the applications provided in vehicular networks. Section 4 sheds the light on three important services, describes their characteristics and provides an accurate source traffic modelling. Section 5 describes the mathematical modelling of the V2I scenario at a large scale and burst scale. In section 6, we provide a performance analysis before concluding the paper.

2. LITERATURE SURVEY ON QUALITY OF SERVICE

One QoS mechanism proposed for the MAC layer in the IEEE 802.11p is the EDCA mechanism. EDCA supports some degree of service differentiation between different types of classes of services, referred to as access categories. The main advantage of EDCA is that the mechanism is completely distributed among stations and thus overcomes the problem of intelligence centralization and vulnerability. For this, EDCA defines:

- Four Access Categories (ACs): Background (AC_BK), Best-Effort (AC_BE), Video (AC_VI) and Voice (AC_VO). Each access category has an index denoted by Access Category Index (ACI) such that ACI= 00 for Best effort access category (AC=0), ACI= 01 for Background access category (AC=1), ACI= 10 for Video access category (AC=2), ACI= 11 for Voice access category (AC=3).

Contention and access priority to the medium are resolved through the following EDCA transmission parameters:
- ***Arbitration inter-frame space (AIFS[AC]):*** The minimum time interval between the wireless medium becoming idle and the start of transmission of a frame.
  - It is to be noted that: AIFS [AC] =SIFS+AIFSN [AC].aSlotTime; Where-AIFSN [AC] is defined as the number of slots, after a SIFS duration, a station should defer before either invoking a backoff or starting a transmission. The minimum value for the AIFSN subfield is 2 and aSlotTime is the time slot.
- ***Contention window (CW [AC])***: An interval from which a random number is drawn to implement the random back-off mechanism. The interval range varies through CW_{min}[AC] to CW_{max}[AC].
- ***Transmit opportunity limit (TXOPlimit[AC])***: is required for limiting transmission duration.

The EDCA idea is the following: The higher the backoff entity access category priority is, the smaller the value of AIFS, contention window and Transmit opportunity limit is.

Many research works in the literature tackled the performance of IEEE 802.11p EDCA mechanism. In [16], authors proposed an analytical model for dimensioning the RSU coverage area; the study aims at deriving the minimum contention window, Cw_{min}, required for a vehicle to connect with RSU during its sojourn time, and that for different classes of average speed. Authors in [17] proposed an analytical model for EDCA performance evaluation. They modelled three access categories with a Markov chain. For each access category, three states are defined: idle state, collision state and success state. Numerical resolution is adopted to determine the throughput. In [18], authors derived the expression of maximum number of transmitters according to the intensity, distance between transmitters and transmission time.
In order to perform the analysis of the control channel CCH, authors in [19] modeled the transmission over the MAC layer, with a Markov chain; they distinguished between two states: state 1 refers to the case when no packet is waiting to be sent and state 2 refers to the case when a packet is waiting to be sent. Consequently, they evaluated the throughput expression in a different scenario context.
The work published in [20] evaluates the performance of a wireless vehicular network and takes into account the fact that data frames in WAVE are transmitted in broadcast mode. The model has one backoff stage to reflect the fact that there are no acknowledgments. It therefore inherits the characteristics of being only applicable to the saturated case and to systems with only one access category. Additionally, reference [21] analyzes a situation related to broadcast transmissions. Slotted transmissions are considered with fixed-size slots. Further, authors assume that the probability that a station starts transmitting during a given slot is a system parameter with constant value, independent of nodes number, node traffic generation rate, and packet length. In [22], the author proposes formulas to evaluate the throughput and the collision probability in a wireless vehicular environment in which nodes are in a saturation condition.
Most of these articles focused solely on the physical and MAC layers, without taking into account the features of wireless vehicular architecture layers and traffic characteristics. In this paper, we aim at evaluating vehicular network performance that takes into account the MAC layer and higher layer processing while considering traffic characteristics of three main ITS services.

3. VEHICULAR APPLICATIONS

Vehicle networks provide a wide spectrum of applications and services ranging from lane change service, to Electronic Emergency Brake Light, to map download. In the literature, many research studies focused on classifying vehicular applications [1] [2] [3]. We basically adopted the ETSI approach [4] and modified it in order to integrate larger panoply of vehicular applications [5]. Vehicular applications are then classified into three main categories: Safety, Traffic Management and Comfort (Figure 1).

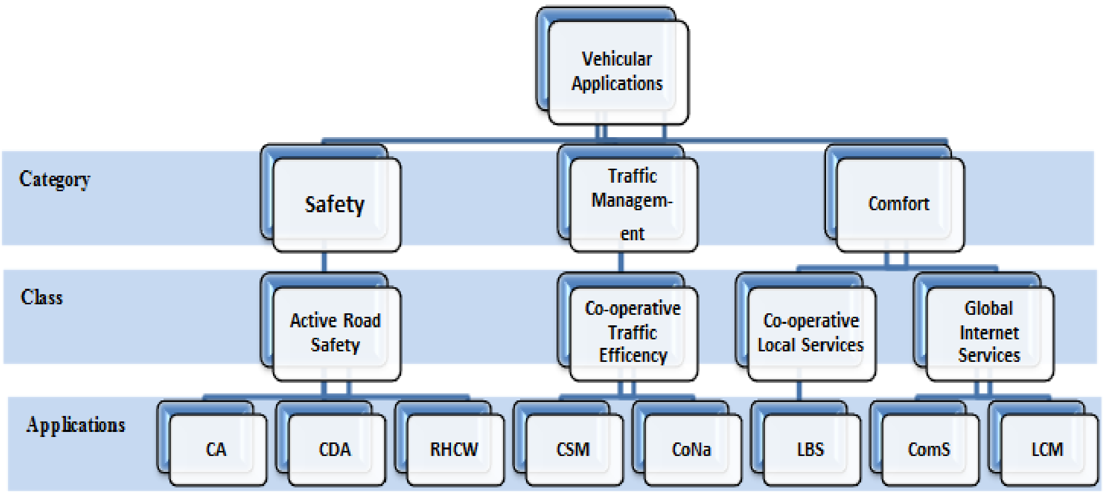


Figure 1. Vehicular applications classification.

3.1 Safety category

Safety applications have attracted considerable attention since they are directly related to minimizing number of accidents on the road. Safety category is mapped to *Active Road Safety* class which aims at providing driver awareness and warning services through *Cooperative Awareness (CA), Cooperative Driver Assistance (CDA)*, and *Road Hazard and Collision Warning (RHCW)* applications. In fact, active road safety provides awareness functions that deliver information to the driver during normal driving, warn the driver of road hazard conditions and probable accidents and actively assist the driver in avoiding impending accidents. In other terms, safety related applications are responsible of: *awareness, warning* and *assistance.*

3.1.1 Cooperative Awareness application (CA)

Cooperative Awareness applications make drivers aware of other vehicles or situations and provide information about the vehicle's surrounding environment. Several applications are offered within this class. Among others are Emergency vehicle indication, Motorcycle approaching indication and Slow Vehicle Advisor. For these applications, an emergency vehicle, a motorcycle, or a slow/stopped vehicle broadcasts messages to approaching vehicles in its neighborhood. The information propagated to road drivers help them to adapt to road conditions.

3.1.2 Cooperative Driver Assistance application (CDA)

This application provides driver assistance services. Many services fall within this class, among others:

- *Cooperative driving system*, which exploits the exchange of sensor data or other status information among cars. Cooperative driving systems assist drivers for maintaining a safe time-headway distance between vehicles to ensure that emergency braking will not cause rear-end collisions between cars. The headway calculation system adapts a vehicle's headway by accounting for changed environmental conditions, vehicle dynamics, and safety considerations.
- *Lane Change Assistance (LCA)*: This application assists the driver in choosing the optimum instant for lane changing and influences the drivers' behavior towards improving driving performance.

3.1.3 Road Hazard and Collision Warning application (RHCW)

Road Hazard and Collision Warning applications provide information about imminent collisions due to hazardous road conditions, obstacles and erratic drivers. Crash detection systems (CDS) rely on radars, sensors or cameras to detect an imminent crash. These systems may warn the driver, pre-charge the brakes, inflate seats for extra support, move the passenger seat to a better position, fold up the rear head rest for whip lash, retract the seat belts removing excess slack and automatically apply braking to minimize the crash severity [6]. Several services are offered within this application, among others:

- *Cooperative Collision Warning:* A vehicle actively monitors kinematics status messages from vehicles in its neighborhoods to warn of potential collision [7].
- *Electronic Emergency Brake Light*: A vehicle braking hard broadcasts a warning message, giving warning notification to endangered drivers about the critical situation with a minimum latency [8].
- *Road Hazard Condition Notification*: When detecting a road hazard (e.g. fog, fluid, ice, and wind), vehicles are notified within the affected area.
- *Road Feature Notification*: A vehicle detecting a road feature (e.g. road curve, hill) notifies approaching vehicles in the neighborhood.

3.2 Traffic Management Category

Traffic Management category is mapped to the Cooperative Traffic Efficiency class (Figure 1). Since congestion occurs when the demand for travel exceeds highway capacity, an efficient approach, based on traffic management, is required to reduce congestion [9] [10]. Cooperative Traffic Efficiency provides two applications: *Cooperative Speed Management (CSM)* and *Cooperative Navigation (CoNa).*

3.2.1 Cooperative Speed Management (CSM) application

Cooperative Speed Management (CSM) includes two services.

- *CSM-Speed limits notification*: It delivers speed limits notifications that contain current regulatory speed limits and recommended contextual speed limits.
- *CSM-Traffic light optimal speed advisory*: It is responsible for traffic light optimal speed advisory. For this, a road side station provides information about the current traffic light phases, the remaining time before phases changes and the duration for each phase.

3.2.2 Cooperative Navigation (CoNa)

With the Cooperative navigation application, a vehicle gets advised for the optimal itinerary and gets assisted in navigation. The CoNa application offers many services among others:

- *Traffic Probe*: Vehicles aggregate traffic probe information and transmit it to roadside units.
- *Free Flow Tolling (TOLL)*: TOLL save road travelers time, allowing them to drive non-stop through tolling areas. Vehicles are billed automatically as they pass through the tolling area, minimizing delay.
- *Vehicle registration, inspection, credentials*: Vehicle inspection helps to control the legality of goods/person transportations. The actions of stopping vehicles to verify the validity of the driver's license or to check the physical status of vehicles before entering a road infrastructure are examples of vehicle inspections. A wireless vehicular network allows vehicle data exchange between vehicles and road infrastructures.

3.3 Comfort category

The general aim of this category is to improve passenger comfort. The Comfort category is mapped to *Cooperative local services* and *Global Internet services class*.

3.3.1 Cooperative local services class

The Cooperative local services class provides Location Based Services (LBS) application which provides:

- *Point Of Interest* notification services include vehicles energy supply station, vehicle maintenance facility, public transport management, rest area, parking, hotel/restaurant, tourism place, local event meeting place, medical center, police station and toll points.
- *Service Announcements*: Enterprises transmit marketing data to potential customers passing by.
- *Content Map or Database Download*: A vehicle downloads maps, multimedia from mobile hotspots. These services provide passengers with audio and video data obtained from other vehicles or the infrastructure.

- *Real-Time Video Relay:* A vehicle transmits and relays real-time video to other vehicles or road-side units.
- *Vehicular sharing services* distribute data or computations on vehicles.

3.3.2 Global Internet Services class

Global Internet Services class provides *Communities Services (ComS)* and ITS station *Life Cycle Management (LCM)* applications. Communities Services applications offer many services:

- *Insurance and financial services* provide insurance services to the concerned communities, e.g. discount on public transport at given periods of time.
- *Fleet management services* are dedicated to the related professional fleet, e.g. local intervention base of the professional fleet.
- *Cargo monitoring and tracking*: Wireless access for vehicular environment fills the gap for seamless and continuous tracking at the cargo-level for transit from indoors to outdoors and from warehouses to containers.

ITS station Life Cycle Management applications provide

- *Remote Vehicle Personalization/Diagnostics*: Personalized vehicle settings are downloaded and vehicle diagnostics are uploaded from/to infrastructure.
- *Vehicle and RSU data calibration services* aim at calibrating of local roadside ITS station by a local operational support ITS station.

Services	Category	Application Class
Service 1: Warning to a foggy zone: Road Hazard Condition Notification	Safety	Active Road Safety
Service 2: Inter-distance measurement: Cooperative driving system	Safety	Active Road Safety
Service 3: Road warning event: Road Feature Notification	Safety	Active Road safety

Table 1. Services Classification.

4. PROJECT VEHICULAR APPLICATIONS: DESCRIPTION AND TRAFFIC MODELLING

The work is being conducted in the context of Co-Drive project[1], a French project that is a co-pilot for an intelligent road and vehicular communication system. Within this project, we are mainly interested by three types of services belonging to Safety and Traffic Management categories. More specifically, we study the following services (Table1):

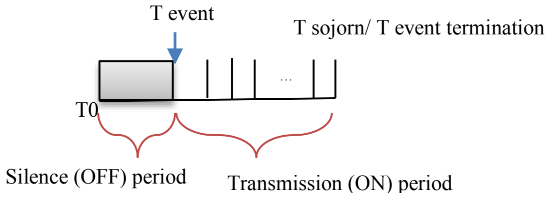
- *Service 1*: Warning to a foggy zone. This service aims at warning the driver in the vicinity of a foggy zone about an imminent danger. It is a type of *Road Hazard condition notification (RHCN)* services. This service belongs to the *Road Hazard and Collision Warning (RHCW)* application that falls into the *Active Road Safety Application* Class. The latter belongs to the Safety Category (ref. section 3.1.3).
- *Service 2*: Inter-distance measurement. The OBU exploits the exchange of sensor data and sends measurements related to vehicle inter-distance. This service assists drivers for maintaining a safe time headway distance between vehicles to ensure that emergency braking will not cause rear-end collisions between cars. It is a type of *Cooperative Driving System* service. This service belongs to the *Cooperative Driver Assistance* Application that falls into the *Active Road safety* class. The latter belongs to the Safety Category (ref. section 3.1.2).
- *Service 3*: Road warning event. The OBU is equipped with a frontal camera which captures and sends a photo upon detection of a road warning event (road curve, hill, road-sign speed,etc); thereby triggering warning and photo messages. This allows the RSU to judge the relevance of the warning event. It is a type of Road feature Notification service. This service falls into the *Road Hazard and Collision Warning* (RHCW) application that belongs to the *Active Road Safety Application* class. The latter belongs to the *Safety Category* (ref. section 3.1.3).

Since a network performance is highly impacted by traffic variations and traffic statistical distribution, we exhibit the characteristics of each studied service and perform traffic modeling as shown in next sub-sections:

[1] Co-Drive aims at validating a pre-industrialization approach towards a cooperative driving system between user, vehicle and Infrastructure to suggest an intelligent secure and calm route for sustainable mobility.

4.1 Service 1: Warning to a Foggy zone service (DEN)

When a vehicle detects a dangerous situation (e.g. foggy zone), it will not wait for the periodic transmission of a safety message and issues instead a *Decentralized Environmental Notifications* (DEN) warning message [11] (figure 2). The DENs have very strict temporal requirements and require a high level of QoS. Message transmission continues during the sojourn time of the station in the RSU coverage area.



Parameters	Distribution
Message size in ON period	Deterministic :171 bytes
Packet Inter-arrival time	Deterministic: 0.1s
Process arrival	Poisson
ON period duration	Exponential: 60 s
OFF period duration	Exponential: 20 s

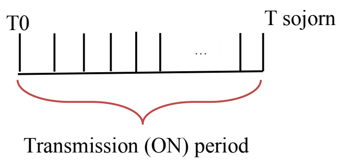
Figure 2. Warning service.

Table 2. Warning traffic model parameters.

Since messages are periodically generated in case of the event detection, messages transmission occurs during an activity period (ON period); the remaining time is a silence time interval (OFF period). The ON period lasts until the OBU station leaves the RSU zone or when it stops detecting the dangerous event.
Table 2 presents the parameters of the warning traffic.

4.2 Service 2: Inter-distance Measurement Service (CAM)

Cooperative Awareness Messages (CAM) [12] messages are transmitted periodically by every vehicle and carry information gathered from on-board sensors (figure 3). In the project, we consider CAM messages carrying vehicle inter-distance metric. Each second, the OBU sends a message of 50 bytes size to the RSU with a frequency of 10Hz. The service model parameters are indicated in the following table (Table 3):



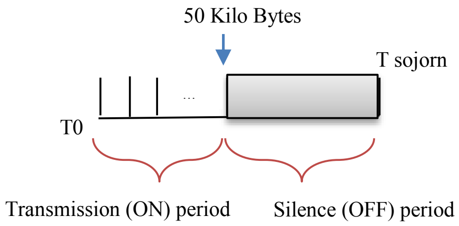
Parameters	Distribution
Message size	Deterministic:50 bytes
Inter-arrival time	Deterministic: 0.1s
Process arrival	Poisson

Figure 3. Inter-distance Measurement service.

Table 3. Measurement service traffic parameters.

4.3 Service 3: Road Warning event (CoDM)

While the car OBU is in the RSU coverage area, it sends a picture upon detection of a road feature warning event. Depending on the application, the picture can be sent in a single block or in several fragments. Contrarily to ITS application messages (CAM, DEN), road warning service is specific to CoDrive project and is called *CoDrive Messages (CoDM).*



Parameters	Distribution
Size packet in ON period	Determinist :200 to 1200 bytes
Time inter-arrival	Deterministic : 1 s
Process arrival	Poisson

Figure 4. Road warning service.

Table 4. Road warning traffic parameters.

Road warning traffic adopts the ON/OFF model; the ON period represents the time in which the car sends photo packets, and the OFF period is the time in which the car is in the coverage area of the RSU but it does not send any packet (figure 4). During the ON period, the OBU sends each second a CoDM message of size ranging between 200 and 1200 bytes to the RSU during OBU sojourn time [13], [14], [15]. Table 4 presents the parameters of the investigated service.

5. PERFORMANCE MODELING

In V2I communication, OBU and RSU exchange information in uplink and downlink directions. In this paper, we focus on the uplink communication according to the ETSI standard protocol stack (figure 5). At the radio level, MAC and Physical layer correspond to the 802.11p architecture. The facilities layer of this architecture interact with the ITS applications and network/ transport layers.

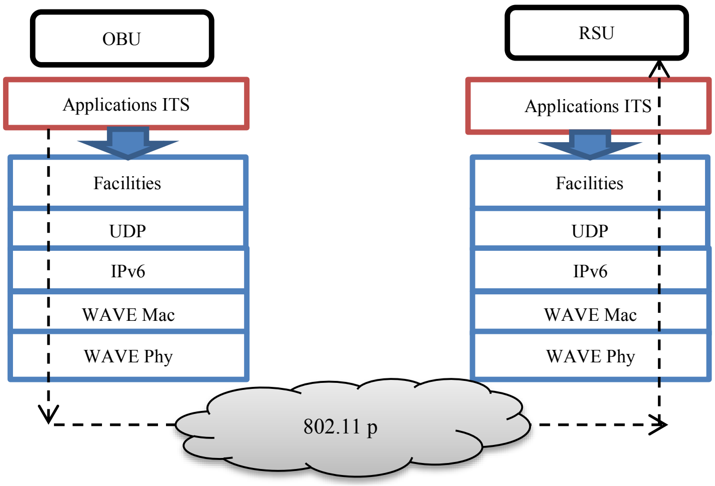


Figure 5. Vehicular protocol stack.

More specifically, when the facilities layer receives the applications messages, it determines the messages category (CAM, DEN, CoDM) according to their functional specifications, then for each message it attributes an ITS identifier specified by *ITS Application Identifier (ITS-AID)* in order to label ITS applications. Moreover, the facilities layer proposes an interface *Human Machine Interface (HMI)* to interact with the driver, through which he receives messages of services applications. At this stage, we are interested by studying the impact of the ITS architecture on the three envisioned services. Therefore, we proceed in two steps. The first step consists at modeling the facilities/network layer at a large scale. Second, we model the MAC radio layer that manipulates the flows transiting from facilities/network layer. The MAC modeling will be performed at the burst scale.

5.1 Facilities and Network Layer Modeling: Large-scale

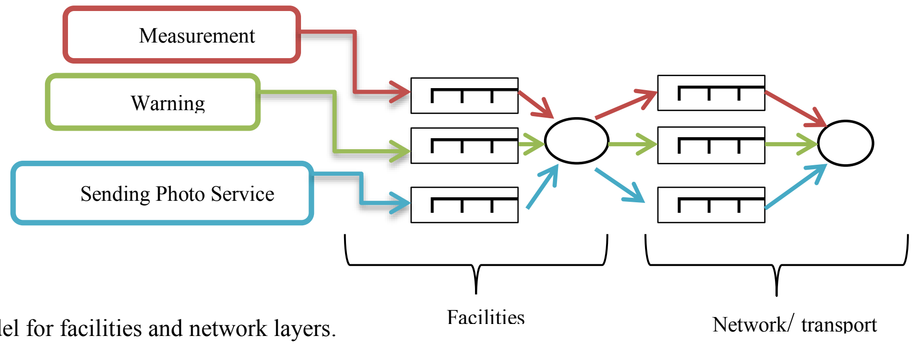


Figure 6. BCMP model for facilities and network layers.

We adopt the following assumption related to three classes of service.

- r is the class of service (r varies between 1 to 3 in our study),
- Traffic arrival flows are Independent Poisson processes, with intensity (λ_r for service r),
- Service rates follow exponential distribution with parameter μ_r for service r,
- M is the number of OBUs,
- n_i (i=1,…,M) represents the total number of packets in an OBU_i in a RSU coverage area,
- The system vector state is defined by $n=(n_1,n_2,\ldots,n_M)$,
- ρ_i is the load of an OBU_i,
- ρ_{ir}, μ_{ir} and λ_{ir} are respectively the load, service rate and mean arrival rate of a service r running on an OBU_i.

The Poisson arrival process and the exponential service rate distribution assumptions enable us to model the system with three M/M/1 queues at each layer (Figure 6). Each queue provides services to one class of service. As a result, we model the traffic carried by the upper layers of the architecture with a Product Form Queuing Networks, or BCMP, [23], [24] for which a product-form equilibrium distribution exists. Moreover, we assume that the BCMP network is open. Therefore, the steady-state probability distribution for a single-class (r) load-independent open BCMP network is defined by the product of steady-state probability distributions of queues in isolation. It is given by:

$$\pi(n) = \prod_{i=1}^{M} \pi i\ (ni) \qquad \textbf{(1)}$$

With : $\pi \mathrm{i}(ni) = (1 - \rho i) ni\ ! \prod_{i=1}^{M} \frac{1}{nir!} \left(\frac{\lambda r\ e\ ir}{\mu i}\right)^{nir}$ **(2)**

- And eir: average visits number of a station OBUi by a class of service r.
- For each class of service running on an onboard unit i, we derive the performance parameters at the facilities/network layer as follows:
  - Mean rate: $Dir = \lambda ir$ **(3)**
  - Average number of packets: $Lir = \frac{\rho ir}{1-\rho i}$ **(4)**
  - Average sojourn time: $Tir = \frac{Lir}{Dir}$ **(5)**
  - Average waiting time: $Wir = Tir - \frac{1}{\mu ir}$ **(6)**

This performance analysis allows us to evaluate the applications flow in the upper layers, and defines the inputs of the underlying layer. At this stage, we pursue our modeling study and perform the MAC radio layer modeling.

5.2 MAC Radio layer modeling

After being processed by facilities and network layer, services packets are passed to the radio MAC layer. In order to implement service differentiation, service packets should have different priorities. Therefore, we propose to map the three services to the EDCA access categories as follows.
Warning service carries critical information and is mapped to the highest priority Access category AC_VO. Measurement service generates important data and is mapped to the AC_BE; the frequent transmission of CAM messages overcomes the unreliability of AC_BE. Finally, road warning service is mapped to AC_BK. The EDCA parameters used in the mathematical study and simulation are resumed in Table 5. Reader may refer to Table 6 that recalls the EDCA most important parameters definition [25] [26]:

ITS Service	EDCA Access Categories	CW_{min}		CW_{max}		AIFSN	
		CCH	SCH	CCH	SCH	CCH	SCH
Road Warning event	AC_BK	15	15	511	511	9	7
Measurement of inter-distance	AC_BE	7	15	15	511	6	3
Warning to a foggy zone	AC_VO	3	3	7	7	2	2

Table 5. EDCA Access categories parameters.

Parameters abbreviation	Definition
AC_BK	Background
AC_BE	Best Effort
AC_VO	Voice
CCH	Control channel
SCH	Service channel

Table 6. EDCA parameters definition.

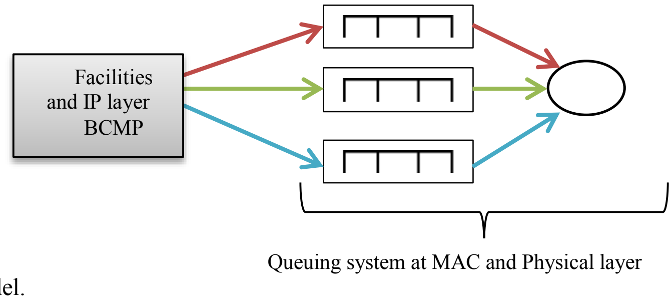


Figure 7. M/GI/1 radio model.

We model the MAC radio layer with an M/GI/1 multiclass (with three classes of service, as shown in figure 7) which adopts a non-preemptive priority policy for each class of service. Packets belonging to a class of service arrive according to a Poisson process. The service follows a general law with Independent arrivals GI. For each service r, we denote by:

- E $[N_r]$ the number of waiting packets, E $[X_r]$ the average service time, E $[W_r]$ the average waiting time and $E[R_r]$ the unfinished work in the waiting queue server.
- Using Pollaczek-Khinchin (P-K) Formula we derived the main performance parameters to evaluate the M/GI/1 non preemptive priority system for each service class r as following:

- Average number of packets E (N_r): $\rho r + \frac{\rho^2 r\,(1+C^2)}{2(1-\rho r)}$ **(7)**
- Average sojourn time E (Sr): $E(Sr) = \mathrm{E}(\mathrm{Xr}) + E(Wr)$ **(8)**
- Average waiting time E (W_r) : $\frac{\mathrm{E(W0)}}{(1-\rho r)(1-\sum_{r=1}^{3}\rho r)}$ **(9)**

With:

- C: coefficient of variation,
- E [W0]: average waiting delay when the server is busy.

It is noteworthy that the average waiting time (9) does not take into account the backoff time. Therefore, we modified the expression in order to capture the backoff effect as follows:

$$\frac{\mathrm{E(W0)}}{(1-\rho r)(1-\sum_{r=1}^{3}\rho r)} + \sum_{i=0}^{cwmin} \mathrm{p}\ (\mathrm{backoff}\ r = i).\,i \qquad \textbf{(10)}$$

Since the backoff window is an integer value, randomly drawn and following a uniform distribution in [1, CW +1] window size, with Cw € $[CW_{min}, CW_{max}]$, the probability P to draw a backoff window is defined as:

$$\mathrm{p}\ (\mathrm{backoff} = \mathrm{i}) = \frac{1}{\mathrm{Cwmin}\ + 1} \qquad \textbf{(11)}$$

6. PERFORMANCE EVALUATION

In order to evaluate the performance of the V2I network accommodating OBUs that run three services, we compare the analytical results derived from previous mathematical modeling with simulation.

6.1 Simulation scenario

We conducted an extensive set of simulation runs with Network Simulator NS3. The simulated topology is a one-lane highway of 10 Km. We mainly investigate one RSU with 300m of coverage area (radius). Vehicles are moving according to a random model in one direction way with a mean speed of 20 km/h which corresponds to a traffic jam situation. The vehicle is estimated to stay 3.6 minutes in RSU coverage area.
Each OBU node runs the three modeled services: Warning service (DEN messages with mean Poisson arrival rate $\lambda 1$= 10 messages/s), Measurement service (CAM messages with mean Poisson arrival rate $\lambda 2$ =10 messages/s and road warning event (CoDM messages with mean Poisson arrival rate $\lambda 3$= 1 messages/s).

These services are mapped to EDCA Access categories according to Table 5 and present the traffic models defined in section 4. The envisioned services generate packets which are sent on the service channel SCH N°176, with a constant propagation model. The transmission rate 6Mb/s is controlled by a rate manager algorithm, and a -10db of gain is considered. The vehicle number varies in the range of [5…100] in step of 5 vehicles, which correspond to: 18, 35, 53, 71, 88…354 vehicles/Km².

6.2 Simulation and analytic measurements:

Our work aims at determining the maximum vehicles number in the RSU coverage area and the RSU capacity to transmit ITS messages. For this purpose, we are interested by measuring the average packet loss rate and delay. Figure 8 shows a comparison between average packet loss rates in function of the vehicle number. Each curve is related to an ITS service (warning, measurement and road warning event).
First, we note that packet loss rate increases moderately when traffic density varies between 20 and 80 vehicles, but beyond that, the rate increases significantly for all application services. In fact, the more vehicles are associated to a single RSU, the more the vehicles experience backoff process and the higher the collision rate is.
Another observation concerns the service differentiation which is well illustrated by the different packet loss rates experienced by the three services. More precisely, road warning service experience higher packet loss rate than that of measurement which is higher than that of warning message. This is mainly due to the different priority levels allocated to the services.

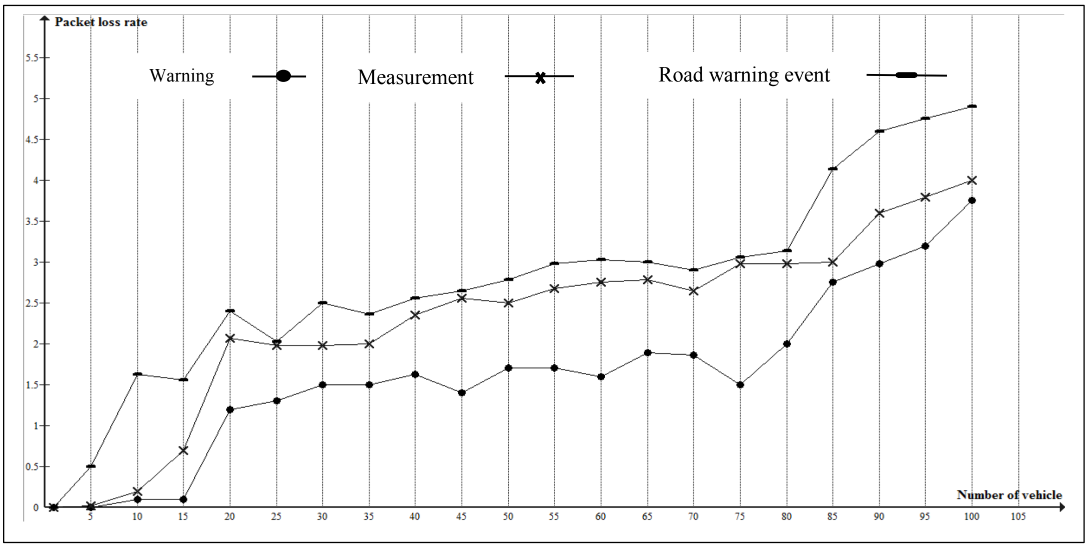


Figure 8. Packet loss rate VS vehicles number.

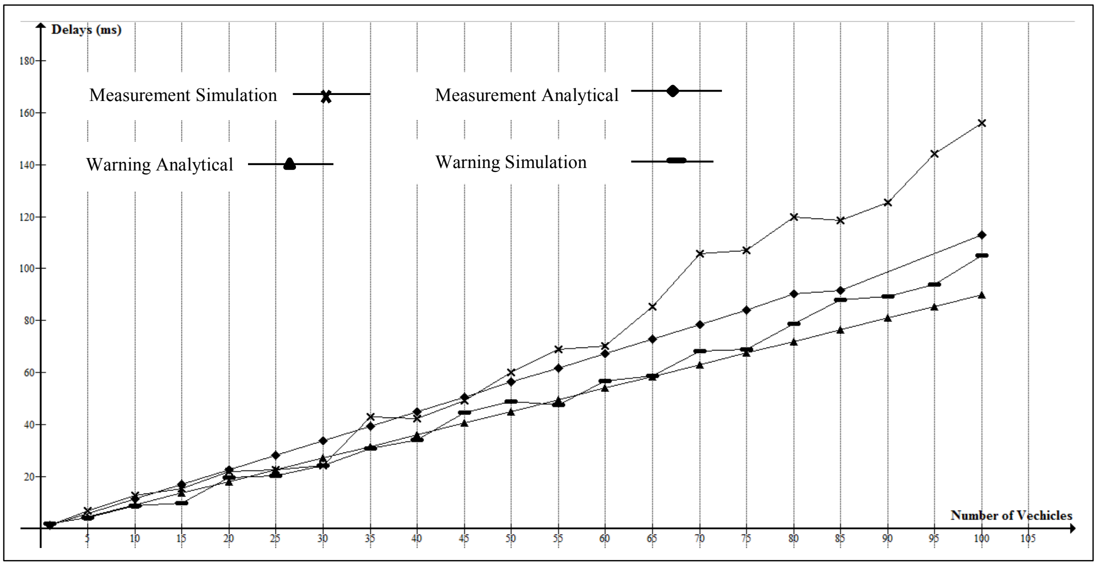


Figure 9. End to end delay of measurement and warning service VS vehicles number.

The end to end delay is a QoS parameter of paramount importance in vehicular networks, especially when it concerns warning and measurement messages which carry critical information. It is to be noted that the end to end packet delay corresponds to the sum of transmission and waiting time.
Figure 9 illustrates the end-to-end average delay in function of the vehicle numbers for each of the two critical services (warning, measurement). The curves concern analytical and simulation results. We observe that when vehicles number varies in the range of [5...30] the delay is almost the same for both services. However, it increases significantly for measurement service when vehicle number exceeds 45. The warning delay is more regular in the range [5...80]. This result confirms the EDCA performance which succeeds at prioritizing warning over measurement service.
An important finding concerns the linear curve for analytical measurement, as exhibited in figure 9. In fact, backoff evolution is a linear function of road traffic load for different zone ranges (300m, 500m and 900m). Reader may refer to reference [25].

7. CONCLUSION

Wireless vehicular networks perform crucial functions in road safety, detecting and avoiding traffic accidents, reducing traffic congestion as well as improving driving comfort. In this paper, we shed the light on three ITS services: warning to a foggy zone, inter-distance measurement and road warning event. Since QoS performance is highly sensitive to traffic statistical distribution, we started by modeling the services traffic. Then, we oriented our efforts towards modeling the ETSI high layers (facilities, network) and MAC layer that process packets generated by the three mentioned services. The proposed model is based respectively on BCMP and M/GI/1 queuing model. We evaluated then the performance of a vehicular network through measuring packet loss rate and end-to-end delay obtained by the mathematical modeling and simulation. Analytical and simulation results confirm the service differentiation and the respect of the critical nature of warning service.
Moreover, we have derived the range of vehicle density at which QoS metrics start to highly increase. In our future work, we target at improving the mobility model by taking into account a car-to-car following model.

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