

# TRANSPARENT GAP FILLER SOLUTION OVER A DVB-RCS2 SATELLITE PLATFORM IN A RAILWAY SCENARIO: PERFORMANCE EVALUATION STUDY

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**Abstract.** In this work, a performance study of a system equipped with a transparent Gap Filler solution in a DVB-RCS2 satellite platform has been provided. In particular, a simulation model based on a 3-state Markov chain, overcoming the blockage status through the introduction of a transparent Gap Filler (using devices on both tunnel sides) has been implemented. The handover time, due to switching mechanism between satellite and Gap Filler, has been taken into account. As reference scenario, the railway market has been considered, which is characterized by a N-LOS condition, due to service disruptions caused by tunnels, vegetation and buildings. The system performance, in terms of end-to-end delay, queue size and packet loss percentage, have been evaluated, in order to prove the goodness of communications in a real railroad path.

cal and maritime scenarios the environment conditions can be considered as Line-Of-Sight (LOS), in terrestrial ones the transmissions are sometimes interrupted by obstacles, which inhibit communications. In order to prevent this issue, many works exist, aimed to analyze satellite communications in the terrestrial scenario. In this paper, on the basis of previous works on channel studies over other technologies [10], a channel model has been studied for Land Mobile Satellite Communication (LMSC), and its performance have been deeply analyzed. It relies on a 3-state Markov channel model, each one representing the condition of LOS, Shadowing and Blockage respectively, that is to say, the three main conditions suffered onboard a train. In this work, the attention has been focused on the Blockage state, as illustrated in Fig. 1, and a mechanism for facing with this issue is proposed.

## Keywords

Blockage, DVB-RCS2, gap filler, railway, satellite.

## 1. Introduction

The current trend in telecommunication networks is towards convergence of communication services [1], [2]. Satellite systems have a key role in future integrated networks. They often represent the only means to provide network access due to lack of suitable terrestrial infrastructure or to economic factors in remote areas. Moreover, they play a key role also in transportation market communications, like trains, ships, vehicles, aircrafts [3], [4]. In this scenario multicast applications [5], scheduling [6] and routing [7], [8], [9] algorithms are important topics of research. While in aeronauti-

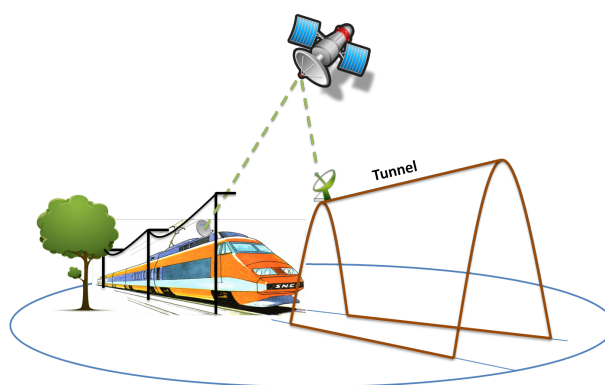


Fig. 1: Railway scenario with tunnel.

A performance study of a system equipped with a transparent Gap Filler (GF) solution in a Digital Video Broadcasting - Return Channel Satellite second generation (DVB-RCS2) [11], [12] satellite platform has been provided. The handover time, due to switching mechanism between satellite and GF, has been taken

into account. As reference scenario, the railway market has been considered, which is characterized by a Non-Light-Of-Sight (N-LOS) condition, due to service disruptions caused by tunnels, vegetation and buildings. This work is organized as follows: Section 2. presents the main existing works in the available literature; in Section 3. the channel models for satellite communications are shown; Section 4. describes the Railroad Satellite Channel (RCS) with the introduction of the GF solution; Section 5. describes simulation environment and, last, performance evaluation and conclusions are summarized respectively in Section 6. .

## 2. Related Work and Contribution

The GF issue is an important and relevant topic, deeply analyzed by the scientific community. Also, many projects have been funded in order to investigate the possible solutions to blockage conditions. In [13] the performance of the DVB-S air interface over the Railroad Satellite Channel (RSC) at Ku-band is investigated and tested, in order to show the resulting link quality of satellite system. The article in [14] is based on FIFTH (Fast Internet for Fast Train Hosts) Project, co-founded by European Commission in the 5<sup>th</sup> Framework IST. It proposes a new and challenging network solution to make available the Internet access through broadband GEO satellite access to the passengers of the high-speed train. A demonstrator has been implemented in a real railway coach to execute experimentations on the Italian Railway Network. In [15] the authors investigate how to provide connectivity to train passengers, considering the blockage caused by tunnels. They propose the realization of GFs in DVB-H and DVB-T technologies. In [16] the authors face with the connectivity problems in railway tunnel environments. They provide a study in order to indicate the best frequency to use inside the tunnels in order to propagate the signal when the train is into the tunnel. Tunnel disruption is also faced with DTN technique based on a new "bundle layer" [17]. Moreover, they study the impact of the switching mechanism when the train enters into the tunnel and when the train leaves it. A study on handover procedure is proposed in order to provide a relation between train speed and handover time. In [18] the authors investigate a ray tracing propagation mechanism inside tunnels in a DVB-S platform equipped with GF, able to extend signal connectivity inside tunnels. They study the channel impulse response in order to derive a bit error rate scheme able to take into account the position of the train along the tunnel. They try to provide an analytical expression of the system outage and of the transmitted power required to guarantee coverage connectivity. In [19] the

authors propose to use a semi-transparent GF solution in DVB-H technology able to use OFDM modulation that results in more robust respect to the multipath propagation. In [20] the authors, on the basis of a trial and measurement campaign, carried out in spring 2004 within the FIFTH project, show the obtained results in order to provide a statistical characterization of the behavior of the railroad satellite channel. Our paper provides a study of the performance of a DVB-RCS2 system, taking into account the 'handover time'/'train speed' correlation found in [16], and considering a simulation software implementing the, so called, 3-state Markov channel model. The simulation campaigns provide results in terms of delay, queue size and packet loss percentage, in order to show the goodness of proposed work.

## 3. Channel Models for Satellite Communications

In vehicular satellite communications, the channel model which is used for mobile terminals is the Land Mobile Satellite Channel (LMSC) [21]. It has been widely studied in literature, as demonstrated by the huge amount of references about it [22], [23], [24], [25], [26]. All the publications state how it is possible to model the satellite channel by employing the results of different simulation campaigns, in the Ka and Ku frequency bands. In this paper, the Ku band has been considered in particular. As stated in the literature [21], the LMSC can be modeled as a Finite State Markov Chain (FSMC). A deep study of the model in literature, in order to describe the behavior of the radio link between the satellite and mobile users, onboard of a moving train has been made.

### 3.1. Land Mobile Satellite Channel

In this study, it is needed to introduce the FSMC to consider more realistic conditions in satellite communications and the fluctuations in the received signal level, due to the various propagation phenomena during a generic connection (shadowing, refraction, fading, etc.). In this way, simulations are affected by the variations of physical parameters. In general, as known from the literature, given a Markovian model, each chain state has an associated ratio, which represents the received percentage of corrupted bits. Letting  $S = \{s_0, s_1, \dots, s_{K-1}\}$  denote a finite set of states and  $\{S_n\}$ ,  $n = 0, 1, 2, \dots$  be a constant Markov process with the property of stationary transitions, then the transition probability is independent of the time index  $n$  and can be written as in Eq. (1).

$$t_{j,k} = P_r(S_{n+1} = s_k | S_n = s_j). \tag{1}$$

$$\mathbf{T} = \begin{bmatrix} T_{0,0} & T_{0,1} & T_{0,2} \\ T_{1,0} & T_{1,1} & T_{1,2} \\ T_{2,0} & T_{2,1} & T_{2,2} \end{bmatrix}, \vec{p} = \begin{bmatrix} p_0 \\ p_1 \\ p_2 \end{bmatrix}, \vec{e} = \begin{bmatrix} e_0 \\ e_1 \\ e_2 \end{bmatrix}. \tag{2}$$

For all  $n = 0, 1, 2, \dots$ , and  $j, k \in 0, 1, 2, \dots, K - 1$ . It is possible also define a  $K \times K$  state transition probability matrix  $\mathbf{T}$  with elements  $t_{j,k}$ . Moreover, with the stationary transition property, the probability of state  $k$  without any state information at other time indexes can also be defined as  $p_k = P_r(S_n = s_k)$ , where  $k \in 0, 1, 2, \dots, K - 1$ , so a  $K \times 1$  steady probability vector  $\vec{p}$  can be defined with its element  $p_k$ . To complete the description of the chain model, additional information on the channel quality for each state is required, so it is possible define a  $K \times 1$  probability density functions vector  $\vec{e}$ , with its elements  $e_k$ ,  $k \in 0, 1, 2, \dots, K - 1$ . Each element of  $e$  represents the probability density function (pdf) associated to the received signal strength (considered as a stochastic variable). At this point, the FSMC is completely defined by  $\mathbf{T}$ ,  $\vec{p}$ , and  $\vec{e}$ . More details on the modeling and a graphical representation can be found in [21].

From [21] it is easy to verify that, for the considered satellite context, it has been shown that, for  $K = 3$ , the model is able to describe the evolution of the wireless link accurately. In particular, following the theory and measurements of [21] the elements of the Markovian model are the ones in Eq. (2):

In particular, the statistical model in [21] has been considered, strictly related to the Ku band, for which the different chain states have the following meaning (see Fig. 2):

- State 0 (Line of Sight - LOS): the satellite is directly related to the receiver, without any obstacles, with a high value of received signal strength.
- State 1 (Shadowing - SHW): the satellite signal is partially obfuscated by some obstacles or reflected by some objects; the received signal strength is sometimes low; this state represents an average condition, with some obstructions like trees, homes, leaves, etc.
- State 2 (Blockage - BLK): the satellite is not able to transmit to destination, since big obstacles are present on the path, such as tunnels, mountains or tall buildings.

Let us now have a look at the main parameters  $\mathbf{T}$ ,  $\vec{p}$  and  $\vec{e}$  of the considered FSMC model.

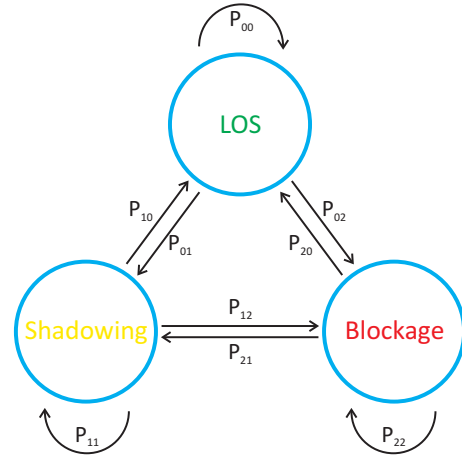


Fig. 2: 3-State Markov channel model.

From [22], some examples of the FSMC parameters for different scenario are illustrated in Tab. 1.

Tab. 1: FMSC parameters.

Environment	State transition matrix			S	Rice factor
Highway	0.9862	0.0138	0.0000	0.8922	17 dB
	0.1499	0.8378	0.0123	0.0823	-1.6 dB
	0.0008	0.0396	0.9596	0.0255	
Rural	0.9795	0.0204	0.0001	0.7844	17 dB
	0.1007	0.8277	0.0716	0.1556	1.2 dB
	0.0010	0.1813	0.8177	0.0600	
Suburban	0.9796	0.0204	0.0000	0.7831	18 dB
	0.0929	0.8571	0.0500	0.1715	2.6 dB
	0.0015	0.1876	0.8109	0.0454	
Urban	0.9902	0.0097	0.0001	0.6025	17 dB
	0.0714	0.8756	0.0530	0.0825	3.7 dB
	0.0000	0.0140	0.9860	0.3150	

Regarding the 3-state Markov channel model, the elements of the  $\vec{e}$  vector can be defined as follow.

The **Line of Sight (LOS)** state is the first one and it is modeled by a Rice distribution as following:

$$P_{Rice}(s) = c \cdot e^{-c(s+1)} \cdot I_0(2c\sqrt{s}), \tag{3}$$

where:  $I_0()$  is Bessel function of first kind of zero order

The Rice factor  $c$  (ratio between direct signal power and multipath one) is comprised between 17 dB and 18 dB, depending on the terminal environment, as a result of the use of the directive antenna.

The Shadowing state is the second one, and it is caused by vegetation and other small objects. It is modeled by a Suzuki/Lognormal-Rayleigh distribution of received power  $s$ :

$$P_{Suzuki}(s) = \int_0^\infty P_{Rayleigh}\left(\frac{s}{s_0}\right) \cdot P_{lognormal}(s_0) d_{s_0}, \quad (4)$$

where:

- $P_{Rayleigh}\left(\frac{s}{s_0}\right) = \frac{1}{s_0} e^{-\frac{s}{s_0}}$ .
- $P_{lognormal}(s_0) = \frac{1}{\sqrt{2\pi\sigma\ln 10}} \cdot \frac{1}{s_0} e^{-\frac{(10\log s_0 - \mu)^2}{2\sigma^2}}$ .
- $s_0$  is the average received power due to slow fading, it follows a lognormal distribution.
- $\mu$  is the decreasing of average power level (in dB).
- $\sigma^2$  is the variance of power level due to shadowing.

The Rayleigh term considers the multipath phenomena.

The Blockage state is a third one, and it is due mainly to big buildings and tunnels.

In [21], many measurement campaigns performed in the south of Germany have classified the environment in: highway (an open area characterized by an high train speed), rural (mainly composed of open area, streets with trees and forests characterized by a moderate speed around  $60/70 \text{ km}\cdot\text{h}^{-1}$ ), suburban (village and small cities with small obstacles with a speed below  $50 \text{ km}\cdot\text{h}^{-1}$ ), urban (tall buildings that produce signal blockage and characterized by a low velocity, under  $50 \text{ km}\cdot\text{h}^{-1}$ ).

## 4. Railroad Satellite Channel

On the basis of [23] the main solutions adopted in RSC are now illustrated. RSC is specific to railroad environment, in which there are brief fading phenomena due to power arches or long term fading (because of tunnels and/or tall buildings). Generally, it is possible to consider two scenarios, one in direct visibility with the satellite (LOS) and the other tie to GF solution for blockage issue.

### 4.1. Gap Filler Solutions

The signal degradation in a railroad scenario is due mainly to power arches, vegetation, buildings (shadowing) and, in the blockage case, to tunnels and tall buildings. While for resolving shadowing issue it is

possible to operate temporal diversity, FEC packets, long channel interleaving, instead when there are tunnels, the signal transmission is impossible. Then, it is necessary to provide GF solution with devices that are able to transmit signals inside the tunnels. There exist different gap filling technologies for seamless satellite connectivity in a high-speed train. GF can be classified in two main category: one is Transparent GF method and the other is a Non-transparent method.

Transparent Gap Filling configuration provides only air interface (coding, modulation, and frequency) changing, no need for new packet decapsulation / encapsulation and new Real-Time Resource Management (RTRM). Just frequency conversion gap filling method is included in the transparent configuration.

Non-Transparent Gap Filling configuration, instead, provides air interface and/or data packet format changing. New RTRM may be required. There are two methods for realizing it: a Satellite-Based Access Point (SB-AP) for direct extension of the service hot-spots inside the tunnel and a Terrestrial Network Node (TNN) for seamless connection to the WiMAX or WiFi services. For these methods, the network layer, as well as the air interface, should be changed for the gap filling. For the SB-AP model method, the GF (connected to the satellite terminal mounted at the edge of the tunnel) gets the forward DVB-S2 signal from satellite and regenerate WiMAX or WiFi (for short tunnels) signals. In return, the GF will receive the WiMAX or WiFi signals from passengers and data will be recovered for regeneration of DVB-RCS signals. WiMAX to WiFi conversion may be necessary on-board the train considering the tunnel length. For the TNN extension method, WiMAX or WiFi RF nodes are extended into the tunnel without satellite support.

In our study, a transparent GF solution has been chosen for facing the issue introduced by a tunnel in the train's path. The considered GF solution takes into account the time values obtained in [16], where handover time values, due to the switching from satellite to GF on the tunnel entrance and from GF to satellite on the tunnel exit, are shown for different trains speed. Therefore, on the basis of a detailed study of the lower link layers for railway scenario, Mobile Terminals (MTs) mounted on trains, where the end-users are the passengers accessing to applications like HTTP, FTP, and Video Conference, have been implemented in the simulator. The time necessary for handover procedure has been calculated with a linear regression curve on the basis of the values indicated in [16].

In the regression model it has been assumed that the regression function  $f(x)$  is linear, that is:

$$Y = \beta_0 + \beta_1 X, \quad (5)$$

where  $\beta_0$  and  $\beta_1$  are unknown values, called regression coefficient. The linear model approximates with a straight line the function. In our case, the independent variable  $Y$  is the train speed while the dependent variable  $X$  is the handover time.

Let  $y_i = \beta_0 + \beta_1 x_i$  the value of  $Y$  obtained from estimated curve in correspondence of  $x_i$  value, where  $\beta_0$  and  $\beta_1$  are estimated regression coefficients. It is necessary to calculate the estimated values  $\vec{y}_1, \vec{y}_2, \dots, \vec{y}_n$  as near as possible to observed values  $\vec{y}_1, \vec{y}_2, \dots, \vec{y}_n$ . Through least squares method it is possible to obtain the estimation of the regression coefficients:

$$\beta_1 = \frac{\sigma_{XY}}{\sigma_X^2} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^n (x_i - \bar{x})^2}, \quad (6)$$

where  $\sigma_{XY}$  is the covariance of  $XY$  and  $\sigma_X^2$  is the variance of  $X$  and

$$\beta_0 = \bar{y} - \beta_1 \bar{x}. \quad (7)$$

The determination coefficient  $R_{XY}^2$  indicates the proportion of the variability of  $Y$  explained by the explanatory variable  $X$ , through the regression model. It is:

$$R_{XY}^2 = \left( \frac{\sigma_{XY}}{\sigma_X \sigma_Y} \right)^2, \quad (8)$$

where  $\sigma_{XY}$  is the covariance of  $XY$ , while  $\sigma_X$  and  $\sigma_Y$  represent the standard deviation of  $X$  and  $Y$ . The determination coefficient varies between 0 and 1: its value is 0 in the absence of linear statistical relation between observations. Its value is 1 when there is a perfect linear dependence. Then, the more this ratio is close to 1 the greater the fit goodness of the estimated model to observed data. In our case, the calculated regression line, shown in Fig. 3, is:

$$Y = -0.0027X + 1.341. \quad (9)$$

$R_{XY}^2$  value is 0.9868 and, then, the linear model can be considered quite accurate. Substituting the train speed value to  $X$  it is possible to obtain different handover time values, that are used in the software simulation.

## 5. Simulation Environment

The simulation software is realized in Java and permits to analyze the performance of the considered system. In particular, the considered parameters are: end-to-end (e2e) delay, queue size, and packet loss. Moreover, the software allows to choose between two mobile railway scenarios: Fixed Scenario (FS) and Random Scenario (RS). In the first one it is possible to

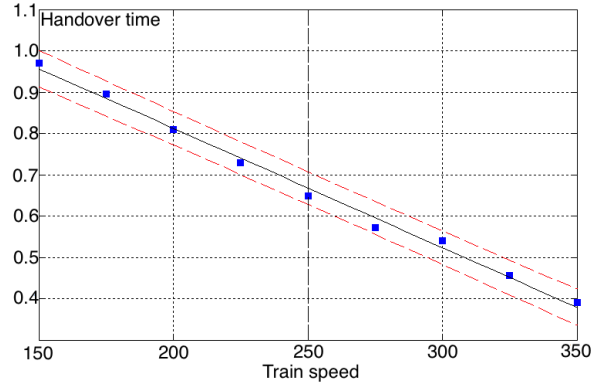


Fig. 3: Linear regression trend for handover time computation.

insert a particular real railroad path. In the second one, the train path is generated in a random way following, the LMSC/RSC model taking into account the 3-state Markov model. Then, the considered scenario is a DVB-RCS2 standard for railway environment. The simulation parameters used in the simulation campaigns are shown in the following:

Tab. 2: Simulation parameters.

Simulation parameters				
Global capacity	10 MHz			
Capacity of RCST MF-TDMA (%)	100			
Capacity of RCST SCPS (%)	0			
MF-TDMA carrier	500 kHz			
SCPC carrier	500 kHz			
MF-TDMA FEC	2/3			
SCPC FEC	3/4			
Scheduler	FIFO, Round Robin (RR)			
Mobile RCST terminals	5, 10, 20			
Average RCST speed	200 km·h <sup>-1</sup>			
Users	30, 40, 50, 60			
Scenario		HTTP	FTP	VIDEO
	1	60 %	25 %	15 %
	2	60 %	20 %	20 %
	3	60 %	15 %	25 %

### 5.1. Railway Scenario

In our study the high-speed railway path Rome-Naples is taken as reference scenario, as shown in Fig. 4 which has the following characteristics:

- Total length of about 205 km.
- Open area length 168 km.
- Tunnels 37 km.
- Maximum speed 300 km·h<sup>-1</sup>.





Fig. 4: Rome-Naples railway path.

The high-speed railroad path Rome-Naples, as illustrated in Fig. 4, is in the Lazio and Campania territories and it is about 205 km long; it crosses 61 countries in the cities of Rome, Frosinone, Naples and Caserta and it is for about 63 % of Lazio region and for the 37 % of Campania’s one.

### 5.2. Performance Evaluation

In order to evaluate the performance of the DVB-RCS2 system with a 3-state Markov channel model and a transparent GF solution, many simulation campaigns have been carried out, and some of the results are shown in the following. The three performance parameters considered in simulations are packet loss percentage, end-to-end delay, and queue size. These parameters give us a good indication of the goodness of system performance and, then, provide some indications to the network operators, when they have to make some system budgets or choices. As shown in Tab. 2, in the railroad scenario 5, 10 and 20 mobile terminals (trains) have been considered in the simulation campaigns hosting 30, 40, 50, 60 passengers accessing to applications like HTTP, FTP and Video Conference. In this work no call admission control mechanism has been took into account [27], [28]. Two category capacities have been considered in the DVB-RCS2 system: Rate Based Dynamic Capacity (RBDC) and Volume Based Dynamic Capacity (VBDC) which map Video Conference, and HTTP / FTP respectively. For the simulations campaigns three different scenarios have been considered in which three different user applications percentage have been simulated. The considered scenario for the simulations shown in this article is scenario 3. In Tab. 2 it is possible to see how applications percentage are divided.

Figure 5 shows the packet loss percentage varying the number of passengers and considering 5, 10 and 20 trains. It is possible to note the trend of the curves both for RBDC and VBDC capacity category. The figure shows that the percentage of packet loss is about less than 1 % for the RBDC case and about less than 2.5 % for VBDC one. This shows a loss that allows of respecting QoS constraints, especially for applications like Video Conference. Also for VBDC the losses highlighted by simulations and, then, positive results for the correct use of passengers applications.

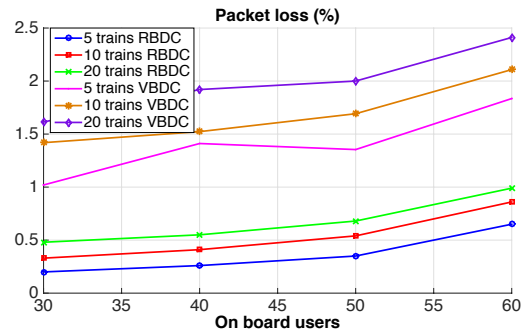


Fig. 5: Packet loss percentage for 5, 10, 20 mobile terminals.

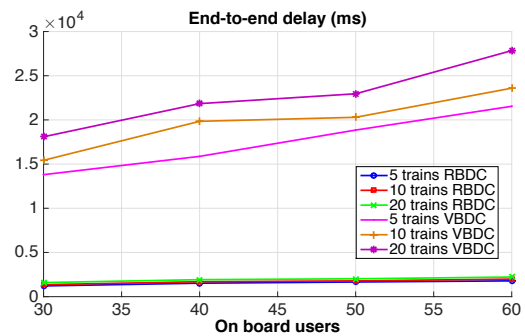


Fig. 6: End-to-end delay for 5, 10, 20 mobile terminals.

Figure 6 shows the end-to-end delay for RBDC and VBDC classes of traffic and highlights low delay for RBDC case, and higher for VBDC that maps applications can support higher delay.

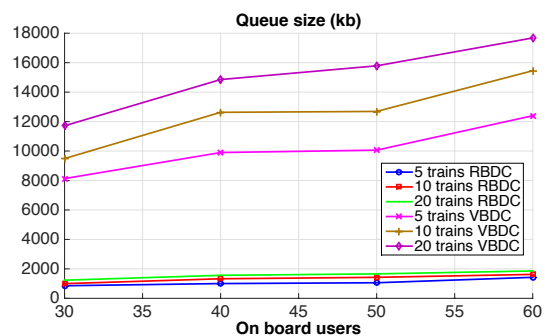


Fig. 7: Queue size for 5, 10, 20 mobile terminals.

Lastly, Fig. 7 shows the queue size trend and gives an indication about this QoS parameters. It is possible to note that the obtained values prove the goodness of studied system.

## 6. Conclusion

In this work, the performance of a DVB-RCS2 railway scenario with a transparent GF solution have been shown. In order to take into account a realistic scenario, a 3-state Markov channel model has been implemented in our simulation software. The Blockage state

has been analyzed in order to study the performance of the system equipped with a seamless GF solution. Our solution provides for placing signal repeater device at the ingress and the egress of tunnels. The synchronization time spent from the Mobile Terminal (Train) in order to be able of transmitting data information has been analyzed, carrying out a series of simulation campaigns aiming to show the packet loss percentage in the considered scenario. The simulation results show that a low packet loss percentage affects the system when the trains switch between satellite and GF devices. Then, the implemented solution is so able to guarantee satisfactory QoS levels inside the system.

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