Simulation of a Feasible Galileo System Operating in L1 and E5 Bands

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Abstract. Galileo is the program that has been launched by the European Union for the purpose of building a Global Navigation Satellite System (GNSS) for serving civilians and to exist under civil control. Our project combines many previous researched scenarios for Galileo system to a final one, which has been simulated and adjusted to meet the most demanding standards (of proposed GNSS services). The final simulated scenario is consisted of 30 (27+3 spare) satellites allocated in 3 orbital planes.

Keywords: Galileo, GPS, GNSS, BPSK, BOC, EIRP, RAAN, Satellite coverage, Satellite access time, BER.

1 Introduction

GPS was built by the US as a revolutionary precise positioning system in order to play a key role in various military operations. But almost twenty years ago a change of scene took place considering the need for additional GPS civil services. Due to its primary goal and institutional status, GPS cannot guarantee such kind of services which would keep up the pace with the actual increasing rate of satellite demanding applications.

Galileo will fill the actual gap of high quality satellite services absence, in terms of performance, better signal tracking and therefore position accuracy. In comparison to GPS it will not be controlled by any government. GNSS Supervisory Authority and the Concessionaire will be responsible for the whole project.

The Galileo system will be consisted of 27 satellites in MEO (Medium Earth Orbit) with 3 additional spare satellites intended for broadcasting navigational signals. This constellation will provide 4 kinds of navigation services such as Open Service, Safety-of-Life Service, Commercial Service and Public Regulated Service [1]. Consequently, development of scientific fields such as GNSS-R altimeter for characterizing mesoscale ocean feature, sea-ice altimetry and soil moisture monitoring will be major breakthroughs of GNSS reflectometry [2].

In this paper, taking into consideration previous mentioned needs for better performance we study various proposed scenarios for Open Service (L1 and E5 frequency bands). This is the first stage of our work followed by the second stage where

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we investigate the feasibility of combining all proposed systems to a final and even better one. In this way, we conclude in constructing a scenario consisted of a constellation of 30 satellites (27 + 3 spares). Final stage is devoted in the simulation procedures and results.

2 Technical Specifications of the Proposed Galileo System

Binary offset carrier (BOC) modulation will be used for the purpose of sharing the same centre frequency among various GNSSs. It has advantages compared to BPSK modulation from the aspect of frequency correlation function. In this function the main lobe of BOC signal is narrower and in turn provides higher positioning accuracy [3], [4].

The Galileo Open Service signal (L1) will be consisted from BOC signals. Symbolic expression of BOC(f_S, f_C) is transformed to BOC(1,1) for a given subcarrier frequency of f_S = 1.023 MHz and chipping rate of f_C = 1.023 MHz. Signal characteristics for the simulated Galileo system including Data rates and Chip rates are summarized in Table 1 [5], [6].

Table 1. Signal characteristics of the simulated Galileo system

Standard	Galileo E1	E5a
Frequency (MHz)	1575.42	1176.45
Bandwidth (MHz)	4.092	25.575
Modulation	BOC(1,1)	BPSK
Data rate (bps)	250	50
Chip rate (Mcps)	1.023	10.23

For the purpose of simulating Galileo system under real conditions, we included in our scenario signal propagation characteristics. These characteristics consisted of free space path loss, Ionospheric and Tropospheric path delay, Ionospheric and Tropospheric amplitude scintillation, Ionospheric and Tropospheric phase scintillation, Ionospheric refraction, Ionospheric Doppler shift, foliage attenuation, worst case scenario for attenuation by water vapor and oxygen, worst case scenario for rainfall, clouds and fog attenuation. Total signal attenuation was equal to 189.3 dB, satellite and user gain antenna equal to 14 dB and 0 dB respectively [7], [8].

EIRP of each satellite was equal to 12.3 dBW and all receivers' sensitivity equal to -144 dBm [5].

Orbital parameters of all satellites were based on our modifications of GIOVE-A satellite. Apogee and perigee altitude was equal to 23616 km. Inclination and argument of perigee was equal to 56 deg and 317 deg respectively. Right ascension of the ascending node (RAAN) and true anomaly had various values according to 3 satellite planes defined by Walker tool in Satellite toolkit [9], [10].

Table 2 shows all orbital characteristics of 30 satellites constituting the proposed Galileo system.

Table 2. Orbital parameters of simulated Galileo system (apogee and perigee altitude equals to 23616 km and mean motion equals to 1.6713 revs/day for all satellites)

Proposed Satellite name	Inclination (deg)	Argument of perigee (deg)	RAAN (deg)	True Anomaly (deg)
GioveA101 spare	56	317	186	0
GioveA102	56	317	186	36
GioveA103	56	317	186	72
GioveA104	56	317	186	108
GioveA105	56	317	186	144
GioveA106	56	317	186	180
GioveA107	56	317	186	216
GioveA108	56	317	186	252
GioveA109	56	317	186	288
GioveA110	56	317	186	324
GioveA201 spare	56	317	306	12
GioveA202	56	317	306	48
GioveA203	56	317	306	84
GioveA204	56	317	306	120
GioveA205	56	317	306	156
GioveA206	56	317	306	192
GioveA207	56	317	306	228
GioveA208	56	317	306	264
GioveA209	56	317	306	300
GioveA210	56	317	306	336
GioveA301 spare	56	317	66	24
GioveA302	56	317	66	60
GioveA303	56	317	66	96
GioveA304	56	317	66	132
GioveA305	56	317	66	168
GioveA306	56	317	66	204
GioveA307	56	317	66	240
GioveA308	56	317	66	276
GioveA309	56	317	66	312
GioveA310	56	317	66	348

3 Results and Discussion

In order to demonstrate the efficiency of the proposed Galileo system, we inserted a vehicle in our simulation. Vehicle was set to move on an ideal straight line ranging from Thessaloniki (Greece) to Berlin (Germany). Average speed of 80 km/h was assumed. Hardware characteristics of portable Galileo system which were located on the vehicle and onboard satellites are described in the previous section. For the purpose of confirming good theory of operation, coverage (FOM satisfaction) and access time graphs are presented. Coverage is the existence of a clear line of sight from one object to another. Also, Access tool allows determining the times one object can access another object. It models transmission according to the constraints set by the user [10].

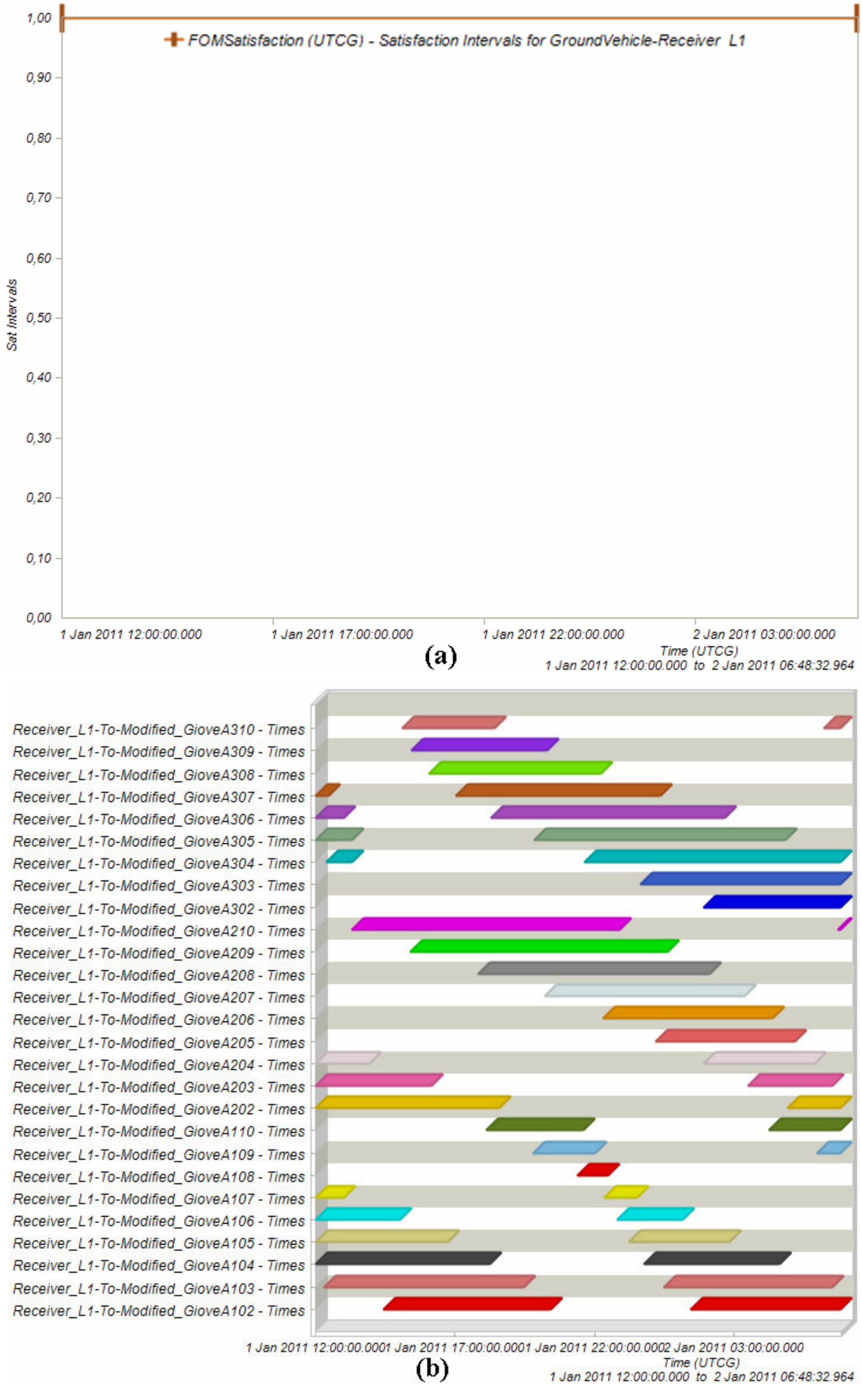


Fig. 1. (a) FOM satisfaction for vehicle receiver and (b) Accessing to Galileo system

FOM satisfaction diagram (Fig. 1a) for vehicle receiver (bands L1+E5a) shows real time coverage from Galileo system. In turn, this is essential for accomplishing real time accessing. The previous principle is shown in Fig. 2b by presenting each satellite access time in relation to vehicle receiver. Time gaps were expected due to medium earth orbits of Galileo system. Nevertheless, they do not affect the final outcome of accomplishing real time data transfer, because multi-locking procedure of several Galileo satellites at the same time gives excellent results.

In Fig. 2a is presented the simulation scenario of Galileo system and moving vehicle in 2 dimensions. Fig. 3 shows real time accessing in 3D representation (denoted with lines ranging from each satellite to vehicle).

Using link budget analysis, we investigated BER performance for all Galileo satellite links of the moving vehicle. BER was found in most occasions not to supersede the value of 10^{-3} [11]. The previous result is linked with worst case scenario noise, included in simulation computations.

Also, diagrams are shown (Fig 4) which are related with accessing Galileo system (27 satellites) from its spare satellites. These diagrams explain the reason of choosing the certain spare satellites orbital parameters (Table 2). Graphical results which are derived from Fig.3 (a) (b) and (c) are summarized in Table 3.

Table 3. Observations in accessing Galileo system from each spare satellite

Real time accessing specifications	Accessing from GioveA101 spare	Accessing from GioveA201 spare	Accessing from GioveA301 spare
Absence of satellite accessing	GioveA106	GioveA206	GioveA306
Time accessing under conditions (with gaps)	GioveA203 GioveA204 GioveA307 GioveA308	GioveA303 GioveA304 GioveA108 GioveA109	GioveA104 GioveA105 GioveA208 GioveA209
Real time access	All others	All others	All others

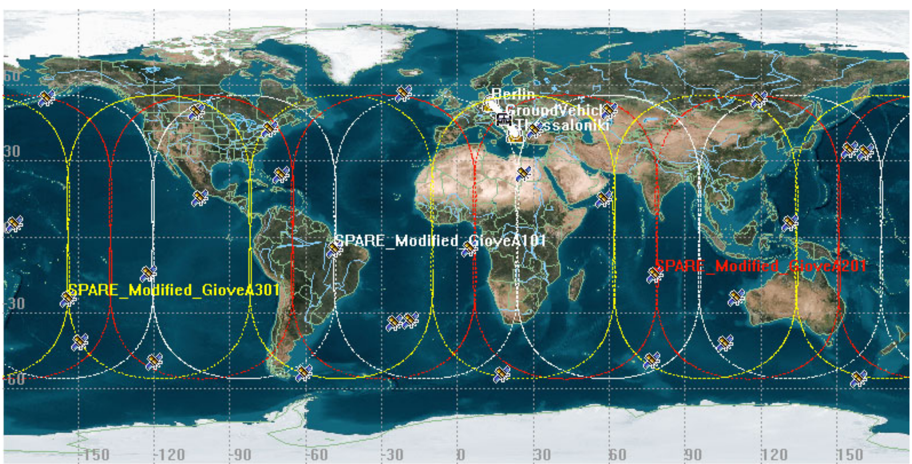


Fig. 2. 2D representation of Galileo system (only spare satellites orbits are shown)

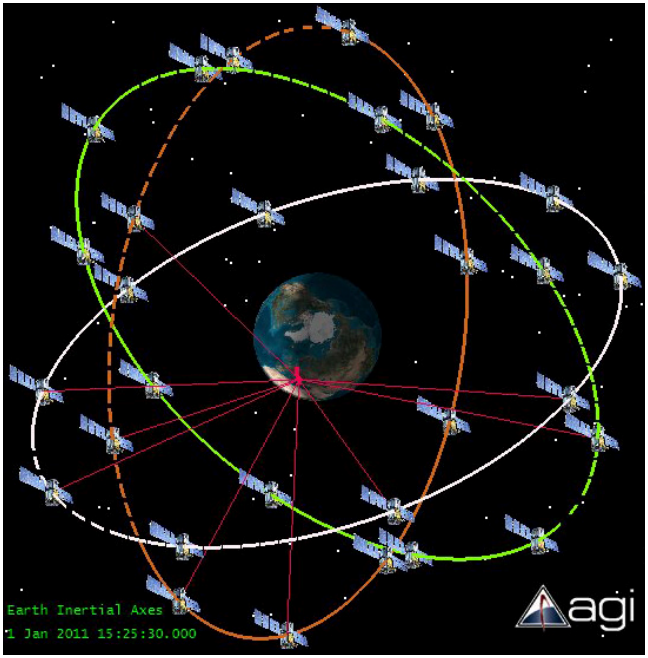
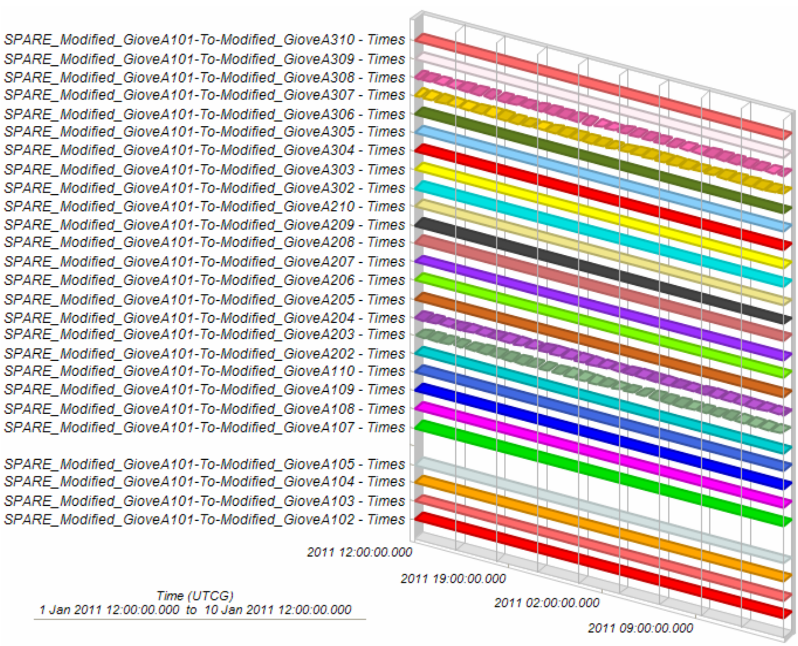
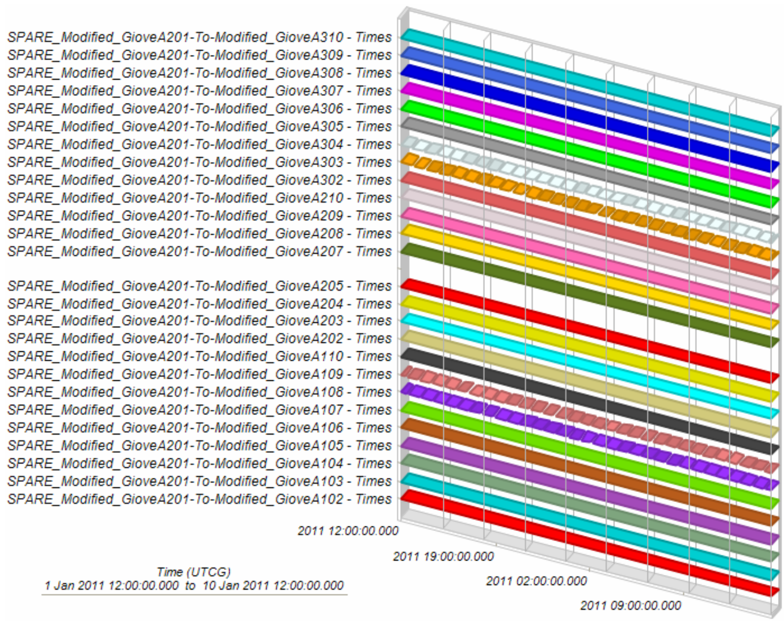


Fig. 3. 3D representation of simulated system

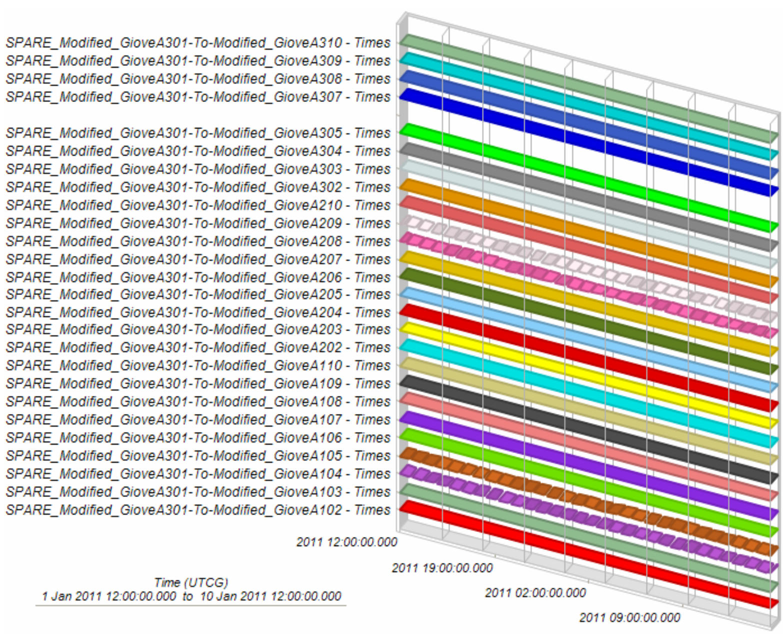


(a)

Fig. 4. Time accessing for spare satellites (a) GioveA101, (b) GioveA201 and (c) GioveA301



(b)



(c)

Fig. 4. (*Continued*)

4 Conclusion

In this paper we presented a study that has been based on the modification of an existing satellite called GIOVE-A. The main purpose was to find all orbit parameters of a satellite constellation that could constitute Galileo system. Consequently simulation of this system was conducted in order to determine good theory of operation even under worst case scenario noise. Results confirmed the feasibility of the proposed system working in L1 and E5a bands through the existence of real time accessing to various mobile units all over the world.

Another outcome of this project would be to investigate and if possible to develop a new scenario unifying services provided by GPS, GLONASS and Galileo for the benefit of the final user. A next step to our research will be also to investigate (based on our method of finding orbit elements for Galileo system) the feasibility of GPS III system under real conditions in order to verify its interoperability even under worst jamming conditions. Finally, a simulation will be conducted for unifying services of Galileo and GPS III systems using the outcome of technology based on previously manufactured or researched hardware components like synthetically generated, phased-array antennas for global navigation systems [12].

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