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Juraj Micek – Jan Kapitulik *

TRANSMIT POWER CONTROL ANALYSIS IN V2X COMMUNICATION SYSTEM

Transmit power control is applied for reduction of transmission power to the level needed for reliable communication. The article describes problematic of transmit power control in ad-hoc V2X communication system applied in intelligent transport system environment.

Key words: transmit power control, inter-vehicle, roadside-to-vehicle, V2X communication system, intelligent transport system

1. Introduction

Present day communication technologies as well as microelectronics allow production of reliable and low energy consumption devices suitable for intelligent transport system (ITS) applications, [1]. Communication platform became integral part of ITS infrastructure.

In 1999, U.S. Federal Communication Commission (FCC) allocated 75 MHz spectrum at 5.9 GHz for Dedicated Short Range Communications (DSRC) devices to be used for car-to-car as well as car-to-road infrastructure communications. The primary goal of above mentioned decision was to improve traffic flow and safety aspects of public road transport.

On 5th August 2008, the EU Committee decided to allocate a frequency band from 5875 to 5905 MHz for ITS applications, which is going to be used on non-exclusive basis. Intelligent transport V2X communication frequency band as well as maximum limit of mean spectral power density (EIRP) is illustrated in Fig. 1, [2]. Inter-vehicle (IVC) and roadside-to-vehicle (R2V) communication is permitted in all of frequency bands.

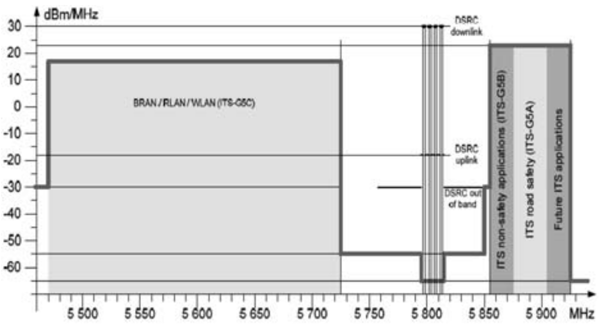

Fig. 1 Maximum limit of mean spectral power density (EIRP)

Channel allocation is defined as specified in table 1, [3]. One physical channel is allocated as a G5CC and four fixed channels are identified as G5SCs.

G5CC and G5SC1 to G5SC4 are dedicated for the following usage:

- The G5CC shall be used for road safety and traffic efficiency applications and may be used for ITS service announcements of services operated on G5SC1 to G5SC4.
- G5SC1 and G5SC2 shall be used for ITS road safety and traffic efficiency applications.
- G5SC3 and G5SC4 shall be used for other ITS user applications.

Fig. 2 presents power density limits of ITS transmitting units at a frequency band of 5.9 GHz. Transmit power limit as well as power density limit for a defined channel is presented in table 1. Maximal transmit power limit equal to 33dBm was defined on the basis of the study of electromagnetic compatibility between ITS and other radio systems for fixed, mobile and satellite services, [4].

The total RF output power and the power spectral density when configured to operate at the highest stated power level of the transmit power control (TPC) range shall not exceed the levels of 33dBm and 23dBm/MHz, respectively. The total RF output power and the power spectral density when configured to operate at the lowest stated power level of the TPC range shall not exceed the levels of 3dBm and −7dBm/MHz, respectively, [4], [7].

* **Juraj Micek, Jan Kapitulik**
Faculty of Management and Informatics, University of Zilina, Slovakia, E-mail: juraj.micek@fri.uniza.sk

European channel allocation Table 1

Channel type	Centre frequency	Channel number	Channel spacing	Default data rate	TX power limit	TX power density limit
G5CC	5 900 MHz	180	10 MHz	6 Mbit/s	33 dBm EIRP	23 dBm/MHz
G5SC2	5 890 MHz	178	10 MHz	12 Mbit/s	23 dBm EIRP	13 dBm/MHz
G5SC1	5 880 MHz	176	10 MHz	6 Mbit/s	33 dBm EIRP	23 dBm/MHz
G5SC3	5 870 MHz	174	10 MHz	6 Mbit/s	23 dBm EIRP	13 dBm/MHz
G5SC4	5 860 MHz	172	10 MHz	6 Mbit/s	0 dBm EIRP	-10 dBm/MHz

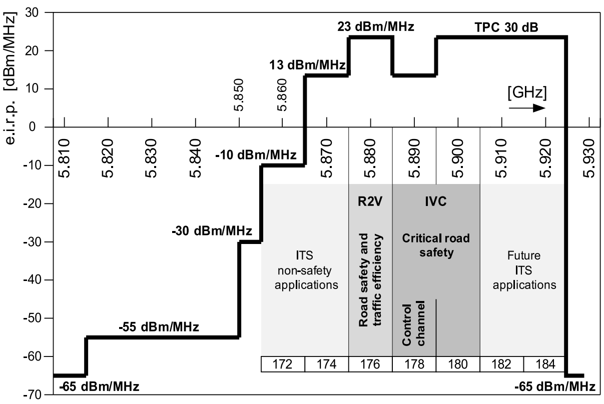

Fig. 2 Power density limits of ITS transmitting units at frequency band 5.9 GHz

V2X communication system allows dynamic control of transmit power of a device in a range of 30 dB. Settings of the transmit power shall be in steps of 0.5 dB controlled by the congestion control manager. Half-duplex and broadcast data transmission mode is supported.

Data rates for 10 MHz channel spacing are defined in table 2, [3].

2. RF Output power analysis

As it was mentioned above, V2X communication system supports dynamic control of transmit power of a device to support scalable and reliable communication between communication units of V2X network. Transmit power control block plays one of main roles in sense of guarantee high quality communication between vehicles as well as roadside units and vehicles.

The analysis of RF output power delivered to the transmit antenna could be principally based on adaptation of Friis transmission equation utilizing a proper radio propagation model that represents path loss between two on-board units (OBU) or roadside unit (RSU) and on-board unit (OBU) of a vehicle. Path loss models accepted by standardization bodies will be used in the analysis.

Friis transmission equation

Mathematical model of Friis transmission equation is as follows, [5]:

$$P_R / P_T = G_T \cdot G_R \cdot \left(\lambda / 4\pi \cdot d \right), \quad (1)$$

where:
G_T and G_R are the antenna gain of the transmitting and receiving antennas, respectively, λ is the wavelength, d is the distance. The inverse of the factor in parentheses is the so-called free-space path loss. This simple form applies only under the following ideal conditions:

- The antennas are in unobstructed free space, with no multi-path.
- P_R is understood to be the available power at the receive antenna terminals.
- P_T is understood to be the power delivered to the transmit antenna.
- The bandwidth is narrow enough that a single value for the wavelength can be assumed.

Equation (1) is possible to rewrite to logarithmic form as follows:

$$P_T = P_R - G_T - G_R + L, \quad (2)$$

where:
P_T is the transmit power in dBm,
P_R is the received power in dBm,
G_T is the transmit antenna gain in dBi,
G_R is the receive antenna gain in dBi,

Data rates and channel spacing Table 2

Modulation coding scheme (MCS)	0	1	2	3	4	5	6	7
Data rate in Mbit/s 10 MHz channel	3	4.5	6	9	12	18	24	27
Modulation scheme	BPSK	BPSK	QPSK	QPSK	16-QAM	16-QAM	64-QAM	64-QAM
Coding rate R	1/2	3/4	1/2	3/4	1/2	3/4	2/3	3/4

L is the free-space path loss in dB:

$$L = L_0 = 20 \cdot \log_{10}\left(4\pi \cdot d_0 / \lambda\right), \quad (3)$$

where:
λ is the carrier wavelength in [m],
d_0 is the breakpoint distance in [m] up to which it is possible to calculate free space path loss using equation (3).

Relation (2) represents obvious form of equation for RF output power level calculation.

ETSI propagation model (European Telecommunications Standards Institute)

ETSI accepted a large scale fading propagation model used for mobile communication applications, [6]. To account for the increased path loss coefficient, the total path loss is split up into two contributions:

$$L = L_0 + L_1, \quad (4)$$

where:

$L_0 = 20 \cdot \log_{10}\left(4\pi \cdot d_0 / \lambda\right)$, $d_0 = 15$ m, $d \leq d_0$, is free space transmission path loss, (5)

$L_1 = 10 \cdot \log_{10}\left(d / d_0\right)^n$, $d_0 < d$, is the path loss assuming a path loss coefficient $n = 2.7$ beyond the breakpoint distance d_0 in [m], (6)
λ is the carrier wavelength in [m],
d is communication distance in [m].

ECC propagation model (Electronic Communications Committee)

Improved path loss factor of a large scale fading propagation model is presented in [7]. Signal degradation beyond the first breakpoint distance is taken into account and path loss corrections are defined. ECC propagation losses L are considered as the conventional expression up to d_0 (3) and the corrected expression beyond:

$$L = L_0 = 20 \cdot \log_{10}\left(4\pi \cdot d_0 / \lambda\right), \quad d \leq d_0 \quad (7)$$

$$L = L_1 = 20 \cdot \log_{10}\left(4\pi \cdot d_0 / \lambda\right) + 10 n_0 \cdot 10 \log_{10}\left(d / d_0\right), \quad d_0 < d \leq d_1 \quad (8)$$

$$L = L2 = 20 \cdot \log_{10}\left(4\pi \cdot d_0 / \lambda\right) + 10 n_0 \cdot 10 \log_{10}\left(d / d_0\right) + 10 n_1 \cdot 10 \log_{10}\left(d / d_1\right), \quad d_1 < d \quad (9)$$

where:
λ is the carrier wavelength in [m],
d is communication distance in [m],
d_0 is the breakpoint distance in [m] (up to which it is possible to calculate free space path loss),
d_1 is the breakpoint distance in [m],
n_0, n_1 are path loss factors.

ECC performed studies to estimate the impact from FWA (Fixed Wireless Access) systems on the RTTE on-board units (OBU), including false wake up detection and its effect on OBU battery life. Breakpoint distances and path loss factors were defined on the basis of the studies, table 3.

Parameters of propagation Table 3

	Urban	Suburban	Rural
Breakpoint distance d_0 [m]	64	128	256
Path loss factor n0 beyond the first breakpoint	3.8	3.3	2.8
Breakpoint distance d_1 [m]	128	256	1024
Path loss factor n1 beyond the second breakpoint	4.3	3.8	3.3

3. Simulation

Referring to equation (2) and radio propagation models, it is clear that RF output power level of transmitter, P_T, is depended on:
P_R receiver sensitivity in dBm,
G_T transmit antenna gain in dBi,
G_R receive antenna gain in dBi,
L path loss propagation model in dB,
λ carrier wavelength in [m],
d communication distance in [m],
d_0, d_1 breakpoint distances in [m],
n_0, n_1 path loss factors.

Receiver sensitivity: P_R [dBm]

The minimum receive sensitivity (OBU or RSU) specifies the required receive input power (i.e., at the antenna connection) including an implementation margin of 5 dB for a receiver noise figure of 10 dB and a BER of 10^{-5}, table 4 [8]. P_R is defined in compliance with a communication channel bandwidth for corresponding data rate.

Referring to simulation, value of P_R is selected on the basis of information in table 1:

$P_R = -72$ dBm ($BW = 10$ MHz, data rate = 6 Mbits/s).

Transmit and receive antenna gains: G_T, G_R [dBi]

ITS applications expect 10 dBi antenna gain for road-side unit (RSU), 8 dBi or 5 dBi antenna gain for on-board unit (OBU) of a vehicle, [4].

Appealing to simulation, values of G_T and G_R are selected in compliance with Inter-vehicle (IVC – channels numbers: 178, 180) or roadside-to-vehicle (R2V – channel number: 176) communication: G_T = 5dBi, G_R = 5dBi (IVC communication).

Path loss propagation model: *L* [dB]

Minimum receiver sensitivity for a BW of 10 MHz Table 4

Data rate [Mbits/s]	Minimum sensitivity [dBm]
3	−85
4.5	−84
6	−72
9	−80
12	−77
18	−70
24	−69
27	−67

Referring to simulation purposes, a radio wireless propagation model must be proposed in compliance with practical applications. Relating to above mentioned models, value of carrier wavelength λ is corresponding with the channel type (channel number) used for ITS services, [3]: λ = 0.0508m (channel type: G5CC; channel number: 180; centre frequency 5.9 GHz). Breakpoint distances d_0, d_1 as well as path loss factors n_0, n_1 are defined by practical measurements or standards: equations (3), (5), (6) and table 3.

Communication distance (range): *d* [m]

It is distance between two communication units, i.e. transmitter and receiver (RSU and OBU, OBU and OBU). Appealing to simulation, values of d are defined up to the communication range limit: 1000 m, table 5.

Table 5 presents results of calculations based on theoretical models representing relation of TX power level of the transmit unit and the distance between on-board units of two vehicles. Calculations were done for several radio propagation models. A free-space model (M1) expects no obstacles between transmitter and receiver, i.e. propagated waveform is not degraded (path loss coefficient $n = 2$). ETSI model (M2) expects line-of-sight communication with severely destructed first Fresnel zone (path loss coefficient is in the range: $n = 2.5 ... 3$; $n = 2.7$ was selected; the pass loss coefficient for non-line-of-sight conditions would be in the range: $n = 3 ... 5$). ECC models (M3, M4, M5) were derived from mobile communication ones. They respect three different ITS environments: urban, suburban, rural. Path loss coefficients were adapted for ITS applications.

Referring to differences between estimated values for a defined distance of the models (table 5), validity of the models had to be verified by practical measurements in ITS environments. Unfortunately, this step was impossible to realize due to lack of technical equipment. That is why the results of simulation could be interpreted only on theoretical basis.

TPC dynamic range for channel number: 180 is 30dB. Minimal TX power level is defined on the level of 3dBm, maximal is equal to 33dBm. Appealing to table 5, theoretical TX power values lower than minimal limit were replaced by 3dBm and higher ones than maximal limit by 33dBm. Adaptation of the values is in compliance with defined TX power limits as well as practical realization of TPC block. Increasing TX power to minimal limit will improve reliability of communication between vehicles. Unfortunately, decreasing TX power to maximal limit will shorten communication distance, i.e. communication range limit 1000 m does not need to be met. Looking for the solution to solve this topic, communication range limits at maximal TX power = 33dBm were calculated, table 6.

Communication range limits at maximal transmit power 33 dBm Table 6

Models		Communication range limit [m]	
		G_R = 5 dBi	G_R = 8 dBi
Free-space model	M1	1278	1805
ETSI model	M2	405	523
*ECC model: **Urban***	M3	279	328
*ECC model: **Suburban***	M4	471	565
*ECC model: **Rural***	M5	933	1033

The values in table 6 show that improvement of communication range limits for inter-vehicle communication (IVC) via selected channel type and defined minimum receiver sensitivity could be realized by increasing the receiver antenna gain of the vehicle. Models M2, M3 and M4 did not meet expected 1000 m limit neither after increasing the receiver antenna gain. In this case it

Dependency of TX power level of the transmit unit on the distance between OBUs of two vehicles (channel number: 180; TX power = $P_T + G_T$) Table 5

Models		Distance [m]	10	50	100	250	500	1000
Free-space model	M1	**TX power** [dBm] EIRP	3	5	11	19	25	31
ETSI model	M2	**TX power** [dBm] EIRP	3	8.5	17	27.5	33	33
*ECC model **Urban***	M3	**TX power** [dBm] EIRP	3	5	14.5	31	33	33
*ECC model **Suburban***	M4	**TX power** [dBm] EIRP	3	5	11	23	33	33
*ECC model **Rural***	M5	**TX power** [dBm] EIRP	3	5	11	19	27.5	33

would be necessary to arrange OBU with better minimum receiver sensitivity. Unfortunately, data rate had to be decreased to guarantee reliable communication. Referring to values in tables 5 and 6, it is possible to conclude that ECC models estimate TX power in compliance with specific features of ITS environments.

Appealing to values of TX power in tables 5 and 6, it is possible to state:

- *Model M1:* in spite of the fact that communication range limit of 1000m is met and full TPC range of 30 dB is utilized the model would be valid only for very short distance free-space IVC, R2V communication;
- *Model M2:* communication range is shorter than 523 m; better TX power estimation could be expected for urban and suburban environments rather than rural one;
- *Model M3:* communication range is shorter than 328 m; model could be used for TX power estimation in case of urban environment;
- *Model M4:* communication range is shorter than 565 m; model could be used for TX power estimation in case of suburban environment;
- *Model M5:* communication range met the limit of 1000 m; model could be used for TX power estimation in case of rural environment;

4. Conclusion

V2X communication system plays a core role of inter-vehicle as well as road-side-to-vehicle communication allowing development of services focused on the improvement of road safety and traffic efficiency (driving assistance: co-operative awareness, road hazard warning; speed management; co-operative navigation; location based services, etc.). The article presents fundamentals of transmit power control analysis including simulation results for inter-vehicle communication. Road-side-to-vehicle communication could be analyzed in a similar way. Future research steps would be focused on: validation of presented theoretical models, incorporating traffic density aspects into models and analysis of transmit power control from the basic set of applications point of view.

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