COMMUNICATIONS 3A/2010

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.

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].

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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]:

$$ P_r/P_t = G_t G_r \left( \frac{\lambda}{4\pi d} \right)^2, $$

where:

- The antennas are in unobstructed free space, with no multi-path.
- $P_t$ is understood to be the available power at the receive antenna terminals.
- $P_r$ 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:

$$ P_r = P_t - G_T - G_R + L, $$

where:

- $P_t$ and $G_T$ are the antenna gain of the transmitting and receiving antennas, respectively, $\lambda$ 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 bandwidth is narrow enough that a single value for the wavelength can be assumed.
$L$ is the free-space path loss in dB:

$$L = L_0 + L_1.$$  \hspace{1cm} (4)

where:

- $L_0 = 20 \log_{10}\left(\frac{4\pi \cdot d_0}{\lambda}\right)$, $d_0 = 15 \text{ m}$, is free space transmission path loss,
- $L_1 = 10 \log_{10}\left(\frac{d}{d_0}\right)$, $d_0 < d$, is the path loss beyond the breakpoint distance $d_0$ in [m], assuming a path loss coefficient $n = 2.7$
- $\lambda$ is the carrier wavelength in [m],
- $d$ is communication distance in [m].

**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:

$$L = L_0 + L_1.$$  \hspace{1cm} (7)

where:

- $L_0 = 20 \log_{10}\left(\frac{4\pi \cdot d_0}{\lambda}\right)$, $d_0 = 15 \text{ m}$, is free space transmission path loss,
- $L_1 = 10 \log_{10}\left(\frac{d}{d_0}\right)$, $d_0 < d$, is the path loss beyond the breakpoint distance $d_0$ in [m],
- $\lambda$ 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:

$$L = L_0 = 20 \log_{10}\left(\frac{4\pi \cdot d_0}{\lambda}\right), \quad d \leq d_0$$ \hspace{1cm} (8)

$$L = L_0 = 20 \log_{10}\left(\frac{4\pi \cdot d_0}{\lambda}\right) + 10n_1 \cdot 10 \log_{10}\left(\frac{d}{d_0}\right),$$ \hspace{1cm} (9)

where:

- $L_0$ is the free-space path loss in dB, (3)
- $d_0$ is the breakpoint distance in [m] (up to which it is possible to calculate free space path loss),
- $d$ is communication distance in [m],
- $n_0$, $n_1$ are path loss factors.

3. Simulation

Referring to equation (2) and radio propagation models, it is clear that RF output power level of transmitter, $P_T$, is dependent 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,
- $\lambda$, 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:

$$P_R = -72 \text{ dBm} \quad (\text{BW} = 10 \text{ MHz}, \text{ data rate} = 6 \text{ Mbits/s}).$$

**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 Intervvehicle (IVC – channels numbers: 178, 180)

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### Table 3

<table>
<thead>
<tr>
<th>Parameters of propagation</th>
<th>Urban</th>
<th>Suburban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakpoint distance $d_0$ [m]</td>
<td>64</td>
<td>128</td>
<td>256</td>
</tr>
<tr>
<td>Path loss factor $n_0$ beyond the first breakpoint</td>
<td>3.8</td>
<td>3.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Breakpoint distance $d_1$ [m]</td>
<td>128</td>
<td>256</td>
<td>1024</td>
</tr>
<tr>
<td>Path loss factor $n_1$ beyond the second breakpoint</td>
<td>4.3</td>
<td>3.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>
or roadside-to-vehicle (R2V – channel number: 176) communication: $G_p = 5\, \text{dBi}$, $G_r = 5\, \text{dBi}$ (IVC communication).

### Path loss propagation model: $L$ [dB]

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 $\lambda$ is corresponding with the channel type (channel number) used for ITS services, $[3]$: $\lambda = 0.0508\, \text{m}$ (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: $n = 2.5 \ldots 3$; $n = 2.7$ was selected; the pass loss coefficient for non-line-of-sight conditions would be in the range: $n = 3 \ldots 5$). 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 30 dB. Minimal TX power level is defined on the level of 3 dBm, maximal is equal to 33 dBm. Appealing to table 5, theoretical TX power values lower than minimal limit were replaced by 3 dBm and higher ones than maximal limit by 33 dBm. Adaptation of the values is in compliance with defined TX power limits as well as practical realization of TPC block. Increasing TX power to maximal 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 $= 33\, \text{dBm}$ were calculated, table 6.

<table>
<thead>
<tr>
<th>Models</th>
<th>Communication range limit [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$G_p = 5, \text{dBi}$</td>
</tr>
<tr>
<td>Free-space model M1</td>
<td>1278</td>
</tr>
<tr>
<td>ETSI model M2</td>
<td>405</td>
</tr>
<tr>
<td>ECC model: Urban M3</td>
<td>279</td>
</tr>
<tr>
<td>ECC model: Suburban M4</td>
<td>471</td>
</tr>
<tr>
<td>ECC model: Rural M5</td>
<td>933</td>
</tr>
</tbody>
</table>

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 was impossible to realize due to lack of technical equipment.

### Table 4: Minimum receiver sensitivity for a BW of 10 MHz

<table>
<thead>
<tr>
<th>Data rate [Mbits/s]</th>
<th>Minimum sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-85</td>
</tr>
<tr>
<td>4.5</td>
<td>-84</td>
</tr>
<tr>
<td>6</td>
<td>-72</td>
</tr>
<tr>
<td>9</td>
<td>-80</td>
</tr>
<tr>
<td>12</td>
<td>-77</td>
</tr>
<tr>
<td>18</td>
<td>-70</td>
</tr>
<tr>
<td>24</td>
<td>-69</td>
</tr>
<tr>
<td>27</td>
<td>-67</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Models</th>
<th>Distance [m]</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>250</th>
<th>500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free-space model M1</td>
<td>TX power [dBm]</td>
<td>EIRP</td>
<td>3</td>
<td>5</td>
<td>11</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>ETSI model M2</td>
<td>TX power [dBm]</td>
<td>EIRP</td>
<td>3</td>
<td>8.5</td>
<td>17</td>
<td>27.5</td>
<td>33</td>
</tr>
<tr>
<td>ECC model: Urban M3</td>
<td>TX power [dBm]</td>
<td>EIRP</td>
<td>3</td>
<td>5</td>
<td>14.5</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>ECC model: Suburban M4</td>
<td>TX power [dBm]</td>
<td>EIRP</td>
<td>3</td>
<td>5</td>
<td>11</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>ECC model: Rural M5</td>
<td>TX power [dBm]</td>
<td>EIRP</td>
<td>3</td>
<td>5</td>
<td>11</td>
<td>19</td>
<td>27.5</td>
</tr>
</tbody>
</table>
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 1000 m 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.

**Acknowledgement:**
This contribution is the result of the project implementation: Centre of excellence for systems and services of intelligent transport, ITMS 26220120028 supported by the Research & Development Operational Programme funded by the ERDF.

References