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The Impact of Operating Frequencies and Neural Network Training Program Properties on the Performance of Neural Network Topology Generator Methodology

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Until now, Neural Network Topology Generator Methodology (NNTGM) has been theoretically proposed so that its generated overhead low-voltage broadband over power lines topologies (NNTGM OV LV BPL topologies) may populate the existing OV LV BPL topology classes. With reference to the OV LV BPL topology class maps, which are defined by the graphical combination of ACA and RMS-DS of the OV LV BPL topologies, and the NNTGM OV LV BPL topology footprints for given indicative OV LV BPL topologies, the impact on the relative position and the size of the NNTGM OV LV BPL topology footprints has been assessed for a number of factors that affect the preparation of the Topology Identification Methodology (TIM) OV LV BPL topology database being used during the NNTGM operation. In this companion paper, the effect of the operating frequencies and the Neural Network (NN) training program properties on the relative position and the size of the NNTGM OV LV BPL topology footprints is here examined. The effect study is supported by suitable Graphical Performance Indicators (GPIs).

Keywords: Smart Grid; Broadband over Power Lines (BPL) networks; Power Line Communications (PLC); Distribution and Transmission Power Grids; Neural Networks; Simulation; Modeling

Introduction

Overhead Low-Voltage (OV LV) power lines, originally not intended for data transmission, exhibit varying line lengths, impedance, and noise, which can degrade signal quality if not properly managed. By accurately classifying and updating these OV LV Broadband over Power Lines (OV LV BPL) topologies, network operators can optimize signal propagation and minimize interference based on real-time grid conditions, which is especially important as grids incorporate renewable energy and smart technologies [1]. Detailed topology information may enhance channel modeling and routing algorithms, improving network reliability and scalability of smart grids. Populating OV LV BPL topology classes with appropriate OV LV BPL topologies has become a critical task in modern BPL networks since machine learning (ML) techniques can also benefit from the data, enabling predictive and automated grid management as power networks evolve in complexity [2].

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Neural Network Topology Generator Methodology (NNTGM), which has been theoretically proposed in [3] and numerically tested in [4], addresses the need for generating appropriate virtual OV LV BPL topologies (NNTGM OV LV BPL topologies) that can populate OV LV BPL topology classes. Based on the topological characteristics of the indicative OV LV BPL topologies of the topology classes, NNTGM OV LV BPL topologies of each examined topology class maintain the topological characteristics of its indicative one but with similar virtual channel attenuation behavior. Actually, NNTGM, which is the last member of the neural network identification methodology (NNIM)-based family products, achieves to generate similar channel attenuation behaviors for given OV LV BPL topological characteristics by procedurally reversing the network identification methodology for the line length approximation (NNIM-LLA) [5-7]. Exploiting artificial intelligence (AI), ML and neural network (NN) features, the ability of NNTGM to create NNTGM OV LV BPL topologies that imitate the characteristics of the real-world OV LV BPL topologies has been demonstrated on OV LV BPL topology class maps, which are based on the graphical representation at the same plot of the average theoretical channel attenuation (ACA) and the root mean square delay-spread (RMS-DS) [4].

Based on the OV LV BPL topology class maps and the corresponding graphical performance indicators (GPIs), the impact of the parameters of the NNTGM operation settings on the relative position and the size of the NNTGM virtual topology footprints have first been assessed in [4] and are further examined in this paper. In accordance with [3, 4], NNTGM OV LV BPL topologies lie close to their indicative OV LV BPL topologies thus defining the respective NNTGM virtual topology footprints. To assess the relative position and the size of the NNTGM virtual topology footprints with respect to the corresponding OV LV BPL topology class borderlines, two GPIs have been applied in [4]; say, the percentage of the NNTGM OV LV BPL topologies that remain inside the OV LV BPL topology class of their respective indicative OV LV BPL topology and the percentage of the NNTGM OV LV BPL topologies that remain inside specific ACA / RMS-DS limits with respect to their indicative OV LV BPL topology. According to [3, 4], the impact of the following parameters of the NNTGM operation settings on the NNTGM virtual topology footprints have been recognized and benchmarked, namely: (i) The inclusion or not of the examined indicative OV LV BPL topology in the Topology Identification Methodology (TIM) OV LV BPL topology database during the NNTGM operation;

(ii) the length of the distribution / branch line segments; and (iii) the number of the distribution / branch line segments. In this paper, with reference to the NNTGM default operation settings of [3], the impact of the following parameters of the NNTGM operation settings on the NNTGM virtual topology footprints and GPIs are further assessed, namely: (i) The operating frequencies (i.e., frequency range and flat-fading subchannel frequency spacing); and (ii) the participation percentages of the three phases (training, validation and testing) of the MATLAB NN training program of NNTGM [8, 9]. The findings of this paper are combined with the ones of [4] so that a more extended populating strategy for the OV LV BPL topology class can be available.

The rest of this paper is organized as follows: Section 2 synopsizes the class maps and GPIs of the indicative OV LV BPL topologies of [3] when the NNTGM default operation settings of [3] are adopted. Section 3 analyzes the impact of the aforementioned parameters of the NNTGM operation settings on the NNTGM virtual topology footprints and GPIs. Section 4 concludes this paper.

NNTGM Default Operation Settings, OV LV BPL Topology Class Maps and GPIs

In this Section, NNTGM has been proposed in [3]. In order to assess NNTGM performance when various parameters of its operation settings change, NNTGM default operation settings are briefly reported in this Section. Also, the channel attenuation metrics of ACA and RMS-DS and the occurring OV LV BPL topology class maps for the indicative OV LV BPL topologies of [3] with their respective NNTGM virtual OV LV BPL topologies are also given in this Section for benchmark purposes. Finally, GPIs, which have first been demonstrated in [4] and assessed the impact of the parameter changes of the NNTGM operation settings on the relative position and the size of the NNTGM virtual topology footprints of the OV LV BPL topology classes, are also given in this Section.

NNTGM Definition and NNTGM Default Operation Settings

NNTGM procedurally reverses NNIM-LLA by exploiting its same main components; say, the TIM OV LV BPL topology database and the MATLAB NN training program [5-7]. In fact, TIM OV LV BPL topology database acts as the big data pool for the NNTGM operation while it contains the following fields: (i) the ID number p of the OV LV BPL topology when the number of all OV LV BPL topologies in the TIM OV LV BPL topology database is equal to P; (ii) the actual number of branches N of the OV LV BPL topology; (iii) the actual lengths of the distribution lines of each OV LV BPL topology; (iv) the actual lengths of the branch lines of each OV LV BPL topology; and
(v) the theoretical coupling scheme channel transfer function values with respect to the frequency. In contrast with the preparation of the TIM OV LV BPL topology database for the other NNIM-based family products, TIM OV LV BPL topology database for NNTGM should be filtered so as to contain only OV LV BPL topologies with the lengths of their distribution and branch lines to remain close to the respective values of the examined indicative OV LV BPL topology, as it has been defined in [3]. Therefore, NNTGM virtual topologies are expected to present theoretical channel attenuation behaviors that can remain close to the one of the examined indicative OV LV BPL topology but this can be further adjusted by the change of the parameters of the NNTGM operation settings as it has been shown in [4].

With reference to [4], the NNTGM default operation settings support NNTGM virtual topology footprints that remain close to the examined indicative OV LV BPL topology in each scenario with extents that confine NNTGM virtual topology footprints to remain inside the class of the examined indicative OV LV BPL topology in the vast majority of the cases. As it has previously been mentioned, the NNTGM default operation settings are based on the database representativeness principle of [5], namely:

- For given examined indicative OV LV BPL topology, its number of the branches and its actual lengths of the distribution and branch lines are assumed to be known thus the OV LV BPL topologies that are going to be included in the TIM OV LV BPL topology database are defined by eqs. (4)-(8) of [3] in each case.

- For given examined indicative OV LV BPL topology, the total number of the OV LV BPL topologies that are added in the TIM OV LV BPL topology database is given in eq. (9) of [3] with the inclusion of the indicative OV LV BPL topology in the TIM OV LV BPL topology database that is the default option of the parameter. As the default operation setting values are concerned, the length of the distribution and branch line segments are assumed to be equal to 1m and 1m, respectively, while the number of the distribution and branch line segments are assumed to be equal to 1 and 1, respectively. It is clear that the aforementioned NNTGM default operation setting parameter selection focuses on generating NNTGM virtual topology footprints that derive from the examined indicative OV LV BPL topology in each scenario while higher values of the aforementioned parameters are expected to relax the position and the extent of the NNTGM virtual topology footprints.
- The total distribution line length is assumed to be equal to 1,000m in all the OV LV BPL topologies of the TIM OV LV BPL topology database. Also, the terminations of all the OV LV BPL topologies of the TIM OV LV BPL topology are assumed to be open-circuit ones in a similar way to the indicative OV LV BPL topologies of Table 1 of [3]. With reference to [10, 11], the applied coupling scheme is the WtG[1] one.
- In the TIM OV LV BPL topology database, as its OV LV BPL topologies are concerned the amplitudes of the coupling scheme channel transfer functions are stored in dB with respect to the frequency.
- As the operating frequencies of NNTGM default operation settings are concerned, the frequency range is assumed to be equal to 1-30MHz while the flat-fading subchannel frequency spacing is assumed to be equal to 1MHz. Hence, the number of flat-fading subchannels is equal to 29. In this short paper, the impact of the frequency range and the flat-fading subchannel frequency spacing on the NNTGM virtual topology footprints are going to further be investigated.
- As the NNTGM is based on the MATLAB NN training program of [8, 9], the default participation percentages of its three phases; say, training, validation and testing phases, are assumed to be equal to 70%, 15% and 15%, respectively. In this paper, the impact of the participation percentages of the three phases on the NNTGM virtual topology footprints are going to further be investigated.

Apart from the default operation settings, to assess the performance of NNTGM, the channel attenuation metrics of ACA and RMS-DS, which are exploited for the preparation of the OV LV BPL topology class maps, and the GPIs are briefly presented in the following subsection.

NNTGM Channel Attenuation Metrics, OV LV BPL Topology Class Maps and GPIs

Similarly to the class maps of [12-16], OV LV BPL topology class maps of [3, 4] have been plotted by using channel attenuation metrics for their two axes; say, ACA and RMS-DS. With reference to eqs. (11), (12) of [3], ACA can be calculated for each indicative OV LV BPL topology or NNTGM virtual topology by averaging the amplitudes of the coupling scheme channel attenuations in dB over the flat-fading subchannels while RMS-DS measures the average channel attenuation distance from ACA for the examined OV LV BPL topologies over the same flat-fading subchannels. By exploiting the pair of ACA and RMS-DS values, each indicative OV LV BPL topology with its NNTGM virtual topologies can graphically define its OV LV BPL topology footprint on the class map. With reference to [3, 4], footprints of the indicative OV LV BPL topologies present graphical origin and proximity to their indicative OV LV BPL topologies while their positions and sizes on the class map depend on the applied NNTGM operation settings.

To demonstrate the OV LV BPL topology class areas on the class maps and examine the behavior of the OV LV BPL topology footprints, two graphical milestones are illustrated on the class maps. First, the two class borderlines are roughly derived as the median lines between the neighboring indicative OV LV BPL topologies of [3] when the NNTGM default operation settings are applied; say, the class borderline (rural-suburban) and the class borderline (suburban-urban). Second, the ACA / RMS-DS box of ±10%, which results from the variation of ±10% in the values of ACA and RMS-DS, is defined around each indicative OV LV BPL topology for the applied NNTGM operation settings. With reference to the two previous graphical milestones, two GPIs have been defined in [4] and are going to be applied here in order to evaluate the way of populating the OV LV BPL topology classes with respect to the applied NNTGM operation settings, namely:

- *Inside the class*: This GPI has to do with the percentage of the NNTGM OV LV BPL topologies that remain inside the OV LV BPL topology class of their respective indicative OV LV BPL topology. Note that the class borderlines are the ones of [4] since the changes of the NNTGM operation settings may affect the ACA / RMS-DS position of the indicative OV LV BPL topologies on the class maps of this paper.
- *Inside the box*: The percentage of the NNTGM OV LV BPL topologies that remain inside the ACA / RMS-DS box of ±10% with respect to their indicative OV LV BPL topology. Note that the ACA / RMS-DS box of ±10% is defined for each indicative OV LV BPL topology per each examined scenario and could be differentiated by the respective ACA / RMS-DS boxes of ±10% of [4]. Dashed lines around each examined indicative OV LV BPL topology are going to be used for the ACA / RMS-DS box of ±10%.

To evaluate the impact of the applied NNTGM operation settings of this paper on the NNTGM performance, the combined use of class maps and GPIs is going to significantly help towards the assessment.

Class Maps and GPIs for the NNTGM Default Operation Settings

With reference to [4], in Figure 1, the OV LV BPL topology class map with the NNTGM virtual topology footprints of the rural case, suburban case and urban case A of [3] is presented when the NNTGM default operation settings are applied. Each NNTGM virtual topology footprint consists of 100 NNTGM virtual topologies that are related with the indicative OV LV BPL topology of the class and the footprint. Apart from the two class borderlines, the three ACA / RMS-DS boxes of ±10% of the respective three indicative OV LV BPL topologies are also added. The aforementioned GPIs are applied to the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes and are reported in Table 1.

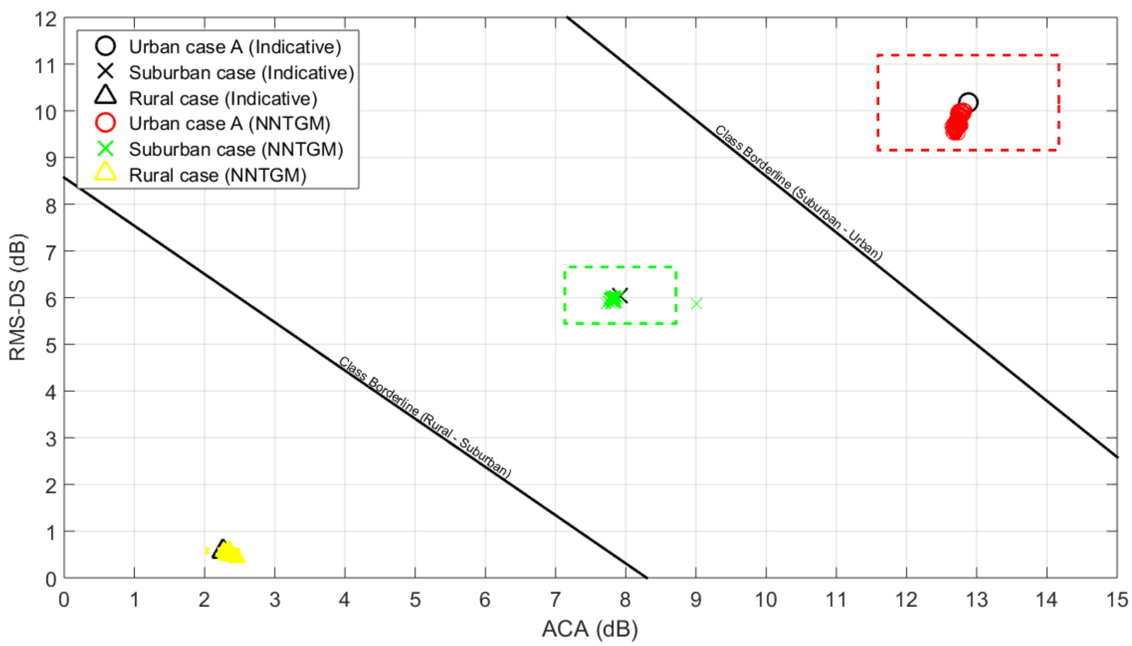

Fig. 1. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied [4].

Table 1. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied) [4]

GPI	**OV LV BPL topology class**		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	100	100	100
Inside the box (%)	84	99	100

As already mentioned in [4], the OV LV BPL topology footprints remain significantly close to the respective indicative OV LV BPL topologies when the NNTGM default operation settings are applied. Namely, 100% of the NNTGM OV LV BPL topologies remain inside the borders of their corresponding OV LV BPL topology class while the majority of the NNTGM OV LV BPL topologies (i.e., above 84%) remain inside the ACA / RMS-DS box of ±10% of their corresponding indicative OV LV BPL topology. Therefore, the NNTGM default operation settings allow the creation of strict OV LV BPL topology footprints to their respective indicative OV LV BPL topologies thus locally populating the OV LV BPL topology classes.

Figure 1 and Table 1 act as the benchmark values so that the impact of a number of NNTGM operation setting parameters could be assessed. Until now, the parameters that have been assessed in [4] are: (i) The inclusion or not of the examined indicative OV LV BPL topology in the TIM OV LV BPL topology database during the NNTGM operation; (ii) the length of the distribution / branch line segments; and (iii) the number of the distribution / branch line segments. In the following Section, the impact assessment continues with the following parameters of the NNTGM operation settings, namely: (i) The operating frequencies (i.e., frequency range and flat-fading subchannel frequency spacing); and (ii) the participation percentages of the three phases (training, validation and testing) of the MATLAB NN training program of NNTGM [8, 9].

The Impact of the Different NNTGM Operation Settings on the NNTGM Virtual Topology Footprints

In this Section, the impact of the following parameters of the NNTGM operation settings of [3] on the NNTGM virtual topology footprints and GPIs is going to be investigated, namely: (i) The operating frequencies; and (ii) the participation percentages of the three phases of the MATLAB NN training program of NNTGM.

Operating Frequencies and Their Impact on NNTGM Virtual Topology Footprints and GPIs

As it has already mentioned, when the operating frequencies of NNTGM default operation settings are concerned, the frequency range is assumed to be equal to 1-30MHz while the flat-fading subchannel frequency spacing is assumed to be equal to 1MHz. Hence, the number of flat-fading subchannels is equal to 29. To investigate the impact of operating frequencies on NNTGM virtual topology footprints and GPIs, the frequency range and the flat-fading subchannel frequency spacing should be separately investigated.

As the frequency range is concerned, in Figure 2, the OV LV BPL topology class map with the NNTGM virtual topology footprints of the rural case, suburban case and urban case A of [3] is presented when the NNTGM default operation settings are applied but the frequency range is assumed to be wider; say, the frequency range is equal to 1-88MHz. In Figure 2, the flat-fading subchannel frequency spacing remains the same with the one of NNTGM default operation settings; say, 1MHz. Similarly to Figure 1, each NNTGM virtual topology footprint comprises 100 NNTGM virtual topologies per indicative OV LV BPL topology. The two class borderlines of Figure 1 and the three ACA / RMS-DS boxes of ±10% of the respective three indicative OV LV BPL topologies for the current NNTGM operation settings are also added. The same GPIs of Table 1 are applied to the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes of Figure 2 and are reported in Table 2.

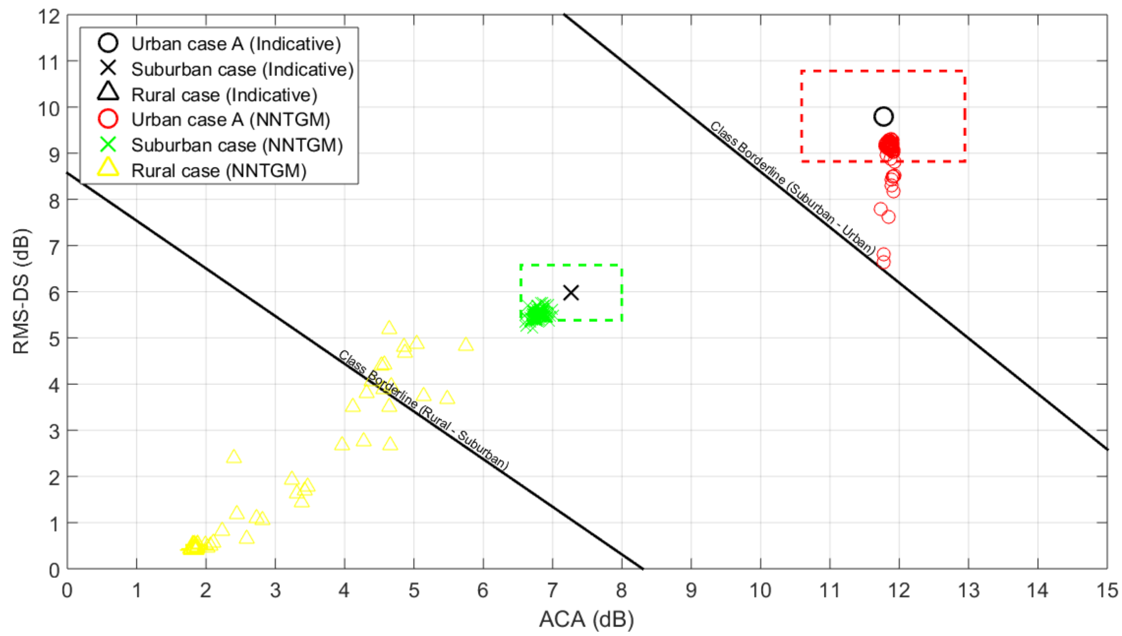

Fig. 2. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied but the frequency range is equal to 1-88MHz.

Table 2. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied but the frequency range is equal to 1-88MHz)

GPI	**OV LV BPL topology class**		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	88	100	100
Inside the box (%)	65	90	89

Comparing Figures 1 and 2, the extended frequency range does not significantly affect the position of the three examined indicative OV LV BPL topologies and their ACA / RMS-DS boxes of ±10% on the class map. Anyway, the two class borderlines of Figure 2 are the same with the ones of Figure 1 regardless of the changes of the NNTGM operation settings. As the extent of the NNTGM virtual topology footprints is examined, verifying the observations of the Figures with the data of Tables 1 and 2, the footprints of the indicative rural case and urban case A are primarily and secondarily affected, respectively, whereas the footprint of the indicative suburban case is slightly affected only in the case of their ACA / RMS-DS boxes of ±10%. More specifically, the only OV LV BPL topology footprint that exceed the class borderlines is the one of the rural case with 12 NNTGM OV LV BPL topologies while 19, 9 and 11 more NNTGM OV LV BPL topologies now leave the ACA / RMS-DS boxes of ±10% of the rural, suburban and urban case A, respectively, in comparison with the corresponding NNTGM OV LV BPL topologies of the NNTGM default operation settings of Table 1. Exhibiting similar footprint and GPI behaviors with the case of the length increase of the branch line segment of the NNTGM default operation settings as reported in [4], the wider frequency range of 1-88MHz has as a result a wider class populating for the rural case, a slightly wider class populating for the urban case A but the same class populating behavior for the suburban case and this is due to the fact that the wider 1-88MHz frequency range increases the number of flat-fading subchannels and, thus, the size of the NNTGM generated channel attenuation column vectors of eq. (3) of [3] and the inner big data of the TIM OV LV BPL topology database. The new spectral notches that occur in the newly added 30-88MHz frequency range are numerically described in the NNTGM generated channel attenuation column vectors in the same way that the new spectral notches from the length increase of the branch line segments have been taken into account. From the previous change, the most affected indicative OV LV BPL topology is the rural one since the relatively smaller number of corresponding OV LV BPL topologies in the TIM OV LV BPL topology database with rare spectral notches is critically affected. From the perspective of sparsely populating the OV LV BPL topology classes, the increase of the frequency range mainly supports sparse NNTGM virtual topology footprints for the rural class. Except for the change of the frequency range, the impact of the flat-fading subchannel frequency spacing on the NNTGM virtual topology footprints is also investigated.

As the flat-fading subchannel frequency spacing is concerned, in Figure 3, the OV LV BPL topology class map with the NNTGM virtual topology footprints of the rural case, suburban case and urban case A of [3] is presented when the NNTGM default operation settings are applied but the flat-fading subchannel frequency spacing is assumed to be wider; say, the flat-fading subchannel frequency spacing is equal to 2MHz. In Figure 3, the frequency range remains almost the same with the one of NNTGM default operation settings; say, 1-31MHz instead of 1-30MHz so that the last 2MHz flat-fading subchannel frequency spacing can fit into the frequency range. Similarly to Figures 1 and 2, the same number of 100 NNTGM virtual topologies are generated per indicative OV LV BPL topology while the two class borderlines of Figure 1 are again plotted the same in Figure 3 and the three ACA / RMS-DS boxes of ±10% of the respective three indicative OV LV BPL topologies for the current NNTGM operation settings are also added. The same GPIs of Tables 1 and 2 are applied to the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes of Figure 3 and are reported in Table 3.

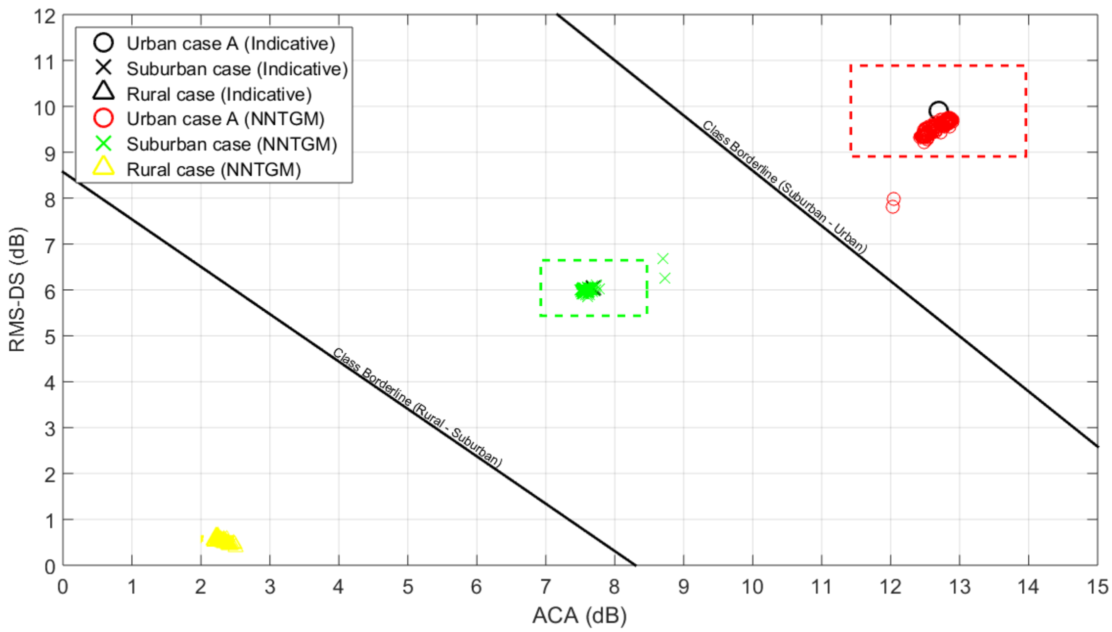

Fig. 3. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied but the flat-fading subchannel frequency spacing is equal to 2MHz.

Table 3. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied but the flat-fading subchannel frequency spacing is equal to 2MHz)

GPI	**OV LV BPL topology class**		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	100	100	100
Inside the box (%)	75	98	98

Comparing Figures 3 with Figures 1 and 2, the extended flat-fading subchannel frequency spacing presents the complementary effect to the increase of the frequency range on the footprints of the class map. First, the position of the three examined indicative OV LV BPL topologies and their ACA / RMS-DS boxes of ±10% remains almost unchanged on the class map with respect to the class borderlines of the NNTGM operation settings. As the extent of the NNTGM virtual topology footprints is examined, verifying the observations of the Figures with the data of Tables 1-3, the footprints of the indicative rural, suburban case and urban case A are shrunk with reference to the respective ones of the NNTGM default operation settings. In fact, all the NNTGM OV LV BPL topologies remain inside the borders of their corresponding OV LV BPL topology classes while the majority of the NNTGM OV LV BPL topologies (i.e., above 75%) remain inside the ACA / RMS-DS box of ±10% of the examined indicative OV LV BPL topologies. Despite the lower values of the inside the box GPI for the footprints of the three indicative OV LV BPL topologies, all the three footprints are more shrunk and located closer to their indicative OV LV BPL topologies in comparison with the respective footprints of the NNTGM default operation settings. In contrast with the increase of the frequency range, the number of flat-fading subchannels decreases given the same frequency range thus reducing the size of the NNTGM generated channel attenuation column vectors of eq. (3) of [3] and the inner big data of the TIM OV LV BPL topology database. The spectral notches that occur in the 1-31MHz frequency range with 2MHz flat-fading subchannel frequency spacing are less or equal to the ones of 1MHz flat-fading subchannel frequency spacing. From the previous change, all the three indicative OV LV BPL topologies get less affected. From the perspective of densely populating the OV LV BPL topology classes, the increase of the flat-fading subchannel frequency spacing mainly supports dense NNTGM virtual topology footprints that remain close to their indicative OV LV BPL topologies.

Except for the operating frequencies, MATLAB NN training program is a critical module for the operation of all the NNIM-based family products [5-7]. Hence, all the parameters of the MATLAB NN training program may significantly affect the performance of NNTGM and the class maps. In the following subsection, the participation percentages of the three phases of the MATLAB NN training program, which is a fundamental part of the MATLAB training program operation, are further examined.

Participation Percentages of the Three Phases of the MATLAB NN Training Program and Their Impact on NNTGM Virtual Topology Footprints and GPIs

As it has already mentioned, when the participation percentages of the three phases of the MATLAB NN training program of NNTGM default operation settings are concerned [8, 9], the default participation percentages of its three phases; say, training, validation and testing phases, are assumed to be equal to 70%, 15% and 15%, respectively. To investigate the impact of the participation percentages of the three phases on the NNTGM virtual topology footprints and GPIs, three value scenarios are going be studied, where in each scenario one participation percentage will take an extreme value, say 98%, and the other two participation percentages will balance to 100% with equal values between them, say 1% and 1%. As the operating frequencies and the frequency range are concerned, these are assumed to be unchanged and the same with the ones of NNTGM default operation settings; say, 1-30MHz and 1MHz, respectively.

In Figure 4, the OV LV BPL topology class map with the NNTGM virtual topology footprints of the rural case, suburban case and urban case A of [3] is presented when the NNTGM default operation settings are applied but the training, validation and testing phase participation percentages are assumed to be equal to 98%, 1% and 1%, respectively. The two class borderlines of Figure 1 remain the same in Figure 4 while the three ACA / RMS-DS boxes of ±10% of the respective three indicative OV LV BPL topologies for the current NNTGM operation settings are also added. The same GPIs of Table 1 are applied to the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes of Figure 4 and are reported in Table 4. Same plots with Figure 4 are given in Figures 5 and 6, but for the training, validation and testing phase participation percentage sets being equal to [1%, 98%, 1%] and [1%, 1%, 98%], respectively. Tables 5 and 6 report the GPIs of Table 1 applied to the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes of Figures 5 and 6, respectively.

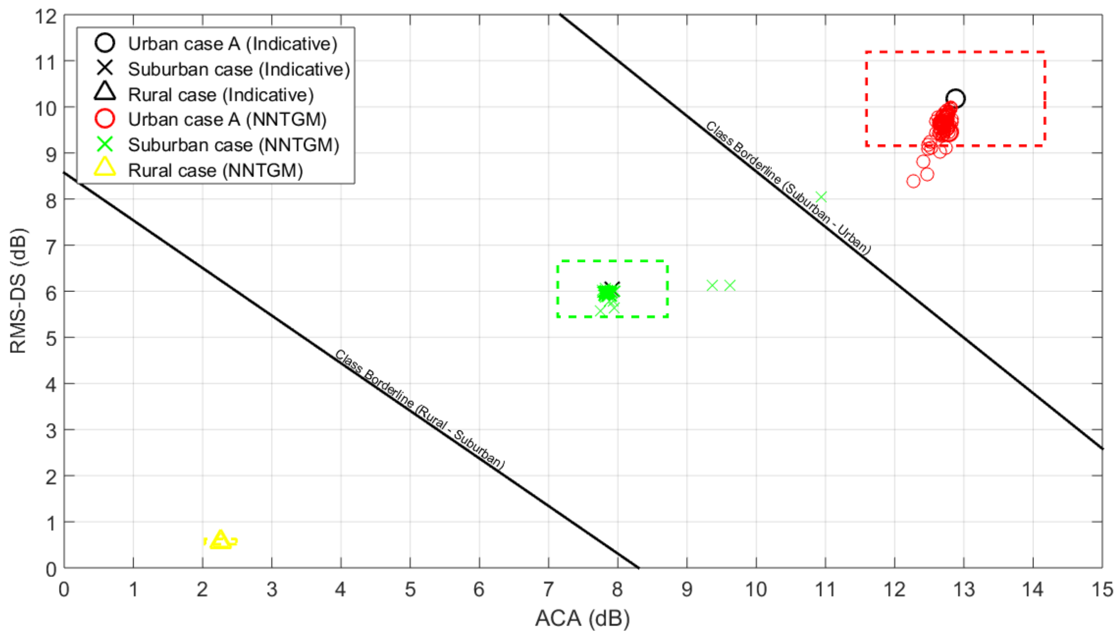

Fig. 4. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied but for training, validation and testing phase participation percentages being equal to 98%, 1% and 1%, respectively.

Table 4. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied but the training, validation and testing phase participation percentages are equal to 98%, 1% and 1%, respectively)

GPI	OV LV BPL topology class		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	100	99	100
Inside the box (%)	100	97	93

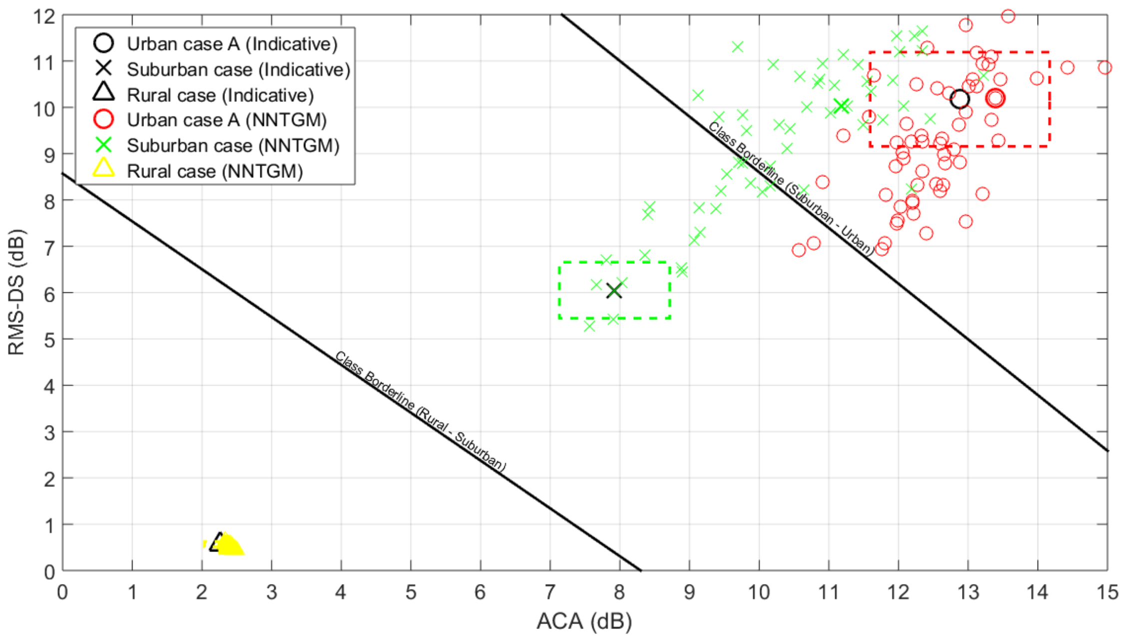

Fig. 5. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied but for training, validation and testing phase participation percentages being equal to 1%, 98% and 1%, respectively.

Table 5. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied but the training, validation and testing phase participation percentages are equal to 1%, 98% and 1%, respectively)

GPI	**OV LV BPL topology class**		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	98	23	100
Inside the box (%)	46	4	26

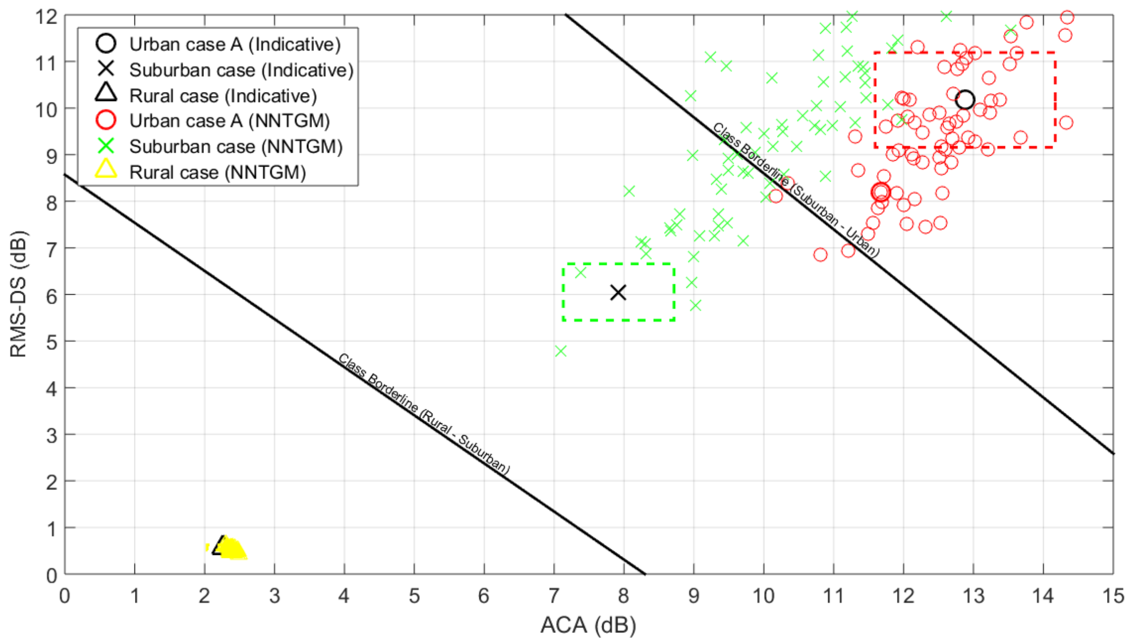

Fig. 6. OV LV BPL topology class map with NNTGM virtual topology footprints of the three indicative OV LV BPL topologies when the NNTGM default operation settings are applied but for training, validation and testing phase participation percentages being equal to 1%, 1% and 98%, respectively.

Table 6. GPIs of the NNTGM OV LV BPL topologies of the three OV LV BPL topology classes (NNTGM default operation settings are applied but the training, validation and testing phase participation percentages are equal to 1%, 1% and 98%, respectively)

GPI	**OV LV BPL topology class**		
	Rural case class	Suburban case class	Urban case A class
Inside the class (%)	100	29	97
Inside the box (%)	34	1	33

Comparing Figures 4-6 with Figures 1-3, the changes in the training, validation and testing phase participation percentages may support a new sparse populating pattern of the footprints on the class map for the suburban case and urban case A. More specifically:

- With reference to Figure 4, the enhanced training phase participation percentage of 98%, which anyway is the enhanced version of the training phase participation percentage of 70% of the NNTGM default operation settings, force NNTGM virtual topology footprints to be more concentrated to their respective indicative OV LV BPL topologies for all the cases, thus creating a confined populating pattern. Indeed, from Table 4, all the NNTGM OV LV BPL topologies remain inside the borders of their corresponding OV LV BPL topology classes when the vast majority of the NNTGM OV LV BPL topologies (i.e., above 93%) remain inside the ACA / RMS-DS box of ±10% of the examined indicative OV LV BPL topologies. In accordance with NNTGM definition of [3], the enhanced training phase participation percentage of the MATLAB NN training program generates

NNTGM virtual topologies with low stochasticity that finally remain close to their corresponding indicative OV LV BPL topologies.

- With reference to Figures 5 and 6, the enhanced validation and testing phase participation percentages may support a new populating pattern of the OV LV BPL topology classes for the suburban case and urban case A that is different from all the populating patterns presented until now and in [4]. In fact, the low training phase participation percentage of the MATLAB NN training program generates NNTGM virtual topologies with high stochasticity that further create NNTGM virtual topology footprints of high extents tending to move away from the indicative suburban case and urban case A class borderlines with a significant number of NNTGM virtual topologies presenting higher values for both ACA and RMS-DS. Indeed, as the high validation phase participation percentage is concerned in Table 5, only 4% and 26% of the NNTGM OV LV BPL topologies remain inside the ACA / RMS-DS box of ±10% for the examined indicative suburban case and urban case A, respectively. Similarly, when the high testing phase participation percentage is concerned in Table 6, only 1% and 33% of the NNTGM OV LV BPL topologies remain inside the ACA / RMS-DS box of ±10% for the examined indicative suburban case and urban case A, respectively. In fact, when low participation percentages for the training phase are assumed, MATLAB NN training program fails to learn the meaningful patterns of the OV LV BPL topologies in the TIM OV LV BPL topology database leading to poor generalization and high bias. The inadequate training phase forces the MATLAB NN training program to learn patterns for the validation and testing sets instead of generalizing from the training set thus causing slow or failed convergence.
- As the NNTGM virtual topology footprint of the rural case is examined, the changes of the participation percentages of the three phases of the MATLAB NN training program does not have any significant effect on the inside the class GPI. In contrast, the low training phase participation percentage of the MATLAB NN training program have almost the same impact on the inside the box GPI of the rural case with the one of the urban case A. Anyway, the absolute extent of the NNTGM virtual topology footprint of the rural case remains significantly lower on the class map in comparison with the NNTGM virtual topology footprint of the urban case A rather indicating a dense populating option.

From the perspective of generating virtual topologies for populating OV LV BPL topology classes, the previous findings concerning the impacts of the participation percentages of the three phases of the MATLAB NN training program on the NNTGM virtual topology footprints may allow the sparse populating when low participation percentages of the training phase are concerned. In this case, the suburban case is characterized by sparse populating either outside the class or outside the box with reference to the corresponding GPIs. As the footprints of the rural case and the urban case A are regarded in the case of the low participation percentages of the training phase, these footprints present sparse populating as the inside the box GPI is examined. Despite the similar values of the inside the class GPIs of the rural case and the urban case A, the footprint extent of the urban case A inside its class borderlines is significantly wide indicating a sparse populating inside the class when low participation percentages of the training phase are applied. In conclusion, the low participation percentages for the training phase lead to a MATLAB NN training program that is highly sensitive to small variations in the data, making it less stable since the MATLAB NN training program memorizes the OV LV BPL topologies of the TIM OV LV BPL topology database instead of learning general patterns thus sparsely populating the corresponding OV LV BPL topology classes.

Conclusions

In this paper, additional numerical results for populating OV LV BPL topology classes by applying NNTGM are demonstrated and analyzed. In [3], the theory for populating OV LV BPL topology classes by applying NNTGM has been given while the first numerical results and parameter investigation have been given in [4]. With reference to the class maps and the GPIs, the impact of the following NNTGM parameters on the NNTGM virtual topology footprints, whose significance has already been recognized in [3], has been assessed, namely: (i) The operating frequencies (i.e., frequency range and flat-fading subchannel frequency spacing); and (ii) the participation percentages of the three phases (training, validation and testing) of the MATLAB NN training program of NNTGM. First, as the operating frequencies are concerned, the increase of the frequency range with respect to its size in the NNTGM default operation settings given the default flat-fading subchannel frequency spacing mainly supports sparse NNTGM virtual topology footprints for the rural class while the NNTGM virtual topology footprints of the suburban case and urban case A are only affected regarding their position and size with respect to the corresponding ACA / RMS-DS boxes of ±10%. In contrast, the increase of the flat-fading subchannel frequency spacing with respect to its value in the NNTGM default operation settings given the default frequency range supports dense NNTGM virtual topology footprints for all the examined indicative OV LV BPL topologies. Generalizing the impact of the operating frequencies on the NNTGM virtual topology footprints, the higher number of operating frequencies introduces more noise and randomness in the TIM OV LV BPL topology database and the MATLAB NN training program of NNTGM, increasing stochasticity while wider flat-fading subchannel frequency spacings provide more global information and reduce local overfitting, decreasing stochasticity. Second, as the participation percentages of the three phases of the MATLAB NN training program are concerned, the main issue regarding the populating mode is the participation percentage of the training phase. In fact, high participation percentages of the training phase, that lie over the default value of 70%, supports dense populating due to the low stochasticity of the generated NNTGM virtual topologies that finally remain close to their corresponding indicative OV LV BPL topologies. When low participation percentages of the training phase are concerned sparse populating is expected for the NNTGM virtual topology footprints of the suburban and urban cases. Concluding this companion paper of [4], five main factors of the NNTGM operation settings have been assessed in total offering a wide portfolio of populating scenarios for the OV LV BPL topology classes by applying NNTGM.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this paper.

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