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Link Budget Equation for a Smart Grid Communication System

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Abstract: Smart grids are the networks which are having intelligence in the generation stage to the after distribution ones. These networks Have very high power efficiency. Moreover, they are applicable stages to the green energy as they depend on green sources as well as intelligence in operation. They may be fully automated. Really, the communication system can connect among different parts of a smart grid. In addition, the communication system performance is governed by the channel performance. In this manuscript, we try to develop a new path loss model for a communication channel in these grids. Moreover, the deduced equation is applied to predict the overall system performance. The received signal strength *RSS* is measured and there are trials to improve it by applying space time block codes *STBC*. The simulation results show that the application of *STBC* codes, inside smart grids, can greatly improve the performance of a smart grid.

Keywords: Smart Grid, Communication System, Link Budget & RSS.

1. Introduction

The smart grid represents an advanced and energy-efficient network that covers all stages of the power from generation to distribution. It is basically a modern electrical grid infrastructure that is efficient, reliable, and secure, incorporating seamless integration of renewable and alternative energy sources through control and advanced communication technologies. The smart grid consists of a few networks: the power network, the information network, and the business network. The main goals of a smart grid are enhancing power quality, cutting consumer costs by energy efficiency, reducing carbon emission, and efficient emergency management. There are many challenges in the implementation of smart grids regarding optimization of business and demand management, transmission, distribution, and generation assets.

The subsystems of the smart grid include communication between network nodes, energy-efficient nodes, secure grids using blockchain technology, and reliable reporting systems. Communication is one of the crucial challenges that links all the parts together. It involves a transmitter, a receiver, and a channel of communication. For reliable communication, the received signal at the receiver must be greater than a certain threshold. For this, the link budget equation has to be established. This equation defines the relation between transmitted power, received power, channel parameters, and possible impairments.

For a communication system, the received signal y can be expressed in terms of the transmitted signal *S* as follows;

$$y = h_1 s + n \quad (1)$$

where h_1 is the channel parameter and n is the channel noise.

For a communication system, the link budget equation can be as follow;

$$M = P_{tx} - L_T + \left(G_T + G_R + ATA\right) - L_J - I - TR_{Loss} - S_{rx} \quad (2)$$

Here, *M* is the *EMI* margin level of the system, and P_{TX} is the power being transmitted. The terms in the brackets are the transmitter antenna gain, receiver antenna gain, and the coupling gain between antennas, respectively. L_j denotes the loss in the signal propagation through the channel, *I* stand for the interference present, TR_{loss} denotes the total loss in the system that is not accounted for by previous terms, and S_{rx} indicates the sensitivity of the receiver [2].

Path loss is a major factor in the link budget equations, and it must be measured and modeled effectively. Several propagation models can be applied to smart grids; however, in this paper, a modern model has been used. This is a model based on accurate measurements in real-life conditions [1].

The actual model of path loss that was used for the propagation is:

$$PL = 32.44 + A_p + A_{SSF} + 10\eta_1 Log\left(d/1m\right) \quad (3)$$

PL is the total path loss in the system, A_p is the path loss at less than 10 meters, which gives the "correction error," *ASSF* is the fading channel, which may follow a Rayleigh distribution, and η is the path loss exponent.

Really, the path loss model of Eq. 3 is a novel model which is based on novel and real measurements. Moreover, it can provide good accuracy especially for short range communication. Furthermore, it considers the fading effects of a wireless channel. This is the reasons for choosing this model in our manuscript.

The main motivations to this manuscript can be as follow;

- We try to determine the link budget equation for a communication system inside a smart grid.
- We try to choose the best available path loss model for a communication system inside smart grids.
- We try to evaluate the performance of a communication system based on its sensitivity "RSS.
- We try to improve the RSS performance in a communication system by applying both multiple input multiple output MIMO system and the STBC codes.
- We also estimate the spectral efficiency SE performance of the proposed system.

The structure of the paper is as follows: Section 2 provides an overview of the related research works on the topic. Section 3 describes the *STBC* codes, while Section 4 outlines the simulation results. Finally, the paper concludes with a summary.

2. Related Work

In [1], the authors assessed some of the path loss models that can be applied in neighboring smart grids. Further, they presented a new radio channel model, optimized for the smart grid environment, that was verified through a very robust measurement procedure. Measurements in real environments give highly accurate models. In [3], several path loss models suitable for industrial IoT networks and smart grids were reviewed. [4] focused on the unmanned aerial vehicle propagation path loss model, assuming the existence of a millimeter-wave propagation channel. [5] Investigated some strategies to overcome the channel characteristics challenges by designing an equalizer to improve radio channels' transmission performance.

Other researchers have worked on developing advanced channel coding schemes to improve wireless channel propagation. The work in [6] presented the comparison of the performance of folded coding versus random Gaussian coding over a wireless additive white Gaussian noise *AWGN* channel. A proposal to support performance improvement in wireless channels, especially for 6G networks, was a serial and parallel concatenated channel coding. Low-density parity-check coding in multiple input multiple output *MIMO* channels and improvement of their characteristics is an important issue that attracted many researchers, as noticed from [8]. New coding scheme with phase rotation extensions were also introduced in [9]. Later, an improved *LT* code was put forward in [10] by introducing a backward coding scheme to reduce the error floor due to the low-degree information nodes. Finally, the authors in [11] explored the feasibility of hybrid analog-digital beamforming for enabling millimeter wave *mmWave* massive *MIMO* with fully-connected and sub-connected architecture. Performance evaluations are made in terms of bit error rate *BER*, signal to noise ratio *SNR*, complexity, spectral efficiency *SE*, and energy efficiency *EE*. Extensive simulation and analytical results are shown in the paper to verify that the partially connected hybrid analog/digital beamforming architecture is an appropriate approach to balance power consumption, cost, complexity, and performance for *mmWave* massive *MIMO* communications.

3. Space Time Block Codes STBS

STBC techniques can improve channel propagation characteristics, resulting in better *RSS*. It ensures lower *BER* for the entire system. In addition to that, the *STBC* methods can improve the signal-to-noise ratio of the signal and also allow improving overall throughput. The typical *STBC* technique is known as the Alamouti 2×2 code using two antennas at both transmitter and receiver ends. In every time frame, a different code is transmitted from the transmitter to the receiver. One data frame can be represented by several signals that are spatially distributed and transmitted at different time frames. The receiver combines the signals to recover the original transmitted data. The mathematical model for the Alamouti 2×2 code is given by:

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} + \begin{bmatrix} \eta_{11} & \eta_{12} \\ \eta_{21} & \eta_{22} \end{bmatrix} \tag{4}$$

$$= \begin{bmatrix} h_{11}s_1 + h_{12}s_2 + \eta_{11} & -h_{11}s_2^* + h_{12}s_1^* + \eta_{21} \\ h_{21}s_1 + h_{22}s_2 + \eta_{21} & -h_{21}s_2^* + h_{22}s_1^* + \eta_{22} \end{bmatrix} \tag{5}$$

The combined signal at each receiver can be expressed as;

$$\tilde{s}_1 = h_{11}^* y_{11} + h_{12} y_{12}^* + h_{21}^* y_{21} + h_{22} y_{22}^* \tag{6}$$

$$\tilde{s}_2 = h_{12}^* y_{11} - h_{11} y_{12}^* + h_{22}^* y_{21} - h_{22} y_{22}^* \tag{7}$$

٤. Simulation Results

In this section, the proposed system is simulated. Moreover, the simulation results are clarified in details. Firstly, in order to carry put our experiment; we used simulation parameters which are concluded in Table 1. These parameters are chosen in order to achieve fair comparisons with previously carried out work. The specifications of the computer machine, which are used in order to carry out our simulation results, are written in details in Table 1.

Table 2 shows the relationship between the transmitted signal S_{tx} and the received signal S_{rx} in the proposed system for application of only 2×2 antennas. It can be shown the received signal can be increased when the transmitted signal is increased. In fact, this is a logic case however; we used to apply such cases in order to verify our simulation codes.

The effect of Alamouti codes application is verified in Table 3. This table provides the relationship between the transmitted signal and the received signal for each different case of combination between antennas at each transmitter and at each receiver. It can be concluded that increasing the number of transmission or reception antennas can increase the received signal strength "receiver sensitivity".

Figure 1 provides the relationship between the received signal to noise ratio *SNR* at the receiver and the total spectral efficiency of the proposed system *bps*. It can be noticed that increasing the signal to noise ratio results in an increase in the total spectral efficiency of the system. Moreover, increasing the number of transmission / reception antennas leads to an increase in the total signal to noise ration as well as total throughput.

Table 1. The simulation parameters.

Parameter	**Value**
Path Loss Model	as in [1] and Eq. 3
Transmitted Power	20 dBm
A_p	1 dB
η	2.5 dB
d	10 m
BER	10^{-3}
RSS	as in Eq. 2
Diversity Codes	Alamouti 2×2
MATLAB	Version R2020a
Operating System	Win 10 – 64-bit operating system, x64-based processor
Processor	Intel(R) Core(TM) i7-4600U CPU @ 2.10GHz 2.69 GHz
Installed *RAM*	8.00 GB (7.88 GB usable)
Product *ID*	00329-10330-00000-AA651
Edition	Windows 10 Enterprise
Version	21H2
OS build	19044.2130
Experience	Windows Feature Experience Pack 120.2212.4180.0

Table 2. The received sensitivity S_{rx} vs the transmitted signal strength S_{tx} for 2×2 antennas.

S_{tx} "dBm"	S_{rx} "dBm"
20	-38.33
15	-43.33
10	-48.44
5	-53.44
0	-58.44
-5	-63.44
-10	-68.44

Table 3. The received signal strength improvement S_{rx} due to Alamouti Codes application.

Transmitted signal strength S_{tx}	*Received signal strength S_{rx}*				
S_{tx}	S_{rx} (1×1)	S_{rx} (1×2)	S_{rx} (2×1)	S_{rx} (2×2)	S_{rx} (4×4)
20	-38.33	-34.33	-36.33	-28.33	-18.33
15	-43.33	-39.33	-41.33	-33.33	-23.33
10	-48.44	-44.44	-46.44	-38.44	-28.44
5	-53.44	-49.44	-51.44	-43.44	-33.44
0	-58.44	-54.44	-56.44	-48.44	-38.44
-5	-63.44	-59.44	-61.44	-53.44	-43.44
-10	-68.44	-64.44	-66.44	-58.44	-48.44

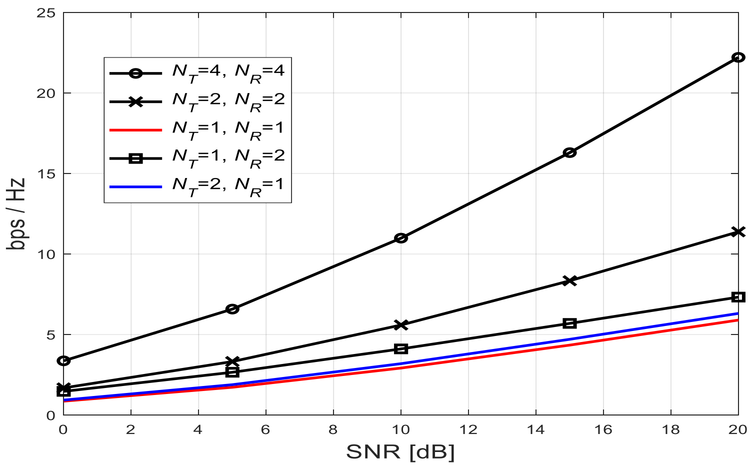

Figure 1. The bit per second *bps* vs signal to noise ratio *SNR* for a smart grid communication channels.

5. Conclusions

This manuscript proposes a new path loss channel model developed for smart grid communication systems. The performance of the radio channel in smart grids was also improved. It was observed that the use of

Alamouti codes *STBC* enhanced the performance of the communication link in smart grids, which increased the spectral efficiency of wireless channels in these systems.

Declarations

The datasets generated or analyzed during the current study are available from the corresponding author upon reasonable request. Financial support for this work is provided by the 6th of October Technological University, 6th of October City, Giza, Egypt.
There is no conflict between this work and other published work.
The Matlab code is available on reasonable request.

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