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Application of OFDM over Indoor Power Line Communication

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***Abstract*—This paper deals with the use of OFDM technology in Broadband over power line (BPL) systems. Here OFDM technology is used for modulating and demodulating data signals in a BPL system. The challenge of using it in the existing low voltage power line is immensely high, as it depends upon topology of the BPL system. In this paper, by varying different parameters like number of branches, lengths of branches and the load impedance by using Zero Forcing and Least Square equalizer, the performance of both the equalizer were simulated and analyzed.**

***Index Terms*—Broadband over power line (BPL), Orthogonal Frequency Division Multiplexing (OFDM), Bit Error Rate (BER), Zero Forcing (ZF), Least Square (LS), Power Line Communication (PLC), Signal to Noise Ratio (SNR).**

I. Introduction

PLC is established on electrical signals, containing useful data, traveling through power lines as a medium. A channel used for communication is described as a substantial path between transmitter and receiver which carries the message signal from one end to another [1].

Many rural people in India do not have direct access to high end communication techniques like FTTX, DSL, optical cable or other telephone mediums. But most of rural internet users in India are connected with power lines [3]. BPL technology is an advantageous alternative for those village dwellers having desire of accessing high speed internet service. On the other hand, in metropolitan area BPL will be another cost efficient and reliable option for getting high speed internet service [3]. Also as the infrastructure required for BPL communication system is already there so implementation of this technique will be less time consuming and economically efficient.

In PLC, message signals are modulated with radio signal (high frequency carrier signal) and than the modulated signal are transmitted through power lines as a transmission channel. The used encoding schemes and frequencies have a eye-seen impact on the efficiency and the speed of the PLC service. OFDM is used as the encoding scheme in BPL. This is a multi-carrier transferal technique which supports high speed data services.

In this paper, a typical BPL system has been modeled in Section III, by using a PLC model described in Section IV. The different BPL parameters like number of branches, line lengths, and load impedance has been varied and its performance based upon ZF and LS equalizer has been compared in Section VI. The BER is used for comparison of different equalizer based on different parameters.

II. Problem Formulation

Behavior of a low voltage distribution system varies with the variation of different parameters like type of load, physical location of network, number of end user load, temperature of surrounding etc. Hence it is very much necessary to predict the consequences of the varying network behaviors upon the performance of BPL system.

This paper highlights a BPL system which has been designed using OFDM technique. also the BER of the system at the output end has been calculated and plotted. At the same time, the BPL system response has been analyzed by varying different channel parameters like branch length, branch load impedance, number of branches etc. It basically provides an understanding of behavior of varying topologies upon the performance of BPL system by using ZF and LS equalizer.

All the simulation has been made using MATLAB software.

III. BPL Topology

BPL topology proposed here is related to low voltage distribution system. In Indian scenario the most rigorous distribution to the end users is basically carried on by a typical 220 V, 50 Hz, 1 phase line. The reason why this model is not used in medium voltage and high voltage system is that High voltage/Medium voltage electricity tremble at a changeable frequency, which interferes the transmitted message signal and acts as an external noise [5]. In BPL architecture, a device called as injector is used to fed high frequency, low voltage data signal into high voltage power lines [6].

Message signal strength gradually fades traveling around 300–1000 m through the power lines [11]. Hence in every 1000 m(approximately) repeaters are used. Which improves the signal quality and removes unwanted signals. And finally extractors are used to extract the data signals from high voltage power lines to low voltage distribution lines. Generally extractors are put at distribution transformers (step down transformers). Some extractors amplify the BPL signal strength sufficiently to make the transmission of the signal possible through the distribution transformers [6] (see Fig. 1).

IV. PLC Modeling

The power line has to be modeled taking into the account of various factors like attenuation due to heat and noise, propagation loss as well as the effect of number of branches, impedance and line lengths on the power line. The PLC has been designed as described in [7]. In this model, we have

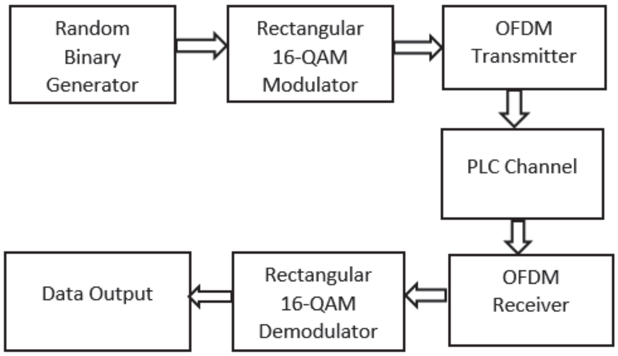

Fig. 1. BPL system block diagram.

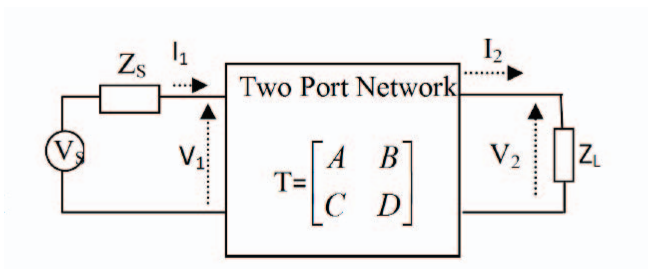

Fig. 2. Two port network.

used bottom up approach as it allows obtaining the frequency response of the channel beginning from the properties of the components in the power network, such as lines, branches and loads.

In this model first the characteristic impedance and propagation constant is derived by using ABCD parameters of a 2 port network (2PN) as mentioned in Fig. 2.

Voltage and current relation using transmission line parameters of this two port network power line model is given by (1).

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}. \tag{1}$$

The coefficients of the 2PN are defined as follows

$$A = \left.\frac{V_1}{V_2}\right|_{I_2=0} \qquad B = \left.\frac{V_1}{I_2}\right|_{V_2=0}$$
$$C = \left.\frac{I_1}{V_2}\right|_{I_2=0} \qquad D = \left.\frac{I_1}{I_2}\right|_{V_2=0}.$$

The transfer function can be written as follows

$$H(f) = \frac{V_2}{V_S} = \frac{Z_L}{AZ_L + B + CZ_L Z_S + DZ_S}. \tag{2}$$

The two intrinsic line parameters characteristic impedance (Z_o) and propagation constant (γ) can be expressed as

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C} \tag{3}$$
$$Z_0 = \frac{R + j\omega L}{G + j\omega C} \tag{4}$$

where R, L, G and C are the resistance, inductance, conductance and capacitance per unit length of a power line respectively. The four constants of a two wire transmission line can be expressed as

$$R = \frac{1}{\pi a}\sqrt{\frac{\pi f}{\mu_c}}\,\Omega/m \tag{5}$$
$$L = \frac{\mu}{a}\arccos\left(\frac{D}{2a}\right) H/m \tag{6}$$
$$G = \frac{\pi\sigma}{\arccos\left(\frac{D}{2a}\right)} S/m \tag{7}$$
$$C = \frac{\pi\epsilon}{\arccos\left(\frac{D}{2a}\right)} F/m \tag{8}$$

where

$a =$ conductor radius
$D =$ cable separation
$f =$ frequency of wave
$\mu_c =$ conducting material permeability
$\sigma_c =$ conducting material conductivity
$\sigma =$ dielectric material conductivity between conductors
$\mu =$ dielectric material permeability between conductors
$\epsilon =$ dielectric material permitivity between conductors.

V. OFDM Transmitter and Receiver

In a low voltage BPL system the effect of the variation in lengths, impedance lead to Inter Symbol Interference (ISI) that decreases the performance. OFDM is used to reduce the effect of multipath in a BPL system [8–10]. OFDM is a frequency multiplexing technique used as a digital multi carrier modulation method. This technique uses a large number of closely spaced orthogonal sub carriers to carry data. Modulated data are given to a IFFT block generating an OFDM signal. The OFDM signal is converted into serial data which is then fed to cyclic prefix block which appends 1/4th data to each sample to minimize symbol interference.

At receiving side, all the techniques used in transmission process are inverted. The cyclic prefix is initially detached and the signal is followed by serial to parallel converter. These data are given to FFT block which is then fed to an equalizer (ZF, LS). Finally, the data signals are recovered doing demodulation. Fig. 3 gives more information regarding the OFDM transmitter and receiver used in this BPL system.

In Telecommunication, the equalizer is a device that attempts to reverse the distortion incurred by a signal transmitted through a channel. In this paper, we have used two types of equalizer Least Square (LS), Zero Forcing (ZF).

VI. Result and Analysis

All Simulations in this paper are carried out by using MATLAB software. The BPL system behavior by varying number of branches, line lengths and load impedance was studied and the comparisons between two equalizers using 16-QAM at 40 dB SNR were shown in the Figs. 5, 6, 8 and 9. Here the cable cross-section is 2.5 mm^2, cables separation (D)

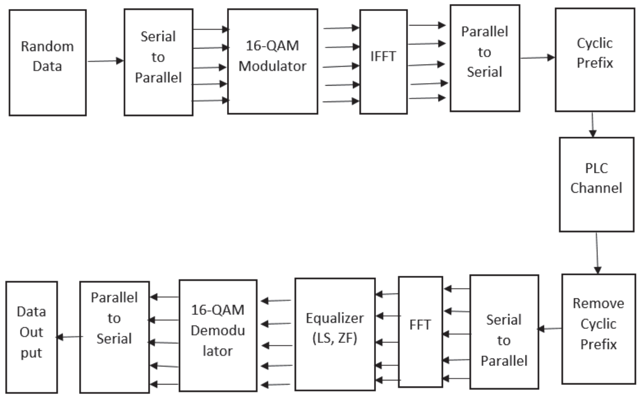

Fig. 3. OFDM transmitter and receiver block diagram.

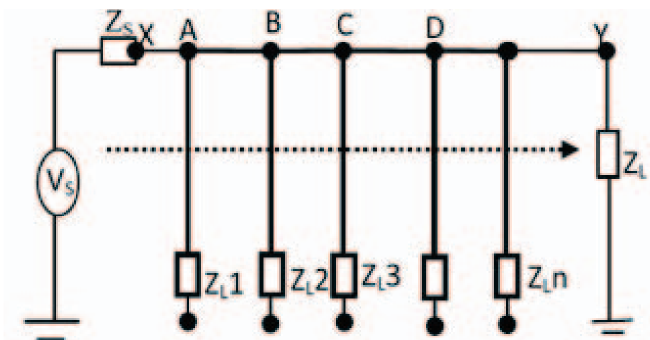

Fig. 4. Power line model with distributed bridge taps.

is 3 mm and operational frequency is 30 MHz. The line parameters can be calculated using the values of the cross section and separation of the cables as mentioned above and putting it in (9), (10) are $R = 0.0585\ \Omega/\mathrm{m}$, $L = 0.44388\ \mu\mathrm{H/m}$, $C = 61.734$ pF/m.

In the Fig. 4, the line length XY was varied as 20 m, 40 m, 60 m and 80 m with respect to number of branches (1, 2, 4, 6, 8, 10) each having load impedance of 50 Ω respectively. The source impedance Z_s and load impedance Z_L of the power line was kept at 85 Ω each respectively. From the Fig. 5(a)–(d), it was observed that with increase in the number of branches the BER increases because as the OFDM signal that passes through the branches are reflected back. The reflection of these signals interferes with the transmission signal to create a destructive interference that leads to attenuation and distortion of the signal. It was also observed that increasing line lengths, error rate also grows and with further increase in length would attenuate the signal. The comparison shows that an OFDM system with ZF equalizer performs better than LS equalizer in order to minimize the ISI in the PLC channel.

In the Fig. 4, the load impedance of the branches were varied from 50 Ω to 1500 Ω with respect to number of branches (1, 2, 4, 6, 8, 10) each having branch length 10 m respectively. The source impedance Z_s and load impedance Z_L of the power line was kept at 85 Ω each respectively. From

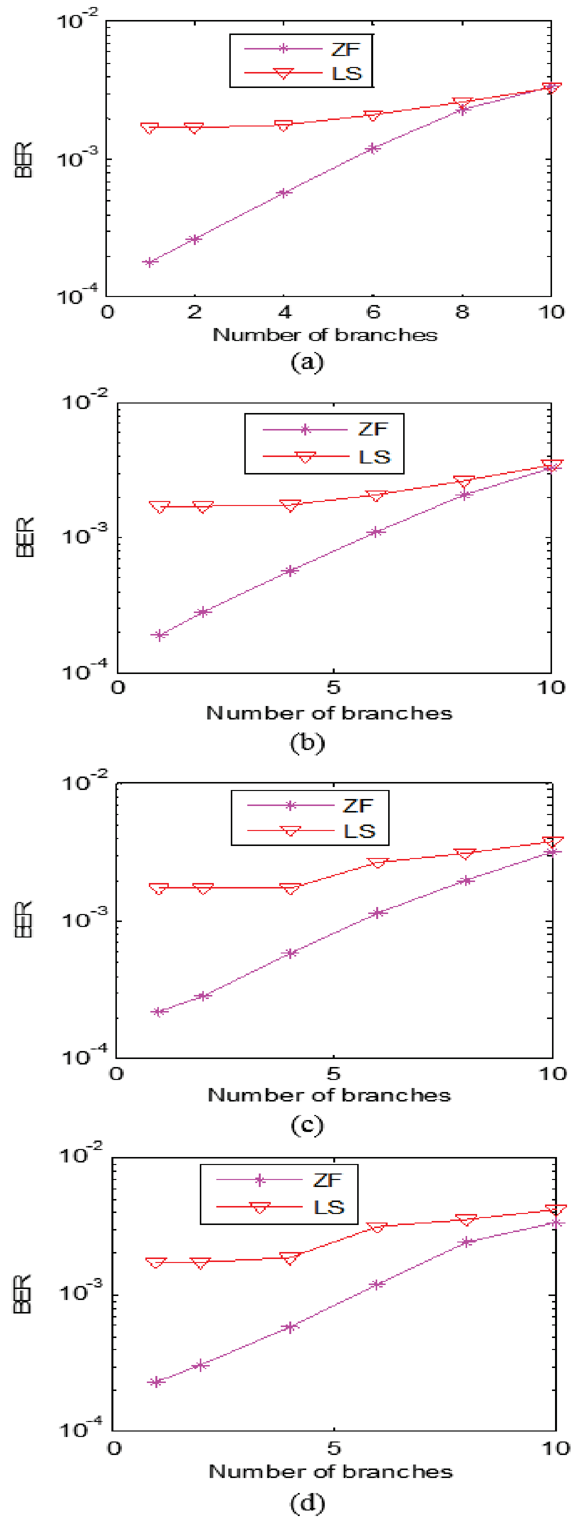

Fig. 5. Performance of ZF and LS equalizer in a distributed bridge tap power line of length (a) 20 m (b) 40 m (c) 60 m (d) 80 m.

the Fig. 6(a)–(d), it was noticed that increasing load, error rate also goes high. The comparison shows that an OFDM system with ZF equalizer performs better than LS equalizer in order to minimize the ISI and bit error rate (BER) in the PLC channel.

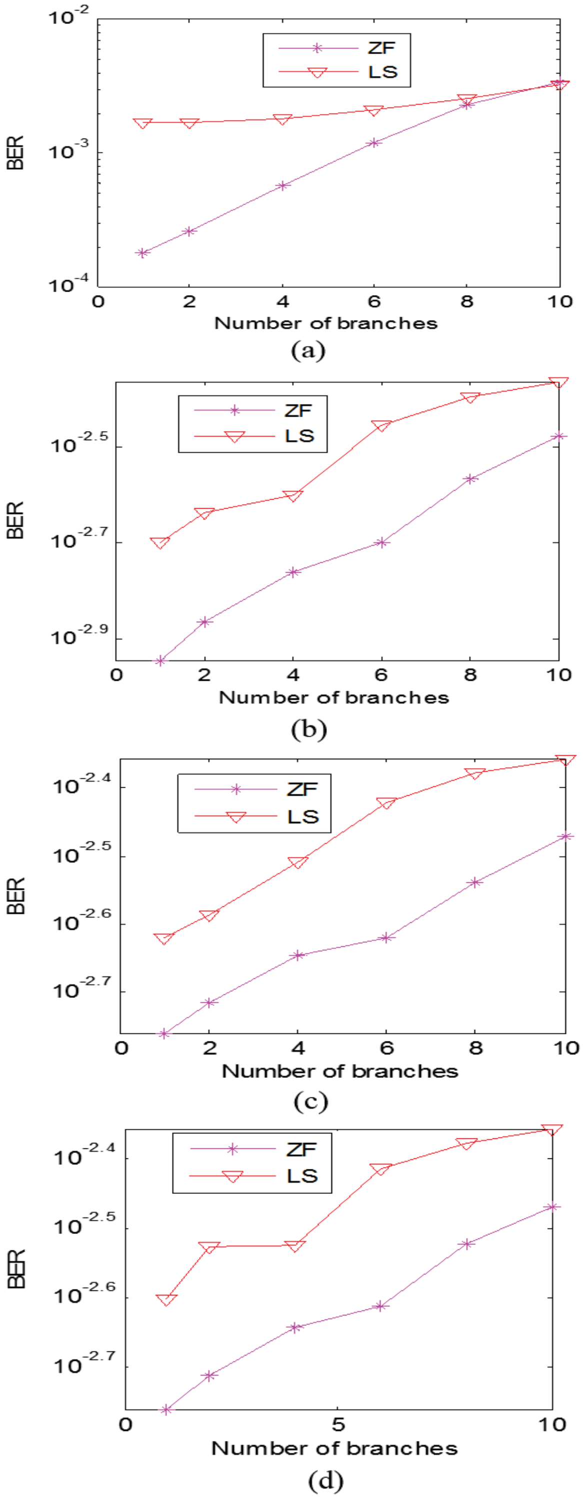

Fig. 6. Performance of ZF and LS equalizer in a distributed bridge tap power line of load impedances (a) 50 Ω (b) 500 Ω (c) 1000 Ω (d) 1500 Ω.

In the Fig. 7, length of AX was changed from 10 m to 60 m with respect to number of branches (1, 2, 4, 6, 8, 10) each having load impedance of 50 Ω respectively. The source impedance Z_s and load impedance Z_L of the power line was

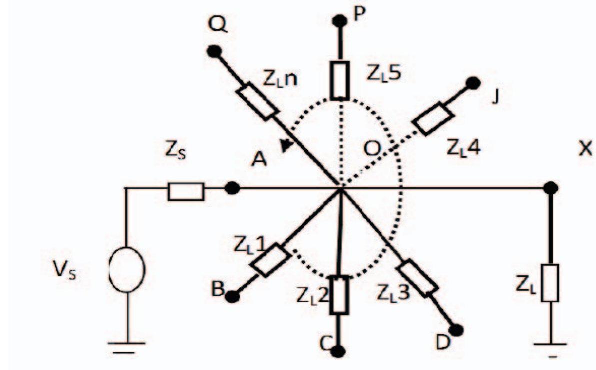

Fig. 7. Single node multi branch power line model.

kept at 85 Ω each respectively. From the Fig. 8(a)–(d), it was observed that with increase in the number of branches the BER increases because as the OFDM signal that passes through the branches are reflected back. The reflection of these signals interferes with the transmission signal to create a destructive interference that leads to attenuation and distortion of the signal. It was also observed that increasing line lengths, the error rate also enlarges and with further increase in length would attenuate the signal. The comparison shows that an OFDM system with ZF equalizer performs better than LS equalizer in order to minimize the ISI in the PLC channel.

In the Fig. 7, the load impedance of the branches were assorted from 50 Ω to 1500 Ω with respect to number of branches (1, 2, 4, 6, 8, 10) each having branch length 10 m respectively. The source impedance Z_s and load impedance Z_L of the power line was kept at 85 Ω each respectively. From the Fig. 9(a)–(d), it was observed that increasing load the error rate also goes up. The comparison shows that an OFDM system with ZF equalizer performs better than LS equalizer in order to minimize the ISI in the PLC channel.

VII. Conclusion

In this paper, various parameters of a BPL system has been analyzed by changing different channel parameters like length of power lines, load impedance, and number of branches. It was observed that with increase in number of branches, BER goes up. This occurs due to the reflection of the signal through various branches collectively distorts the signal transmitted from one end to other. The effects of varying lengths of the branches and load impedance of the branches at distributed taps and single node multiple taps power line models were also studied. It was found out that with increase in lengths of a power line the BER increases because of the attenuation of signal due to exposure to heat and radiation. It was also found out that with increase in load impedance the BER increases due to reflection. Overall by using performance parameters of a BPL system it was concluded that a ZF equalizer performs better than a LS equalizer.

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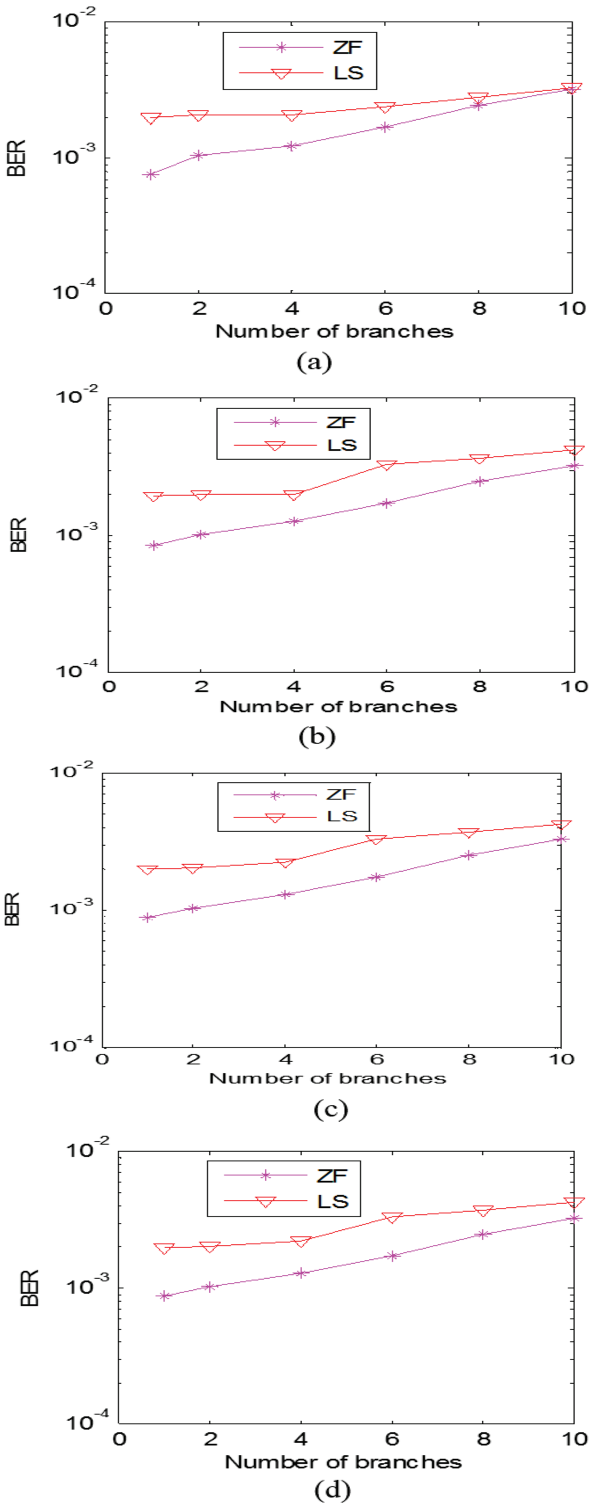

Fig. 8. Performance of ZF and LS equalizer of multiple branches at a single node power line of length (a) 10 m (b) 20 m (c) 40 m (d) 60 m.

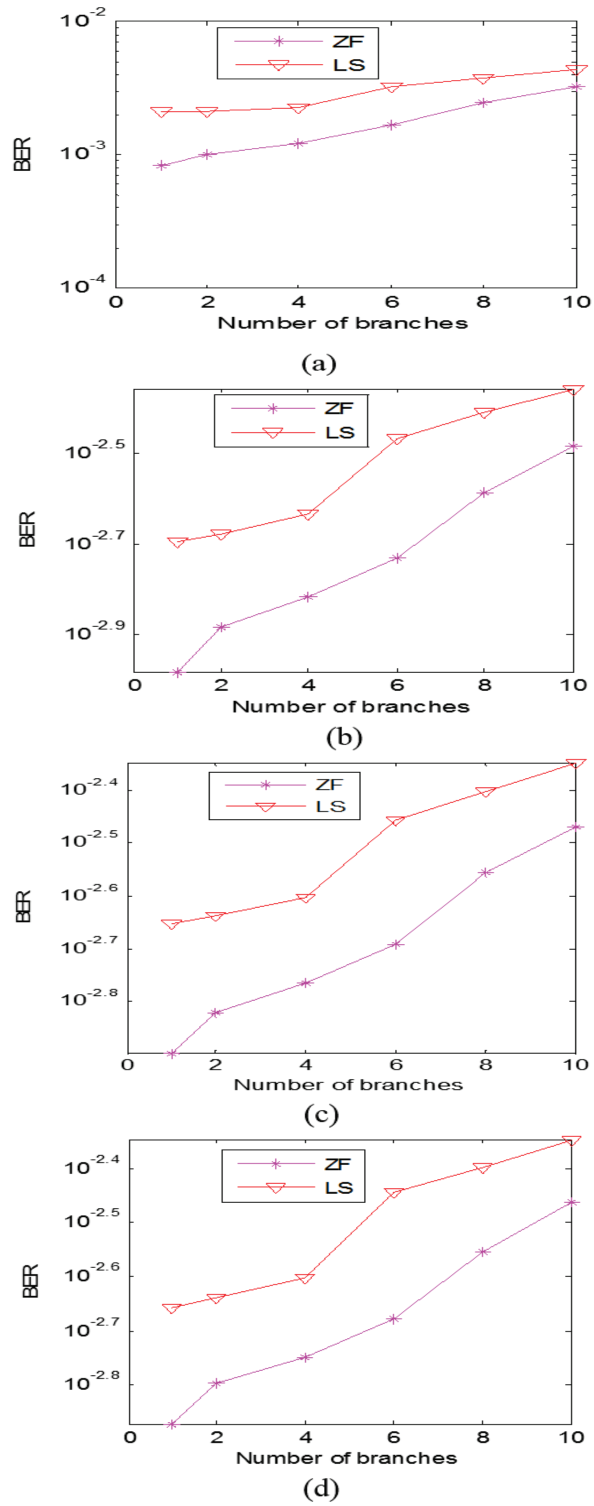

Fig. 9. Performance of ZF and LS equalizer of multi branches at a single node power line of load impedance (a) 50 Ω (b) 500 Ω (c) 1000 Ω (d) 1500 Ω.

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