Assessment of transmitted speech signal degradations in rician and rayleigh channel models

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Abstract. Telecommunications services monitoring is of paramount importance, network operators must meet the expectations of their subscribers. On wireless communications, transmitted signal may suffer different degradations in the transmission channel. In the literature, there are different models of wireless channels, among the most cited are the Rician and Rayleigh fading channel models, each one presents different characteristics of transmission. In the speech quality assessment research area, most of the works focused on wired network type degradations, using parameters as packet losses, delay and jitter; however, wireless degradation characteristics are not considered. In this context, the present paper investigate the impact of different Doppler frequency shifts (Hz) on speech communications, using the fading channel models previously mentioned, and different multipath delay profiles. Performance evaluation parameters are based on the voice quality assessment algorithms described in recommendations ITU-T P.563 and P.862. The experimental results show how the variation range of the Doppler shift is related to speech quality index.

Keywords: voice quality, wireless network, network impairments, channel models, fading, Doppler effect

(Received October 5th, 2018 / Accepted November 5st, 2018)

1 Introduction

The wireless mobile communication systems have undergone several evolutions in recent years to meet the increasing users demand, as well as maximize network performance for data transmission.

On wireless communication, transmitted signal may be attenuated due to natural causes, such as reflection, refraction, scattering, among others, characterizing the fading phenomenon [2, 18]. This effect occurs due to obstacles between transmitter and receiver.

Fading can cause variations in phases, amplitudes or delays in the trajectory time of a signal, being characterized as one of the main problems in wireless communication. Moreover, due to the multiple paths in the transmission of a wireless signal, this may cause fluctuations in the power of the received signal [14]. Another important parameter that affect the communication quality is the Doppler shift (Hz) that is originated by the relative movement between both the transmitter and receiver. Thus, if user is in a phone call, the speech quality can suffer variation according to his or her movement velocity.

Therefore, the evaluation of channel performance considering fading effect is necessary. Thus, to evaluate such degradations, several channel models are analyzed in the literature, as [26] and [17]. These effects are usually described in models of Rayleigh and Rician channels [14].

Voice quality in Voice over Internet Protocol (VoIP) services is not guaranteed due to various problems introduced by Internet and IP terminal degradations such as packet loss [3], [23], [7], time distortion, noise, echo, delay, fading, among others.

According to [8], several techniques have been implemented to improve the quality of speech in VoIP systems. This is a research area of great interest since service providers need to maintain certain levels of voice quality by monitoring VoIP call flows, ensuring competitiveness [22], [21].

Voice quality can be assessed through a subjective approach using the Mean Opinion Score (MOS) index, which is defined according to ITU-T Rec. P.800 recommendation. However, the subjective test, although considered the most accurate, it needs a specific laboratory conditions, and this is its main disadvantage, because makes the process more expensive. In this sense, this method can be replaced by objective measures. It is worth noting that the performance accuracy of objective metrics is determined considering the subjective test results.

Several objective metrics were developed to produce an subjective estimation of the MOS index, such as the algorithms described in the International Telecommunication Union (ITU) recommendations, P.563 and P.862 [8].

The ITU-T Rec. P.563 is a voice quality evaluation algorithm that uses the non-intrusive method, that is, it does not need original signal as a reference to compare with degraded signal [8]; this method is most recommended for real-time applications [16]. The ITU-T Rec. P.862 algorithm uses the original signal for comparison with the degraded signal. Therefore, this is considered a more efficient method to measure the actual level of degradation suffered by the signal.

It is important to note that in communications systems, the parameter most commonly used to evaluate the quality of a transmission medium and therefore the transmitted signal is the Bit Error Rate (BER). This parameter is characterized as an objective evaluation measure of the transmission quality and determines the error rate in the received bits [14]. The MOS index is not commonly used in these studies.

In this arena, the main contribution of this paper is to evaluate a VoIP communication considering wireless degradation, specifically fading channel models and Doppler shift effect. For this, a simulator for wireless communication scenario is built, and it considers the Rician and Rayleigh fading channel models.

The rest of the article is divided into the following sections. Section 2 presents the characteristics of wireless channel degradations. Section 3 discusses the wireless channel models used in this paper. In Section 4, the modulation schemes are briefly described. The simulation scenario implemented is described in Section 5. Section 6 presents the results obtained. Finally, the conclusion of the paper is discussed in Section 7.

2 Wireless Channel Degradations

In wireless transmission systems, due to the existence of different obstacles between the transmitter and the receiver, a transmitted signal may be dispersed. Thus, there is more than one propagation path between the transmitter and receiver. Transmitted signal can reach the receiver via different paths and suffer attenuation, distortion, delays, as well as phase changes, thus characterizing constructive interference, in which the signal power is increased, or destructive interference in which the signal power decreases. This phenomenon is called fading. Fading consists of fluctuating amplitudes or phases, as well as delays of a radio signal in a short period of time or distance. This attenuation is caused by the interference of two signals, which reach the receiver at different times. These signals, sent by multiple paths, add up to the receiver's antenna, resulting in a signal that can have its amplitude or phase varied.

Fading is classified into three different types, according to the transmission distance scale. Large-scale fading refers to signal attenuation due to long-distance propagation. Medium-scale fading refers to adverse effects, such as absorption, reflection and dispersion, which are caused by shadowing and the presence of obstacles between the transmitter and the receiver. Small-scale fading refers to rapid changes in signal amplitudes, phase and delays, over a short distance or time [5].

The fading phenomenon can occur, for example, because the height of the mobile antennas is smaller than the height of the structures in their surroundings, so there is not a single line of sight path between the transmitter and the receiver.

The main effects of fading are:

- rapid changes in signal strength within a short distance or interval of time;
- frequency modulation;
- time dispersion.

In wireless communication systems, the fading effects severely degrade signal transmission performance. This fading phenomenon occurs due to multiple reflections of the transmitted signal of objects in the environment.

In this case, the fading effect is given by the sum of the displaced signals, as shown in 1 [25].

$$c(t) = \sum_{n=1}^{N} A_n e^{j(2\pi f_d t + \phi_n)} \tag{1}$$

where A_n is amplitude, f_d is Doppler frequency, ϕ_n is phase and N is number of reflectors.

During a communication between a transmitter and a receiver, if they are in motion, relative to each other, the transmission frequency will change. If the transmitter and receiver are moving away from each other, the transmitter frequency will become smaller. However, if the transmitter and receiver approaches, the frequency will increase. This phenomenon is known as the Doppler effect, and the frequency shift due to the Doppler effect is called Doppler Shift (Hz), which is determined by [9]:

$$f_d = f_c \frac{v}{c} \cos\theta \tag{2}$$

where v is the speed of the vehicle, c is the speed of light, f_c is the carrier wave frequency and θ is the angle of movement between the transmitter and the receiver. The value of the Doppler frequency (f_d) will be maximum if the value of θ is null.

Due to the fading phenomenon and the Doppler effect, the signal $c(t)$, presented in 1, represents a superposition of complex signals, which are highly variable in time if the mobile speed is considered large. This overlay may result in constructive or destructive interference, damaging the received signal on the receiver. These interferences cause a fluctuation in the signal. The rate of this fluctuation depends on the moving speed of the mobile unit, and the angular distribution of the power of the multiple paths around the receiver.

3 Wireless Channel Models

According to the nature of the signal propagation environment, specific mathematical models are used to describe the statistical behavior of the fading effect. Among these models, the most known in the literature are Rayleigh and Rician [4].

In Rayleigh model, all power received by multiple paths is diffusive, in other words, without line-of-sight (LOS) between the transmitter and the receiver. Thus, signals that arrive at the receiver are the result of a sum of signals reflected, refracted or dispersed by an unlimited number of scatters [10], [12].

In Rician model, there is a LOS between the transmitter and receiver. This LOS is characterized by the K factor, which is a relation between the power of a signal component arriving via direct path and the power of dispersed components. According to [15], in MIMO channels the K-factor affects the capacity of the channel by up to 40%. Thus, the definition of the value of this variable is necessary, as this influences the performance of the system.

Some models of [11] consider that the power of the direct path signal is equivalent to the sum of the powers of all scattered paths, K = 1. However, in real LOS scenarios, considering external environments, the power of the direct path may be many times greater than the power of dispersed paths. Thus, there are several studies that evaluate factor K, such as [15], [24] and [27].

However, the definition of value of this parameter is not simple, since it depends on several properties of the clusters, which are considered random, such as cluster number, radius, arrival times, arrival and departure angles, among others [15]. Thus, in this work, the K factor used corresponds to Matlab standard for the Rician fading channel model, which is equivalent to 3.

4 Modulation Schemes

For the transmission of a wireless signal, it is necessary to modulate, so that signal can be represented digitally. Thus, the modulation schemes commonly used, when the frequency of the carrier wave is unknown, consist of phase and amplitude modulation [6].

In the phase shift switching method, the carrier phase is changed according to the modulation signal. This method is classified in two ways: Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) [6].

The BPSK, also called binary phase shift switching, is a digital modulation scheme that represents the data modulating them according to two phases, 0 or 180 degrees, corresponding to two voltage levels of the binary modulator signal, 0 or 1, respectively [6], [13].

Quadrature Phase Shift Keying (QPSK) is a form of phase shift keying in which two bits are modulated at once by selecting one of the four possible phase changes of the carrier, these being 0, 90, 180 or 270 degrees, corresponding to four symbols, 00, 01, 10 and 11 [6], [13].

Another technique consists of quadrature amplitude modulation, called Quadrature Amplitude Modulation (QAM). This modulation technique uses two amplitude-modulated radiofrequency carriers, which are 90 degrees out of phase. The transfer of information is obtained using a mixture of phase change and amplitude to improve transmission efficiency. This scheme can carry higher data rates than the phase modulation schemes when used for digital radio communications [6].

5 Test Scenario

For the simulation of the level of degradation of an audio signal, 20 voice files were extracted, with telephone conversation characteristics, with voice and silence segment percentages between 60% and 40% [19].All files were extracted from Rec. ITU-T P.862, having an average duration of around 8 seconds.

These signals were evaluated in two types of models, one for pedestrians, called the Extended Pedestrian A model (EPA), and another for vehicles, EVA, both of which belong to the ETSI document [1].

This document specifies the multipath delay profiles as well as the power of each of these paths. In the EPA model, the delay values are: 0, 30, 70, 90, 110, 190 and 490ns; the gains are: 0, -1, -2, -3, -8, -17.2 and -20.8 dB. In the EVA model, delay values are: 0, 30, 150, 310, 370, 710, 1090, 1730, 2510ns; the channel gains are: 0, -1.5, -1.4, -3.6, -0.6, -9.1, -7, -12, -16.9dB. However, to obtain a scale with the maximum quality values in each test scenario, the values corresponding to the delay of each model were divided by a constant, which is equivalent to 10000.

In addition, to determine the influence of the Doppler effect in these models, different tests with different speeds were performed. In the EPA model, the velocity varied from 1 to 4 m/s, with a step of 0.5, while in the EVA model, the velocity was from 3 to 113 m/s, with a step of 10. In terms of frequency of the carrier wave, the signal degradation behavior in the most common carrier frequencies (f_c) was verified, 900 MHz, 1.8 GHz, 1.9 GHz, 2.4 GHz and 5.6 GHz.

Each test was simulated by 35 times, and an average of the values found was obtained to obtain values more coherent with a real scenario.

The channel model used in this simulator to verify the level of degradation of the voice signal when transmitted by these models was Rician and Rayleigh.

TABLE 1 presents the parameters used in the simulator, developed in Matlab environment.

Table 1: Simulator Configuration Parameters.

Parameters	Options
Levels of Quantization	Power of 2
Modulation Type	BPSK
Channel Type	Rician or Rayleigh
Number of Transmitting Antennas	4
Number of Receiving Antennas	2
OSTBC Code Rate	$\frac{3}{4}$
Simulation Replication Numbers	35
Sampling rate	20^6
Doppler Spectrum	Jakes

Figure 1 represents the scheme of the methodology used for the simulator development.

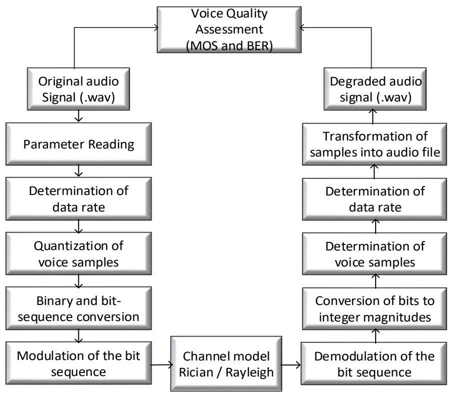

Figure 1: Methodology for carrying out the simulator.

5.1 Performance Evaluation Parameters

The evaluation of the performance of any communication system can be performed by subjective methods, according to human evaluation [20], or objectives, which consist of quantitative methods on the quality of the transmitted signal.

Mean Opinion Score (MOS) index is a metric commonly used in subjective evaluations, in which the user evaluates the quality of the signal received through auditions. This method is described in ITU-T Rec. P.800 [20]. However, there are specific algorithms, such as P.862 of the ITU-T Recommendation, which estimates the value of the MOS index, and the higher its value (the maximum value of 4.5), the lower the signal degradation during transmission.

The BER index is an objective assessment. This index is characterized as the ratio of the transmitted signal bit errors, i.e. error in the bits/total of received bits, the lower this index, the less the degradation suffered by the signal.

Thus, for a received signal to not be degraded, BER index of a signal must be 0 while the MOS must be 4.5, for this specific work.

6 Results and Discussion

To perform a comparison of the a voice signal degradation in the EPA model for Rician and Rayleigh channel models, different speeds (from 1 to 4 m/s) were simulated for the main carrier frequencies, thus characterizing different Doppler shift frequencies. Results are presented in Table 2 to 6.

Table 2: Signal degradations of the 900MHz carrier frequency for the EPA model

EPA Model					
		Rician		**Rayleigh**	
V (m/s)	V_d **(Hz)**	**MOS**	**BER**	**MOS**	**BER**
1	3	4.4499	0.2130	4.4077	0.5831
1,5	5	4.4258	0.1376	4.3873	0.4048
2	6	4.3665	0.1585	4.3743	0.5312
2,5	8	4.3507	0.2567	4.3079	0.5557
3	9	4.2173	0.2105	4.2715	0.4329
3,5	11	4.3342	0.1504	4.1909	0.4548
4	12	4.2321	0.2473	4.2221	0.5712

Table 3: Signal degradations of the 1.8GHz carrier frequency for the EPA model

EPA Model					
		Rician		**Rayleigh**	
V (m/s)	V_d **(Hz)**	**MOS**	**BER**	**MOS**	**BER**
1	6	4.3670	0.1770	4.3310	0.5244
1,5	9	4.3861	0.0757	4.2163	0.5100
2	12	4.2015	0.2663	4.1667	0.5183
2,5	15	4.2525	0.1889	4.0991	0.4923
3	18	4.1477	0.2037	4.0579	0.4837
3,5	21	4.1249	0.2771	3.9751	0.5325
4	24	4.1432	0.1730	3.9842	0.5116

Table 4: Signal degradations of the 1.9GHz carrier frequency for the EPA model

EPA Model					
		Rician		**Rayleigh**	
V (m/s)	V_d **(Hz)**	**MOS**	**BER**	**MOS**	**BER**
1	6	4.3826	0.2193	4.3124	0.5318
1,5	10	4.3779	0.1557	4.2598	0.4316
2	13	4.2737	0.1682	4.1765	0.5133
2,5	16	4.2669	0.2601	4.0284	0.5139
3	19	4.0980	0.2724	3.9904	0.5085
3,5	22	4.0877	0.2069	3.9133	0.4216
4	25	4.1016	0.2123	3.9692	0.4973

Table 5: Signal degradations of the 2.4GHz carrier frequency for the EPA model

EPA Model					
		Rician		**Rayleigh**	
V (m/s)	V_d **(Hz)**	**MOS**	**BER**	**MOS**	**BER**
1	8	4.3976	0.1769	4.3218	0.5029
1,5	12	4.1801	0.2243	4.2382	0.4927
2	16	4.2301	0.2387	4.1525	0.4666
2,5	20	4.1108	0.2164	4.0489	0.4359
3	24	4.1352	0.1547	4.0190	0.5392
3,5	28	4.0663	0.2029	3.9365	0.4553
4	32	3.9258	0.2375	3.9521	0.5688

Table 6: Signal degradations of the 5.6GHz carrier frequency for the EPA model

EPA Model					
		Rician		**Rayleigh**	
V (m/s)	V_d **(Hz)**	**MOS**	**BER**	**MOS**	**BER**
1	19	4.1299	0.2369	3.9954	0.5096
1,5	28	4.1032	0.2164	3.8938	0.4894
2	37	3.9053	0.2247	3.8485	0.5380
2,5	47	3.8669	0.2022	3.7485	0.5339
3	56	3.7751	0.2178	3.6087	0.4630
3,5	65	3.7367	0.1834	3.5630	0.5149
4	75	3.7662	0.2037	3.5084	0.4975

Note that in all cases, as Doppler frequency (f_d) increases, MOS index decreases. This is because Doppler frequency affects signal degradation. Thus, according to 2, greater the relative velocity between the transmitter and the receiver, considering the same frequency of the carrier, higher the Doppler frequency and, consequently, greater the fading effect suffered by the transmitted signal.

Regarding BER, we can observe that the value of this index does not present a linear relation with the Doppler frequency. The BER presents values considered high, characterizing an extreme degradation of the transmitted signal. This finding differs from that shown in the MOS index, since in all cases the MOS value was above 3.5, indicating that the transmitted signal has small degradations.

In addition, it is possible to observe that the level of signal degradation transmitted by the Rayleigh channel model is more pronounced when compared to the Rician transmission, considering the same Doppler frequency. This is because there is not LOS in the Rayleigh model, i.e. there is not direct path between the transmitter and the receiver. Thus, all signals arriving at the receiver are the result of the sum of the reflected and/or refracted signals.

Then, to evaluate the degradation suffered by a voice signal in the EVA model for the Rician and Rayleigh channel models, different speeds (from 3 to 113 m/s) were simulated for the main carrier frequencies. The results are presented in Tables 7 to 11.

In the EVA model, as it is a vehicular model, the speed used in the simulation is higher when compared to the EPA model, which deals with the speed of a pedestrian. Thus, the Doppler frequency is also higher and, consequently, the degradation suffered by the signal in the EVA model is more pronounced.

In EPA model, as the Doppler frequency increases, the signal shows greater degradations. However, although the MOS index presents values considered high (close to 4.5) for the minimum speed (3 m/s), the BER index is considered high, since the optimum value is 0. Thus, BER is not an ideal parameter to verify the degradation of a signal, considering the Doppler effect.

Figures 2 and 3 show the signal degradation in the EVA and EPA model, respectively, according to the Doppler frequency variation, considering the carrier frequency of 5.6 GHz, for the Rician and Rayleigh channel models. Note that as Doppler frequency increases, MOS index decreases and BER increases, on other words, greater the degradation suffered by the transmitted signal. For the Rayleigh channel model this degradation is even greater when compared to the Rician model, due to the characteristic of this channel of not having LOS between the transmitter and the receiver.

Table 7: Signal degradations of the 900MHz carrier frequency for the EVA model

EVA Model					
		Rician		Rayleigh	
V (m/s)	**Vd (Hz)**	**MOS**	**BER**	**MOS**	**BER**
3	9	4.3401	0.2178	4.2335	0.4278
13	39	3.8688	0.2868	3.8164	0.4676
23	69	3.6711	0.2284	3.5276	0.4873
33	99	3.4706	0.2613	3.3595	0.4966
43	129	3.4083	0.2255	3.2628	0.5049
53	159	3.2914	0.2434	3.0721	0.4724
63	189	3.1477	0.2614	2.9680	0.5028
73	219	3.0601	0.2545	2.8924	0.4908
83	249	2.9757	0.2574	2.8518	0.4899
93	279	2.8550	0.2704	2.7773	0.4954
103	309	2.8619	0.2688	2.6145	0.5144
113	339	2.8063	0.2403	2.5704	0.4913

Table 8: Signal degradations of the 1.8GHz carrier frequency for the EVA model

EVA Model					
		Rician		Rayleigh	
V (m/s)	**V_d (Hz)**	**MOS**	**BER**	**MOS**	**BER**
3	18	4.0900	0.2585	4.0322	0.4491
13	78	3.6228	0.2761	3.4655	0.5354
23	138	3.3503	0.2410	3.1705	0.4781
33	198	2.9908	0.2772	2.8806	0.4925
43	258	2.9124	0.2576	2.7608	0.4991
53	318	2.7765	0.2530	2.6868	0.5058
63	378	2.7411	0.2374	2.5507	0.5084
73	438	2.6480	0.2449	2.4124	0.4922
83	498	2.5163	0.2688	2.3559	0.5199
93	558	2.4608	0.2592	2.2548	0.4951
103	618	2.3959	0.2595	2.2328	0.4992
113	678	2.2791	0.2591	2.1618	0.5003

Table 9: Signal degradations of the 1.9GHz carrier frequency for the EVA model

EVA Model					
		Rician		Rayleigh	
V (m/s)	V_d (Hz)	MOS	BER	MOS	BER
3	19	4.1115	0.2729	4.0322	0.5161
13	82	3.5571	0.2446	3.4655	0.5113
23	146	3.2921	0.2336	3.1705	0.4938
33	209	3.0515	0.2677	2.8806	0.5024
43	273	2.8941	0.2581	2.7608	0.5023
53	336	2.7907	0.2556	2.6868	0.5085
63	399	2.6829	0.2560	2.5507	0.5067
73	463	2.5920	0.2548	2.4124	0.5160
83	526	2.4532	0.2701	2.3559	0.4944
93	589	2.4316	0.2553	2.2548	0.4988
103	653	2.2981	0.2564	2.2328	0.5064
113	716	2.2851	0.2554	2.1618	0.4984

Table 10: Signal degradations of the 2.4GHz carrier frequency for the EVA model

EVA Model					
		Rician		Rayleigh	
V (m/s)	V_d (Hz)	MOS	BER	MOS	BER
3	24	4.0861	0.2557	4.0322	0.5201
13	104	3.4224	0.2861	3.4655	0.4896
23	184	3.1714	0.2575	3.1705	0.4989
33	264	2.9436	0.2441	2.8806	0.4990
43	344	2.7725	0.2483	2.7608	0.5122
53	424	2.6560	0.2479	2.6868	0.5019
63	504	2.5322	0.2559	2.5507	0.5140
73	584	2.4749	0.2493	2.4124	0.5069
83	664	2.3399	0.2567	2.3559	0.5076
93	745	2.2782	0.2454	2.2548	0.5060
103	825	2.2401	0.2557	2.2328	0.4983
113	905	2.2062	0.2861	2.1618	0.4936

Table 11: Signal degradations of the 5.6GHz carrier frequency for the EVA model

EVA Model					
		Rician		Rayleigh	
V (m/s)	V_d (Hz)	MOS	BER	MOS	BER
3	56	3.7472	0.2342	3.6619	0.4715
13	243	2.9929	0.2705	2.8149	0.5117
23	430	2.5994	0.2472	2.4094	0.5081
33	616	2.4175	0.2612	2.2116	0.4913
43	803	2.2557	0.2499	2.0593	0.5019
53	990	2.0856	0.2515	1.9201	0.5044
63	1177	1.9827	0.2558	1.7949	0.5037
73	1364	1.8701	0.2549	1.7297	0.4980
83	1550	1.8177	0.2523	1.6864	0.4973
93	1737	1.7664	0.2498	1.6186	0.5031
103	1924	1.7119	0.2525	1.5203	0.4985
113	2111	1.6650	0.2557	1.4840	0.5049

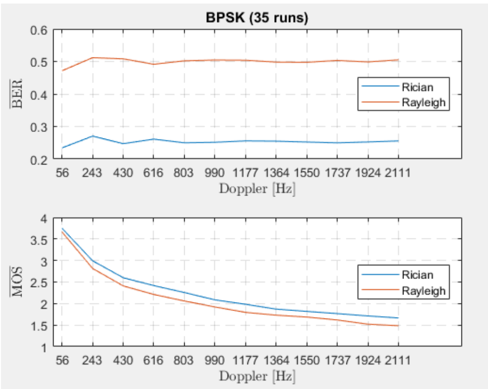

Figure 2: Effect of the degradation of the voice signal according to the variation of the Doppler frequency for the EVA model.

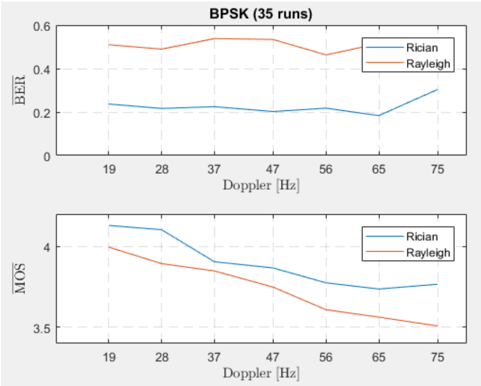

Figure 3: Effect of the degradation of the voice signal according to the variation of the Doppler frequency for the EPA model.

7 Conclusions

This paper analyzed the effect of degradation of a voice signal transmitted via wireless using the two main channel models, Rician and Rayleigh. These effects were analyzed in the EPA and EVA model, since they presented multiple paths.

Due to the higher relative velocity between the transmitter and the receiver in the EVA model, the degradation of the signal transmitted by this model is more significant compared to the EPA model.

In addition, the influence of the Doppler effect on the degradation of the transmitted signal was analyzed, and higher the Doppler frequency, greater the fading effect and, therefore, more degraded the transmitted signal is presented. The analysis was performed for the main carrier frequencies, thus verifying the effectiveness of the simulator in different parameter conditions.

The degradation of the signal when using the Rayleigh model is higher because this model does not present LOS between the transmitter and receiver. Thus, the signal arriving at the receiver is the result of the reflected and/or refracted signals, thus characterizing, larger signal degradations.

This degradation was analyzed considering the MOS index P.862 and the BER. It is worth noting that BER parameter did not present satisfactory results. This index presented extremely high results, in all tests, characterizing a practically null quality in the transmitted signal. The MOS index presented coherent results according to the level of signal degradation. Therefore, it is concluded that, in the case of variation of the Doppler effect, BER is not supposed to be a parameter to verify the level of degradation of the transmitted signal.

References

[1] *ETSI TS 136 141 V12.6.0. Evolved Universal Terrestrial Radio Access (E-UTRA)*, 2015.

[2] Affonso, E. T., Rodríguez, D. Z., Rosa, R. L., Andrade, T., and Bressan, G. Voice quality assessment in mobile devices considering different fading models. In *IEEE International Symposium on Consumer Electronics (ISCE)*, pages 21–22, Sept 2016.

[3] Affonso, E. T., Rosa, R. L., and Rodríguez, D. Z. Speech quality assessment over lossy transmission channels using deep belief networks. *IEEE Signal Processing Letters*, 25(1):70–74, Jan 2018.

[4] Bai, H. and Atiquzzaman, M. Error modeling schemes for fading channels in wireless communications: A survey. *IEEE Communications Surveys Tutorials*, 5(2):2–9, Fourth 2003.

[5] Baki, A. K. M., Absar, M. W., Rahman, T., and Ahamed, K. M. A. Investigation of rayleigh and rician fading channels for state of the art (soa) lte-ofdm communication system. In *4th International Conference on Advances in Electrical Engineering (ICAEE)*, pages 325–329, Sept 2017.

[6] Chandran, I., Raju, M., and Reddy, K. A. Comparative analysis of various channel estimations under different modulation schemes. In *International Conference on Trends in Electronics and Informatics (ICEI)*, pages 832–837, May 2017.

[7] D. Rodriguez, M. A. Voip quality improvement with a ratedetermination algorithm. *Proc. of International Workshop on Telecommunications*, pages 30–34, Feb 2009.

[8] El-Hennawey, S. C23. self-healing autonomic networking for voice quality in voip and wireless networks. In *2015 32nd National Radio Science Conference (NRSC)*, pages 297–304, March 2015.

[9] Fu, H. and Kam, P. Y. Effect of doppler shift on performance of binary dpsk over fast rician fading channels with diversity reception. In *International Symposium on Information Theory and Its Applications*, pages 1–6, Dec 2008.

[10] Georgiou, O. Polarized rician fading models for performance analysis in cellular networks. *IEEE Communications Letters*, 20(6):1255–1258, June 2016.

[11] Giunta, G., Hao, C., and Orlando, D. Estimation of rician k-factor in the presence of nakagami-$m$shadowing for the los component. *IEEE Wireless Communications Letters*, 7(4):550–553, Aug 2018.

[12] Kaur, T., Singh, J., and Sharma, A. Simulative analysis of rayleigh and rician fading channel model and its mitigation. In *8th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, pages 1–6, July 2017.

[13] Koshti, R. and Jangalwa, M. Performance comparison of wran over awgn and rician channel using bpsk and qpsk modulation with convolution coding. In *2013 International Conference on Communication Systems and Network Technologies*, pages 124–126, April 2013.

[14] Mohammed, A. A., Yu, L., Al-Kali, M., and Adam, E. E. B. Ber analysis and evaluated for different channel models in wireless cooperation networks based ofdm system. In *Fourth International Conference on Communication Systems and Network Technologies*, pages 326–330, April 2014.

[15] Mukherjee, S., Das, S. S., Chatterjee, A., and Chatterjee, S. Analytical calculation of rician k-factor for indoor wireless channel models. *IEEE Access*, 5:19194–19212, 2017.

[16] Nunes, R. D., Pereira, C. H., Rosa, R. L., and Rodríguez, D. Z. Real-time evaluation of speech quality in mobile communication services. In *IEEE International Conference on Consumer Electronics (ICCE)*, pages 389–390, Jan 2016.

[17] Orozco, G. N. and de Almeida, C. Performance evaluation of opportunistic wireless transmission in rayleigh fading channels with co-channel interference. In *IEEE Latin-America Conference on Communications*, pages 1–6, Nov 2013.

[18] Rodríguez, D. Z., Pívaro, G. F., Rosa, R. L., Mittag, G., and Möller, S. Improving a parametric model for speech quality assessment in wireless communication systems. In *26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, pages 1–5, Sept 2018.

[19] Rodríguez, D. Z., Pívaro, G. F., Rosa, R. L., Mittag, G., and Möller, S. Quantifying the quality improvement of mimo transmission systems in voip communication. In *2018 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, pages 1–5, Sept 2018.

[20] Rodríguez, D. Z., Rosa, R. L., and Bressan, G. A billing system model for voice call service in cellular networks based on voice quality. In *2013 IEEE International Symposium on Consumer Electronics (ISCE)*, pages 89–90, June 2013.

[21] Rodriguez, D. and Bressan, G. Improving the minimization drive tests using voice quality index. *Proc. of International Workshop on Telecommunications*, pages 10–13, 2013.

[22] Rodriguez, D. and Rosa, L. Apparatus and method for power saving in an ad hoc network. In *Patent number US 9,173,168 B2 by US Patent and Trademark Office*, pages 1–15, Oct. 2015.

[23] Rodriguez, D., Sousa, J., and Pivaro, G. Apparatus and method for evaluating voice quality in a mobile network. In *Patent number US 9,078,143 B2 by US Patent and Trademark Office*, pages 1–15, Jul. 2015.

[24] Sadowski, J. Estimation of rician k-factor values in urban terrain. In *10th European Conference on Antennas and Propagation (EuCAP)*, pages 1–5, April 2016.

[25] T. Eyceoz, A. D.-H., S. Hu. Performance analysis of long range prediction for fast fading channels. *Proc. 33rd Annu. Conf. Inform. Sciences and Systems CISS'99*, II:656–661, 1999.

[26] Wang, L.-C. and Cheng, Y.-H. A statistical mobile-to-mobile rician fading channel model. In *2005 IEEE 61st Vehicular Technology Conference*, volume 1, pages 63–67 Vol. 1, May 2005.

[27] Zöchmann, E., Lerch, M., Caban, S., Mecklenbräuker, C. F., Mecklenbrauker, C. F., and Rupp, M. Directional evaluation of receive power, rician k-factor and rms delay spread obtained from power measurements of 60 ghz indoor channels. In *2016 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, pages 246–249, Sept 2016.