ON-LINE LABORATORY FOR COMMUNICATION SYSTEMS USING J-DSP

Youngwook Ko, Tolga M. Duman, and Andreas Spanias[1]

Abstract – *The J-DSP editor was developed at Arizona State University (ASU) to enable students to conduct on-line simulations and experiments in digital signal processing and related subjects. In this paper, we describe a series of J-DSP communications functions and laboratory exercises that have been developed to support the laboratory portion of the ASU communications elective, EEE455. The functionality developed covers both analog and digital communications. The J-DSP communications laboratories include descriptions of relevant J-DSP functions, lab exercises illustrating the key concepts, and a short quiz that captures the main points of the assignment. The J-DSP communication labs have been assigned in EEE 455 and assessment results have been compiled. The students responded to specific questions on the labs and the J-DSP environment in general. Assessment results indicate that the majority of the students responded that the new J-DSP functionality and the associated lab exercises complemented well the theory covered in class and helped them develop intuition on the communications concepts covered in these labs.*

Index Terms – J-DSP Analog and digital communications, modulation, demodulation, signal-to-noise ratio, bit error rate, channel coding/decoding, Monte Carlo simulation.

INTRODUCTION

Synchronous and asynchronous distance learning methods have become important components of undergraduate and graduate education. Many universities including Stanford University, the Massachusetts Institute of Technology (MIT), Columbia University, and Arizona State University (ASU) are trying to reach off-campus students through the Internet. There are in fact many web courses such as the linear algebra course at MIT and the digital signal processing course at ASU, that are completely taught and administered through the Internet. Although several technologies have been developed to facilitate delivery of courses in these new formats, laboratory experiences have always been an open problem in distance education. J-DSP is an award-winning on-line software tool that was developed from the ground up at ASU to address this problem [1-3]. J-DSP enables students to establish and run on-line DSP simulations through the use of a Java-enabled browser. The J-DSP editor provides an object- oriented visual-programming environment in which all the signal processing functions are represented graphically by blocks. Simulations are formed by establishing a signal flow which is achieved by connecting graphically the blocks, Fig. 1. The J-DSP functionality and the graphical user interface have been enhanced considerably over the past few years. New functionalities to support other systems-related topics, such as speech processing [6], time-frequency representations [7], image processing [8], controls [9], and communication systems [5] are currently being developed [3]. In addition, specialized J-DSP functions with integrated Java animations are being developed to support other types of education [10]

This paper presents the new J-DSP functionality developed specifically to support simulations of analog and digital communication systems [4]. Analog communications functions include a variety of amplitude and angle modulation schemes and their associated demodulators. Function blocks that enable the study of noise effects were also developed. The digital communications blocks include digital modulation schemes, matched filtering, channel coding/decoding blocks, intersymbol interference channels, and equalization algorithms.

Based on the new analog and digital communications functionality, on-line laboratory exercises have been developed. The labs assist the students in understanding the fundamental theory related to communication systems. In particular, analog communications labs include simulations of amplitude and angle modulation, and effects of noise in analog communications. Digital communications labs developed include simulations of digital modulation schemes, exercises on matched filtering, channel coding/decoding, ISI paradigms, and channel equalization. Each lab consists of a detailed description of the related J-DSP functions, examples, lab exercises illustrating the key concepts, and a short quiz capturing the main points of the assignment. Details of the communications labs of the J-DSP are available at http://jdsp.asu.edu, [3] and [5].

The new functions and labs developed have been tested in our undergraduate communication systems course (EEE455) at ASU. The EEE455 students conducted simulations using the new J-DSP functions, performed the communications experiments, submitted reports, and have filled evaluation forms responding to various assessment questions [3]. The majority of the responses to the communication labs developed were positive. In Section 4, we present these assessment results in more detail.

The outline of the paper is as follows: the second section overviews the J-DSP editor. The third section describes the new J-DSP communications functions, and describes the labs developed. In the fourth section, the

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assessment results for the new functionality and the labs are presented. Conclusions and future work are described in the last section.

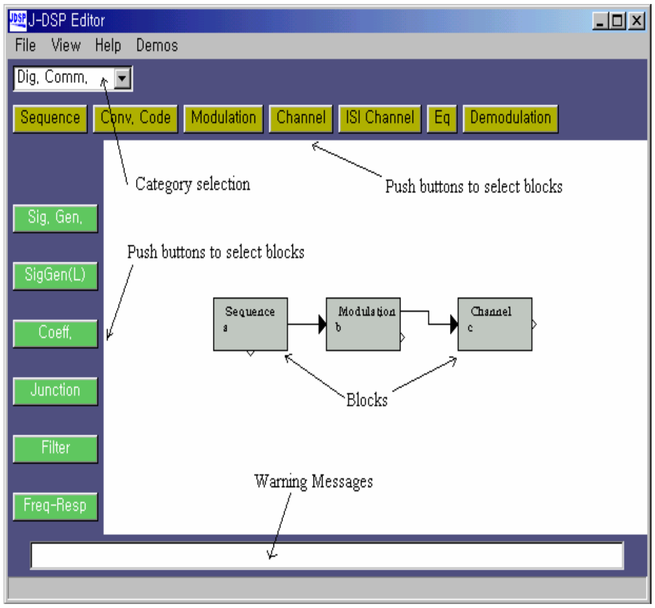

FIGURE 1
J-DSP ENVIRONMENT

J-DSP EDITOR

The J-DSP is a novel DSP simulation tool that provides a user-friendly environment through Java's graphical capabilities. Different J-DSP functionalities are represented through function blocks grouped into several categories. A drag-and-drop process is used to establish each block. Experiments / simulations are performed by selecting appropriate blocks, and connecting them to establish a signal flow. Blocks can be edited through dialog windows, that allow the users to update the function parameters to the desired values or to view the results. It is possible to check the signals at any point of simulation through the appropriate blocks.

As an illustration, Figure 1 shows the basic J-DSP environment. Once the analog or digital communications is chosen in the category selection area, the related buttons such as sequence, modulation, channel, and demodulation related to the chosen category are displayed.

The existing functionality in signal processing includes: filter design, FFT, plotting, autocorrelation, periodograms, correlograms, up-sampling, down-sampling, AR time-series, quadrature mirror filter (QMF) banks etc. The detailed descriptions of these blocks are given in [1-3]. J-DSP scripting capabilities have also been developed and support embedding of interactive J-DSP simulations in web content [11]. This particular aspect of the software is quite useful for instructors developing web courses.

COMMUNICATIONS SYSTEMS USING J-DSP

A variety of J-DSP blocks have been developed to support communication systems simulations. Both analog and digital communication simulations have been considered. For analog communications, three J-DSP lab exercises have been developed. These labs cover amplitude modulation techniques, angle modulation techniques, and the effects of noise on the system performance. For digital communications, four lab exercises, that deal with the performance of different digital modulation techniques over the AWGN channel, matched filtering, signaling for intersymbol interference (ISI) channels, and channel coding, have been developed [5]. The communications related functionality and labs developed are briefly described in the following subsections.

Analog Communications

The analog communication function blocks developed include the continuous signal generator, double sideband suppressed carrier amplitude modulation (DSB-SC AM), single sideband amplitude modulation (SSB-AM), conventional AM, frequency modulation (FM), phase modulation (PM), channel, coherent detection block, demodulation block, envelope detector, and output signal-to-noise power ratio block.

Continuous Signal Generator

The continuous signal generator has been developed to generate several different types of the message signals such as sinusoidal, sinc, rectangular, and triangular signals. Even though the signal generator block is named as the continuous signal generator, the generated message signal is naturally a discrete-time signal sampled at a certain sampling frequency that is much larger than the message bandwidth. Also, the signal generated has a finite duration. The parameter values that need to be specified depend on the specific message signal, and are selected in the corresponding dialog windows. For example, if a sinusoidal signal is chosen as the message, the frequency, phase, amplitude, the signaling interval and the sampling frequency will appear in the dialog window as the parameters to be specified.

Analog Modulation Blocks

Analog modulation blocks such as amplitude modulation (DSB-SC AM, SSB-AM, and conventional AM) and angle modulation (FM/PM) have been developed. The modulated signal corresponding to the message signal can be observed immediately after updating the parameter values in the dialog window of the modulation block. Different output signal types which include the magnitude and the phase of the modulated signal in frequency domain, the modulated signal in time domain, the magnitude of the message signal in frequency domain and the carrier signal in time domain can be displayed. As an example, Figure 2 shows simulation of a DSB-SC AM scheme and a conventional AM scheme over an additive white Gaussian noise channel. In Figure 2, the magnitude plots of the modulated signals are shown in the dialog window. The demodulated signal for the DSB-SC AM modulated signal and the demodulated signal for the conventional AM modulated signal are plotted in the dialog window of phase locked loop block and the dialog window of envelope detector, respectively.

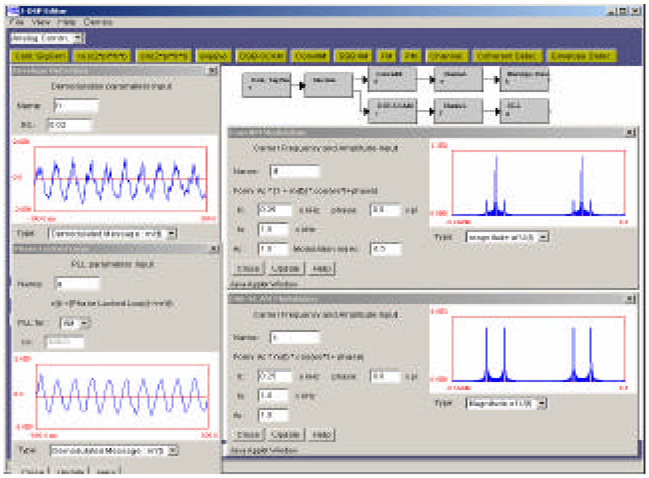

FIGURE 2
SIMULATION OF A DSB-SC AM SCHEME AND A CONVENTIONAL AM SCHEME.

Demodulation

The envelope detector and the coherent detection block are used as the demodulators supported for analog communication systems. After the channel block adds the additive white Gaussian noise (AWGN) with the noise power defined in its dialog window, the signal is fed to the demodulator. If the DSB-SC AM modulated signal is transmitted over an AWGN channel, the coherent detection block is used to recover the message signal. When the bandwidth of the low-pass filter used in the demodulation process, the output signal types, i.e., the demodulated signal in time domain and the magnitude of the message signal in frequency domain are updated, the message signal is observed in the corresponding dialog window. The envelope detector is used as the demodulator for the conventional AM scheme. Once the time constant is defined in the dialog window of envelope detector, the demodulated signal is plotted as shown in Figure 2.

For the demodulation of the angle-modulated signal, the phase locked loop block developed is employed. Once the modulation type, i.e., FM or PM, and the frequency/phase deviation constants are defined, the demodulated signal is obtained.

Noise Effects in Analog Communications

To evaluate the effects of noise for each modulation scheme, the output SNR block enables the users to measure the achieved signal-to-noise ratio (SNR) as shown in Figure 3. To illustrate the details of this process, the output SNR of SSB-AM scheme is computed and compared to that of PM scheme over the AWGN channel in Figure 3.

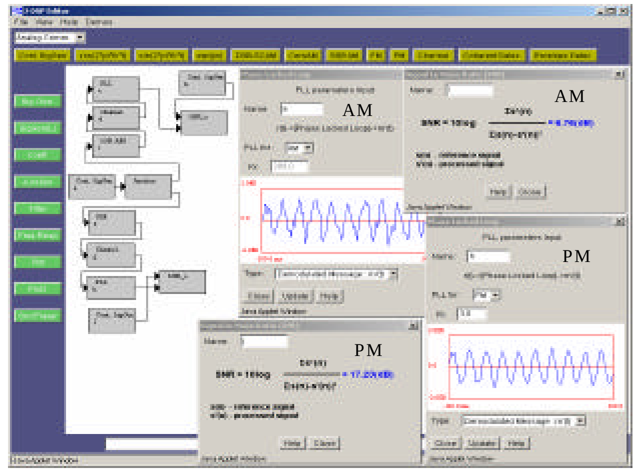

FIGURE 3
PERFORMANCE OF A SSB AM SCHEME AND A PM SCHEME IN TERMS OF THE OUTPUT SNR BLOCK.

Digital Communications

The J-DSP functionality in digital communications has been developed to support simulations of digital communication systems. The currently available function blocks include sequence generator, digital modulation schemes, channel, intersymbol interference channel, equalization, demodulation, convolutional coding, Viterbi decoding, Monte Carlo simulation, bit/symbol error rate computation block, and matched filtering.

Sequence Generator

The sequence generator produces the binary message sequence. The generated binary sequence can be used as the information source in the simulations of digital communication systems.

Digital Modulation Techniques

Digital modulation schemes developed include binary pulse amplitude modulation (PAM), M-ary PAM, phase shift keying (PSK), quadrature PSK, M-ary PSK and M-ary quadrature amplitude modulation (QAM). The modulation type and the constellation size can easily be defined in the dialog window depending on the specific modulation scheme selected.

Demodulation and Detection

The demodulation and detection process is composed of several blocks (demodulator, Monte Carlo simulator and bit error rate estimator). The demodulator block implements the optimum receiver for the AWGN channel, which includes a signal correlator and a maximum likelihood detection algorithm. The bit and symbol error probabilities are computed and displayed in the demodulator block. For more reliable estimation, the Monte Carlo simulation block connected with the demodulator block is required. The Monte Carlo simulation repeats the simulation of the system as many times as the number of iterations defined in its dialog window, and then produces an estimate of the error rate. The bit or symbol error rate block measures the performance of a digital communication system in terms of bit or symbol error probabilities versus SNR per bit. Figure 4 shows a typical bit error rate versus SNR per bit of BPSK scheme over AWGN channel obtained through J-DSP simulations.

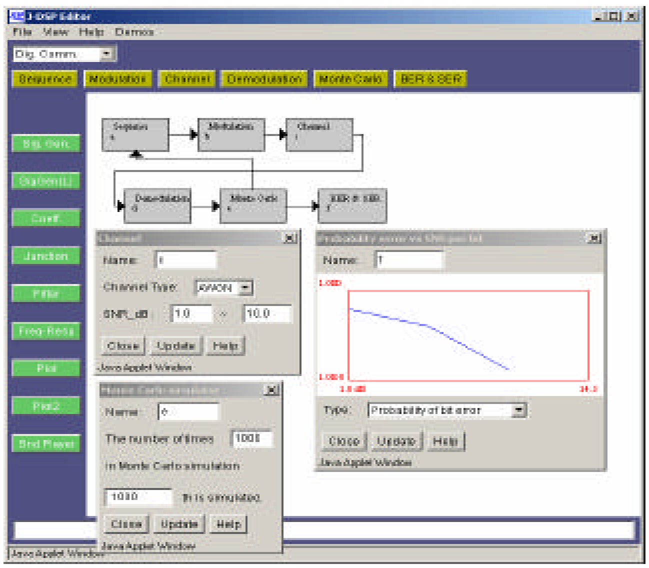

FIGURE 4
SIMULATION OF BPSK SCHEME OVER AWGN CHANNEL.

Channel Coding

Among various channel coding techniques, convolutional coding has been developed in J-DSP. The Viterbi decoding algorithm is also developed as the decoding algorithm for convolutional codes. The convolutional code parameters such as the constraint length, code rate and generator vectors can easily be defined that enables the students study different codes easily.

The Viterbi decoding block provides two decoding methods, i.e., hard decision decoding and soft decision decoding. Once the soft decision decoding method is chosen, the number of quantization levels can be defined. If 0 is selected, a soft decision without any quantization is performed.

Intersymbol Interference (ISI) and Equalization

We consider an intersymbol interference (ISI) channel with AWGN by the use of the ISI channel block. The information bits corrupted by the ISI channel can be recovered by using an equalizer. Once the number of the ISI taps in the channel and the SNR range (in dB) are selected, the channel filter coefficients can be defined. The equalization block estimates the equalizer coefficients and displays the mean squared error (MSE) curve and the estimates of coefficients as shown in Figure 5.

Communication Labs Developed

Three analog communication labs and four digital communication labs have been developed. Each lab includes a description with examples, problems for simulations, and quizzes. The labs assist the students in learning the theory of communications by performing various J-DSP simulations of the analog and digital communication systems.

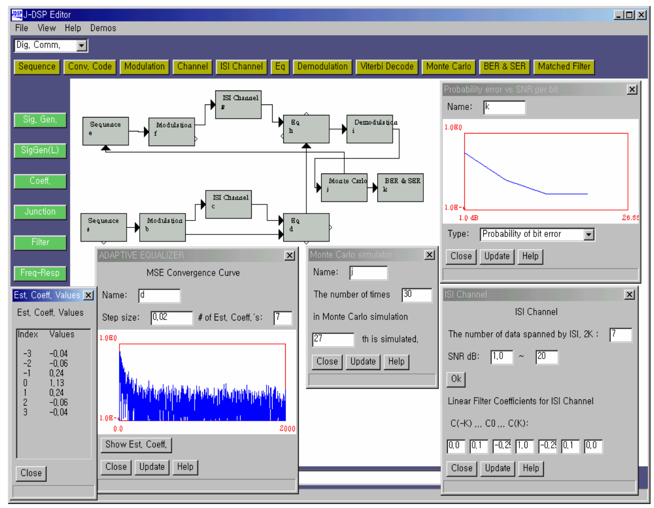

FIGURE 5
BER OF BPSK SCHEME COMBINED WITH EQUALIZATION OVER THE ISI CHANNEL.

Labs for Analog Communications

Three analog communication labs, i.e., amplitude modulation, angle modulation, and noise in analog communications are developed. We now briefly describe each lab, and we refer the reader to [5] for the detailed descriptions.

- **Lab 1 Amplitude Modulation:** Several amplitude modulation schemes, i.e., DSB-SC AM, conventional AM and SSB-AM, are studied in this lab. The problems and the quizzes in the Lab 1 provide the students with further understanding of the amplitude modulation and demodulation processes, and they illustrate the main differences between them. As an example, let us generate the DSB-SC AM modulated signal. The message signal is generated by the continuous signal generator block, in which the parameters such as the message signal type, signal duration, signal gain and message frequency, for the message signal are defined. The DSB-SC AM block is connected with the continuous signal generator block, and the parameters such as the carrier frequency and phase, carrier signal amplitude are defined in the DSB-SC AM block. The DSB-SC AM modulated signal is generated and displayed using the DSB-SC AM block shown in Figure 2.

- **Lab 2 Angle Modulation:** Lab 2 covers angle modulation schemes, i.e., FM and AM. The angle modulation lab exercises demonstrate the modulation of the message signal, the Carson's rule and the effects of the frequency and phase deviation constants on the bandwidth of the modulated signal. The relationship between the modulation index and the modulated signal is examined in detail.
- **Lab 3 Noise Effects in Analog Communications:** In the Lab 3, the effects of noise on different analog modulation systems over AWGN channels are considered. The noise effects on different modulation schemes are observed through the demodulated message signal, and the output SNR computed as the performance measure. For example, let us consider the noise effects in a SSB-AM and a PM scheme. Figure 3 shows the processes of the modulation/demodulation for both the SSB-AM and the PM scheme. The message signal is easily generated as described above. We then connect both the SSB-AM and the PM block into the continuous signal generator and define the parameters in each modulation block. The PLL block displays each demodulated signal in its dialog window, and the output SNR block measures the noise effects by computing the output SNR as shown in Figure 3.

Labs for Digital Communications

Four digital communication labs, i.e., digital modulation techniques, matched filtering, inter-symbol interference (ISI) and equalization, and channel coding are developed [5].

- **Lab 4 Digital Communications:** Lab 4 is concerned with the simulation of the digital modulation techniques, i.e., binary PSK, M-ary PSK, binary PAM, M-ary PAM and M-ary QAM. It explains channel noise effects in digital communications, demodulation and detection algorithms, Monte Carlo simulation techniques, and the estimation of the bit error and symbol error probabilities versus signal to noise ratio over an additive white Gaussian noise (AWGN) channel. The plot of bit/symbol error rate versus signal to noise ratio over the AWGN channel is used to compare the performances of different digital modulation schemes. For example, let us consider the modulation/ demodulation of a binary PSK (BPSK) scheme over the AWGN channel. Figure 4 shows the process of the corresponding modulation / demodulation processes. The binary message is generated by the sequence-generation block. The BPSK scheme can be chosen in the dialog window of modulation block and the channel noise can be selected in terms of the SNR in the channel block. Once the parameters in the other related blocks are defined, the plots of the bit or symbol error rate versus signal to noise ratio in the corresponding dialog windows are shown as in Figure 4.
- **Lab 5 Matched Filtering:** The main focus of the Lab 5 is to examine the characteristics of the matched filter, and consider the effects of Gaussian noise on the filter output. The filter is matched to the transmitted signal. The *Cont. Sig. Gen* Block is used to generate the input signal, and the Channel Block is connected between the *Cont. Sig. Gen*. Block and the Matched Filter Block. The output of the matched filter over the AWGN channel is examined simply via the dialog window of Matched Filter Block.
- **Lab 6 Inter-symbol Interference (ISI):** Lab 6 simulates the transmission of digital data over an ISI channel with AWGN. An equalizer is considered to eliminate the ISI and improve the system performance. Performing this lab helps students understand how equalization based on the minimum mean squared estimation criterion equalizes the channel and how the transmitted data bits can be recovered reliably. Figure 5 shows the process of modulation / demodulation for the BPSK scheme combined with an equalizer over the ISI channel. The block diagram for this lab is easily designed as shown in Figure 5. Once the parameters, i.e., ISI channel coefficients, step size, and the number of tap coefficients of the equalizer are selected, the MSE convergence curve, the values of equalizer coefficients, and the bit/symbol error rate are plotted in corresponding dialog windows.
- **Lab 7 Convolutional Coding:** In the Lab 7, the channel coding techniques over AWGN channels are considered. Specifically, convolutional coding is examined and the Viterbi decoding technique is applied to decode the received coded data. This helps the students understand how much coding gain can be achieved over an AWGN channel by using convolutional codes with hard decision and/or soft decision decoding methods. The block diagram for this lab is designed by simply inserting the convolutional coding block between a sequence block and a modulation block. Once the Viterbi Decoder block between the channel block and the Monte Carlo block is set, the BER and SER block plots the bit/symbol error rate of the coded BPSK scheme over the AWGN channel.

ASSESSMENT

After performing the communication labs, the EEE455 students provided feedback for an initial assessment of the J-DSP communication functionality. In this section, we review their responses and evaluate the usefulness of the labs and J-DSP in general.

For analog communications (Labs 1-3), 85.74% of the users agreed that the contents of the lab exercises improved their understanding of several concepts in amplitude and angle modulation. Regarding the help screens provided, 53.6% of the students found them to be useful, while 10.7% of them did not. 35.7% of the students did not use the help screens. Furthermore, the majority of the students (92.9%) responded that they felt more comfortable with topics in analog communications after they completed the relevant J-DSP lab. As a specific example, a student noted that he/she now understands the relationship between RC time constant and the envelope detector. Another one noted that the display of time-domain signals in the SSB case provided inside not available in most books. The students also believe that the J-DSP is user-friendly; in particular, 89.3% said that setting up the simulations was straightforward.

After performing the digital communications labs (Labs 4-7), 85% of the users responded that they understood the differences amongst the various digital modulation schemes after completing the relevant J-DSP lab. 83% of the students developed a better understanding of the matched filtering concept and 83.3% of the students agreed that they understand the details of ISI channels and equalization techniques while 16.7% of the users were neutral. In general, 75% of the students felt more comfortable with topics in digital communications after completing the relevant J-DSP lab. The students also provided valuable written feedback. For example, a student noted that he/she now understands the relationship between the step size in the least mean squares (LMS) based equalizer and the speed of convergence. Another one noted that it was beneficial to compare the performances of different modulation systems. There were also several written comments suggesting that new functionality needs to be developed such as functions supporting simulations of fading channels and diversity techniques.

In short, our assessment results have shown that the majority of the responses to the J-DSP communications labs were positive.

CONCLUSION

J-DSP [1-3] functionality was extended to cover analog and digital communications topics covered in an undergraduate communications systems class. Several J-DSP laboratory exercises have been developed. The lab exercises include analog and digital modulation, the presence of additive channel noise, characteristics of the matched filter, ISI, equalization, and channel coding/decoding techniques.

To provide an initial assessment, the J-DSP communications lab exercises have been assigned in the senior-level communication systems course (EEE455) at Arizona State University. Students assessed the J-DSP and run assigned on-line simulations, submitted lab reports, and completed evaluation forms tailored to assess whether J-DSP improved their understanding key concepts in the course. The large majority of students found that J-DSP helped them understand better the theory covered in class.

For future work, new blocks can be integrated to make the communications lab exercises cover a more comprehensive set of topics. For example, new laboratories dealing with fading channels, diversity techniques, spreading, and code division multiple access (CDMA) can be studied.

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