2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Paper ID #50844

Affordable Course Content and Open Education Resources for Undergraduate Courses Teaching Fundamentals of Wireless Communications and Networking

Dr. Dimitrie C Popescu, Old Dominion University

Dimitrie C. Popescu received the Engineering Diploma with specialization in Electrical and Computer Engineering from Polytechnic Institute of Bucharest, Romania, and the Ph.D. degree in Electrical and Computer Engineering from Rutgers University, New Brunswick, New Jersey. He is currently a Professor in the Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA. His research interests are in the area of wireless communication systems and include software defined and cognitive radios, spectrum sensing and dynamic spectrum access for cognitive radios, modulation classification, interference mitigation and transmitter/receiver optimization to support quality of service, vehicular networks, and signal processing for communications and radar systems. Dr. Dimitrie Popescu has served as ONR Senior Faculty Research Fellow at Naval Surface Warfare Center Dahlgren, and has also held summer prositions with AT&T Labs in Florham Park, NJ, and with Telcordia Technologies (formely known as Bellcore) in Red Bank, NJ. He is an active Senior Member of the IEEE currently serving as an Associate Editor for IEEE Sensors Letters and participating regularly in the technical program and organizing committees for the IEEE International Conference on Communications (ICC), IEEE Global Telecommunications Conference (Globecom), IEEE Wireless Communications and Networking Conference (WCNC), and IEEE Vehicular Technologies Conference (VTC). He has also served as Associate Editor for IEEE Transactions on Wireless Communications, IEEE Communications Letters, and the IEEE Open Journal of the Communications Society.

Dr. Otilia Popescu, Old Dominion University

Dr. Otilia Popescu received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. Her research interests are in the general areas of communication systems, control theory, signal processing and engineering education. She is currently a Professor in the Department of Engineering Technology, at Old Dominion University in Norfolk, Virginia, and she served for 7 years as the Program Director for the Electrical Engineering Technology Program. In the past she has worked for the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. She is a senior member of the IEEE.

Affordable Course Content and Open Education Resources for Undergraduate Courses Teaching Fundamentals of Wireless Communications and Networking

Abstract

Wireless communication systems and networks along with the services they provide have become an essential component of the modern 21st century society, fueling job growth in the wireless industry and increasing the need for engineers specialized in wireless communication systems. As a consequence, over the past two decades, undergraduate courses teaching fundamentals of wireless communication systems and networks have become common in electrical and computer engineering and technology programs. At the same time, the number of textbooks dedicated to wireless systems and networks published by mainstream publishers has also grown, with availability in various formats and offerings and a significant increase in their associated costs. This makes the choice for education resources (textbooks and ancillary materials) challenging for both instructors and students and has prompted them to look for alternative resources including the use of textbooks available as part of the university libraries in electronic formats as well as other course materials and software that are available in the public domain or have been released under a license that permits their free use, reuse, modification, and sharing with others, which are referred to as Open Educational Resources (OER). In this paper we present the main topics that should be covered in an undergraduate engineering course on wireless communications systems and networks, aligning them with available OER and mapping them into a 14-week semester schedule with homework assignments that include programming and hands-on experiments. Assessment of the material adoption is also discussed in the paper.

Introduction

In recent years, with the introduction of fifth generation (5G) wireless networks and the emerging Internet of Things (IoT) concept, there has been significant growth in the area of wireless communication systems and networks, fueling job growth in the wireless industry and increasing the demand for engineers specialized in wireless communication systems. To meet this demand, universities are revising their electrical and computer engineering curricula to ensure that they cover relevant wireless communications and networks topics through specialized courses at undergraduate and graduate levels. At the same time, publishers have been trying to keep up with the rapid advances in wireless technologies, and the number of textbooks available for courses teaching wireless communications and networking makes the selection of a textbook quite difficult.

An important consideration when choosing textbooks is related to their cost, with recent studies showing that the cost of textbooks and of the other materials used in a given course impacting the students' success in the course when they are not able to afford them and may even deter them from enrolling in specific courses [1]. Furthermore, according to a recent national survey on student course material affordability many students reported that the cost of course materials affected their choice of institution to attend or major to pursue [2]. In this direction we note that traditional publishers of college textbooks are trying to curb the increasing textbook prices by offering electronic versions of copyrighted textbooks at lower prices as semester rentals or part of packages that can be accessed over a limited time period. However, this approach is detrimental to students' success as many times students need to refer to textbooks used in prerequisite courses to which they many no longer have access.

OER are an alternative to paid textbooks and course materials and include "learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others." [3]. OER are available in various formats including open textbooks and course materials, free video lectures, lesson plans, testing materials, as well as other types of educational resources that are made available under an open license that allows their reuse and/or adaptation. Currently, it is common for authors of OER to assign creative commons licenses [4] that let users know how they can use the available materials without seeking permission.

Complementing OER are education materials that are available at no cost to the student, which qualifies them as Affordable Course Content (ACC). These include books and other education materials that are available for free use but not under a creative commons license, as well as resources available as part of the university libraries, which are also free to use for students and for which the university pays for licensing/usage.

Finding and Selecting OER and ACC Resources

Given the diversity of OER and ACC materials available, identifying suitable education resources for any given course should start with the library. Over the past decades, university libraries have been at the forefront of curating OER and ACC, and they have expert librarians who understand the wide range of options available and who can effectively assist in finding relevant content [5]. For instance, many university libraries provide access to various collections of open materials, which librarians can easily find and which can be leveraged for course use. Such collections include:

- The Open Textbook Library at the University of Minnesota [6]
- The Open Education Book Series at Virginia Tech [7]
- The Free ECE Textbook Initiative at the University of Michigan [8]
- OpenStax at Rice University [9]
- Open Books published by University of Massachusetts Amherst [10]

Note that these are only a few of the available online collections that have been consulted for the current paper, and a more comprehensive listing of collections of open textbooks is available on the OER Commons website [11].

The selection of specific OER and ACC materials is also strongly correlated with the course objective and the topics that are expected to be covered as part of the course. In most electrical and computer engineering undergraduate programs, courses teaching fundamental concepts in wireless communications and networking are usually taught as technical electives at the senior level, and they should provide students with a good understanding of the physical layer of wireless networks, which is responsible for the actual transmission of information by using electric signals and radio frequency (RF) wave propagation. In addition, with software defined radios (SDRs) being prevalent in the wireless industry [12], the course should also provide students with an introduction to SDRs along with basic hands-on experimentation on SDR programming.

Course Topics and Prerequsites

Wireless communications rely on radio frequency (RF) wave propagation for information transmission, and from an engineering perspective, a course on wireless communications must include topics on radio wave propagation. However, the course should not require a course on

electromagnetics as a prerequisite since this is not required for computer engineering majors. Rather, the course should provide an understanding of basic concepts using simplified models:

- For antennas, concepts such as patterns, gains, and the reciprocity principle, should be taught using equivalent circuit representations of antennas.
- Radio wave propagation should be covered starting from simple models such as free space propagation to define pathloss, and then continuing with more complex models that introduce multipath propagation and fading channels.
- For RF link analysis topics that include receiver sensitivity and noise floor should be covered followed by a discussion on RF link budgets.

Good understanding of the abovementioned topics requires as prerequisites only knowledge of circuits[1] along with basic concepts in random variables and stochastic processes, which are acquired by students majoring in electrical and computer engineering in a required junior level course on probabilities and statistics.

The course should also cover topics on RF signal analysis such as in-phase/quadrature (I/Q) and envelope/phase representations of signals, quadrature modulation and demodulation, as well as digital modulation schemes for information transmission. Good understanding of these topics requires as prerequisites knowledge operations with signals along with Fourier analysis, which are acquired by students majoring in electrical and computer engineering in a required junior level course on signals and systems.

In addition to the theoretical concepts on radio wave propagation and RF signal analysis, the course should also introduce students to SDRs, which are the building blocks of modern communication systems. Topics covered should include SDR evolution and architecture [12] along with an introduction to SDR programming, which should leverage students' knowledge of MATLAB and Simulink from other courses such as signals and systems along with MathWorks' hardware support packages for RTL-SDR [13], ADALM-PLUTO SDR [14], and USRP [15].

Course Redesign Experience to Incorporate OER and ACC

The ECE 452 course at Old Dominion University entitled "*Introduction to Wireless Communication Networks*" was redesigned during the Fall 2025 semester to incorporate OER and ACC materials, which include:

- The open textbook [16], which is a revised version of the first edition published originally by Cambridge University Press in 2016. The revised first edition, which is included in the Open Textbook Library, was published by Virginia Tech Publishing in 2023 under a Creative Commons Attribution Non-Commercial 4.0 International License (CC BY NC 4.0) and reinforces the course scope, which is on the physical layer of wireless networks, while also providing excellent coverage of the topics mentioned in the previous section.
- Textbook [16] was supplemented with the additional textbook [17], which provides a great introduction to SDRs with hands-on programming exercises using MATLAB and Simulink. While the additional textbook [17] is not published under a Creative Commons license and its copyright is retained by the authors, it is available free online and includes a comprehensive library of open MATLAB and Simulink files, which are a great resource for learning SDR programming and operation.

[1] Knowledge of circuits at the sophomore level is expected to include Thevenin/Norton characterizations of electric circuits in terms of an equivalent load and voltage/current source.

As part of the course redesign, the name of the ECE 452 course has been updated to "*Fundamentals of Radio Communications and Wireless Networking*" to better reflect the course scope, and the catalog description of the course has also been updated accordingly.

The specific topics covered as part of the course during the Fall 2025 semester[2] are outlined in the table below:

	Topics covered
Week 1	Introduction to the course: syllabus, course policies, and grading. Introduction to wireless communication systems and networks. Radio communication systems. Brief history and timeline. (Use material in Ch. 1 of [16])
Week 2	Basic electromagnetic (EM) concepts: radio waves and the radio frequency (RF) spectrum. Commercial radio frequencies and spectrum regulations. Radio link classification. Antennas: gains, pattens, polarization. (Use material in Ch. 2 of [16])
Week 3	Radio wave propagation in free space and Friis equation. Pathloss and power: absolute value and dB representations. (Use material in Ch. 3 of [16])
Week 4	Radio wave propagation through Earth's atmosphere. Physical models: 2-ray flat Earth model and diffraction. Empirical models: propagation outdoors (Hata, Lee) and indoors. (Use material in Ch. 3 and Appendix A of [16])
Week 5	Static channel models: multipath propagation, channel impulse response and power delay profile. Dynamic channel models: mobility, Doppler spread, and fading. (Use material in Ch. 3 of [16])
Week 6	Noise characterization: thermal noise and noise temperature; non-thermal noise and equivalent noise temperature. Two-port devices, s-parameters, noise characterization in two-port devices, noise factor/noise figure. (Use material in Ch. 4 of [16])
Week 7	Radio link analysis: receiver sensitivity, signal-to-noise ratio, link budgets and margins. (Use material in Ch. 7 of [16]) Midterm exam.
Week 8	Mathematical tools for RF signal analysis: in-phase/quadrature (I/Q) and envelope/phase representations of RF signals. Quadrature modulation and demodulation structure. Frequency translation and the heterodyne principle. (Use material in Ch. 5 in [16] and Ch. 5 in [17].)
Week 9	Software defined radios: evolution, architecture, and programming. SDR programming using MATLAB to visualize the RF spectrum. Spectrum analyzer and waterfall plots. Sweeping the RF spectrum. (Use material in [12] and in Ch. 1-3 of [17])

[2] In a semester-based academic program the regular semester includes 14 weeks of classes and one week for final exams, and a 3-credit hour course has 42 contact hours or 150 minutes of lecture time per week.

Week 10	Digital modulation of radio signals: line codes, pulse shaping and bandwidth, signal constellations. Common digital modulation schemes: amplitude-shift keying (ASK), phase-shift keying (PSK), quadrature amplitude modulation (QAM), and frequency shift keying (FSK). (Use material in Ch. 6 of [17])
Week 11	Decoding digitally modulated signals: coherent demodulation, matched filtering, SNR and optimal detection, probability of error. (Use material in Ch. 6 of [17]).
Week 12	SDR programming using MATLAB to implement a radio link with digital transmitter/receiver. Practical aspects on carrier and symbol timing synchronization. (use material in Ch. 11, 12 of [17]).
Week 13	Spread spectrum and orthogonal frequency division multiplexing. (Use material in Ch. 6 of [16]).
Week 14	Selected topics on wireless networking (time permitting): cellular systems, wireless data networks, short-range data communication. (Use material in Appendix B of [16]). End of semester recap and review for final exam.

As can be seen from the table, the course covers in detail the first 7 chapters of the textbook [16] using also the material in the two appendices. The remaining chapters in the textbook [16] cover topics on electronics and digital signal processing including oscillators and mixers, amplifiers, filters, analog-to-digital and digital-to-analog conversion, and digital filtering, which are discussed in other courses such as electronic circuits and discrete-time signal processing. Thus, textbook [16] is also a good reference textbook for practicing radio engineers as it includes a wide range of topics that are relevant to radio communication systems.

Textbook [17] is used for covering the SDR topics taught in the course and for illustrating these with hands-on experimentation. In this direction, a SDR kit was prepared for students, which includes:

- An ADALM-PLUTO SDR active learning module that includes the SDR along with two stub antennas and a USB 2.0 cable.
- An RTL-SDR v3 with the characteristics featured on the RTL-SDR Blog [13] along with a versatile dipole antenna with adjustable elements and a flexible tripod support.

Students will need the kit to complete SDR programming assignments on spectrum visualization, implementing transmitters/receivers that use the digital modulation schemes discussed in class, and studying timing, carrier, and phase synchronization aspects. The SDR kits are available for students for the duration of the semester in the ECE department office, and they should be checked-out in the beginning of the semester and returned at the end of the semester.

From the instructor perspective, redesigning the ECE 452 course to use OER and ACC materials was a successful experience, with students being more engaged and showing more interest in the course. In addition, the course grade average was slightly higher than in past semesters, with a lower percentage of D/F/W grades.

To get a better understanding of the students' perception of the redesigned course, they were asked to answer a few questions at the end of the semester as part of an optional course survey. The survey was anonymous and no incentives were given to complete it, and only 80% of the students enrolled in the course answered the questions.

Because the ECE 452 is a technical elective course, students were asked about the specific areas of radio communications and wireless networking that were of interest to them. Answers to this question were divided into three main categories, with about 50% of the students responding

mentioning SDRs as their interest, 25% mentioning interest in antenna design and RF circuits, and the remaining 25% mentioning interest in cellular networks (4G/5G/6G).

Students were also asked to rate their opinion of the textbooks used for the course, and their answers showed a positive reaction to the open textbooks used, with 75% of the students responding agreeing that these are excellent learning resources and may also be used as references after the completion of the course and the remaining 25% having a neutral opinion and noting that a paid textbook would have been just as useful.

The survey also asked students to rate the MATLAB support library available for download with the textbook [17] and their answers showed consensus among them, with 100% of the students answering agreeing that the library provided with the textbook [17] is a great resource in learning how to program and operate SDRs.

Conclusions

The paper discussed the use of OER and ACC materials in undergraduate engineering courses teaching fundamentals of wireless communications and networking. These courses are usually offered as technical electives and they should provide a good understanding of the physical layer of wireless networks while relying on prerequisite courses on signals and systems and on probability and statistics. In addition, these courses should also introduce students to SDR operation and programming.

During Fall 2025 semester the ECE 452 course at Old Dominion University has been redesigned to incorporate OER and ACC materials. These include textbooks [16] and [17] along with a comprehensive library of MATLAB support files that are available free and support hands-on assignments teaching SDR operation and programming. Overall, the course redesign experience was positive, with students showing more interest in the course topics and being more engaged in the course assignments.

Acknowledgment

This work was supported in part by the Virtual Library of Virginia (VIVA) through an Open Adopt Grant.

References

[1] A. Mowreader, “Cost of Course Materials Impacts Student Success”, online https://www.insidehighered.com/news/student-success/health-wellness/2024/08/26/college-students-avoid-courses-high-textbook-costs, accessed Dec. 21, 2025.

[2] Bay View Analytics, “National Survey on Student Course Material Affordability, 2023”, online https://www.bayviewanalytics.com/reports/2023_student_course_material_affordability.html, accessed Dec. 21, 2025.

[3] UNESCO, “Open Education Resources”, online https://www.unesco.org/en/open-educational-resources, accessed Dec. 21, 2025.

[4] Creative Commons, “Share Your Work”, online https://creativecommons.org/share-your-work/, accessed Dec. 22, 2025.

[5] K. Jensen, “Keeping up with … Affordable Course Content”, American Library Association, online https://www.ala.org/acrl/publications/keeping_up_with/coursecontent, accessed Dec. 22, 2025.

[6] The Center for Open Education at the University of Minnesota, “Open Textbook Library”, online https://open.umn.edu/opentextbooks, accessed Dec. 22, 2025.

[7] Virginia Tech Publishing and Press, “Open Education Series”, online https://publishing.vt.edu/oer, accessed Dec. 22, 2025.
[8] University of Michigan, “The Free ECE Textbook Initiative”, online https://fet.engin.umich.edu/, accessed Dec. 22, 2025.
[9] Rice University, “OpenStax”, online https://openstax.org/, accessed Dec. 22, 2025.
[10] UMass Amherst, “Open Books”, online https://openbooks.library.umass.edu/, accessed Dec. 22, 2025.
[11] The Institute for the Study of Knowledge Management in Education, “OER Commons”, online https://oercommons.org/curated-collections, accessed Dec. 22, 2025.
[12] D. C. Popescu and R. Vida, “A Primer on Software Defined Radio,” *Infocommunications Journal*, vol. 14, no. 3, pp. 16-27, September 2022. DOI: 10.36244/ICJ.2022.3.3.
[13] The RTL-SDR Blog, online https://www.rtl-sdr.com/about-rtl-sdr/, accessed Dec. 24, 2025.
[14] Analog Devices, “ADALM -PLUTO Overview”, online https://wiki.analog.com/university/tools/pluto, accessed Dec. 24, 2025.
[15] National Instruments, “NI Ettus USRP Software Defined Radios”, online https://www.ni.com/pdf/product-flyers/usrp-software-defined-radios.pdf, accessed Dec. 24, 2025.
[16] Steven Ellingson, *Radio Systems Engineering*, revised first edition, Virginia Tech Publishing, 2023. DOI: 10.21061/radiosystemsengineering-revised1st. Available online in the Open Textbook Library https://open.umn.edu/opentextbooks/textbooks/radio-systems-engineering.
[17] Robert W. Stewart et al., *Software Defined Radio using MATLAB & Simulink and the RTL-SDR*, second edition, 2023. Available at https://www.desktopsdr.com.