CYCLOTRON : Jurnal Teknik Elektro
( P-ISSN 2614-5146) dan (E-ISSN 2614-5499 ) | Vol. 6 | No. 02 | Halaman 68-73
Juli 2023

# Radio over Fiber Systems in Cellular Communications: A Systematic Literature Review and Research Agenda

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***Abstract*— A technology combining wireless communications and fiber optics to transmit radio frequency signals via fiber optic networks is called the Radio Over Fiber system. Capacity, range, reliability, and flexibility of the communication system are advantages offered by this method. Converting RF signals to optical signals using an optical modulation technique is a basic principle of the RoF system, in which they are then transmitted over fiber optic cables. Then, with the use of an optic detector and demodulation technique, that signal is restored to an RF signal at the receiving end. In RoF systems, the reduction of power loss and signal amplification is achieved through optical fiber, which allows transmission over long distances without loss of signal quality. Applications of the RoF system are cellular networks, satellite communications, and remote sensors. In cellular networks, the application of RoF such as expanding cellular network coverage, wireless backhaul, and increasing network capacity. In range expansion, RoF enables the transmission of RF signals from a base station to a remote receiving station via optical fiber, overcoming distance barriers and signal attenuation that occurs in traditional RF transmission. In wireless backhaul, RoF is used to connect base stations with the core network via optical fiber, providing higher capacity and reliability compared to traditional wireless backhaul. To increase network capacity, RoF can move its signal processing and amplifier toward the final users to enhance the data speeds and capacities of cellular networks. It is intended that readers will be able to learn more about Radio Over Fiber systems and their potential for improving the performance of a wireless radio network, as well as how this technology can increase its signal quality when it comes to mobile communications. With the continuous development of RoF technology, it is expected that there will be significant improvements to cellular communication services in the future.***

***Keywords: Radio, Fiber Optic, RoF, Cellular.***

## I. Introduction

Radio Over Fiber (RoF) systems have become an interesting research topic in the rapidly developing cellular communications era. RoF combines optical and wireless technology for transmitting radio signals via optical fiber, providing the advantages of long transmission distances, high capacities, and better spectral efficiency.

In the RoF system, the radio signal is converted into an optical signal through optical modulation, then transmitted through an optical fiber with a high capacity and low attenuation loss. The optical signal is reconverted to radio signals in the form of optical demodulation once it reaches its final destination.

Long-distance transmission and optical fiber's ability to transmit far more efficiently than traditional copper cable has been some of the main advantages of RoF. By using RoF, radio signals can be transmitted via optical fiber over longer distances without experiencing significant signal degradation, high capacity, RoF allows for increased cellular communication capacity, transmitting radio signals through optical fiber, RoF systems can handle data traffic which allows for faster data transfer, Better spectrum efficiency, in a RoF system the radio frequency spectrum can be divided and distributed efficiently. Radio signals of various frequencies can be converted into optical signals and transmitted over the same optical fiber, allowing for more efficient use of the existing frequency spectrum, and reduced power losses; in traditional wireless transmission, power losses often occur while radio signals travel by air or cable. copper, in RoF the use of optical fiber reduces power losses in transmission systems, flexibility, and scalability, RoF provides flexibility in the design and adjustment of cellular communication networks. Optical fibers can be laid in a variety of configurations, and thus RoF networks can easily be expanded and scaled as needed.

## II. LITERATURE REVIEW

Research (Singh et al., 2020) The architecture of the FWF's terminal, using FSM and low-cost cameras to enable a combination of its beam steering functions is discussed localization and transmission of 20.6 Gbit downlink data /s full-duplex and 13.425 Gbit/s up-link demonstrating that in the O and C bands, SFP+ transceivers are being used simultaneously.

Research (Wang et al., 2021) A bias-free modulation scheme has been established Using polarization modulations incorporated in polarization-dependent and diffraction gratings in wavelength-dependent fibers. Verify the new beam-oriented bias-drift-free modulation scheme using modulation polarization which is incorporated in polarization-dependent and diffraction gratings in wavelength-dependent fibers. Because polarization modulation is similar to phase modulation, it has become a challenge for DC. Accordingly, bias control has not been implemented. The polarization of the modulation to the modulation intensity can be achieved by using an in-filament polarizer based on a 45-tilted fiber Grating inclined fiber lattice. The beam steering is achieved through the wavelength dependence of the 45° TFG lateral diffraction resulting from the strength of the slanted lattice structure in the fiber core. TFG 45° also provides high diffraction efficiency (> 93%) thanks to its inherent compatibility with fiber links, so that a very large amount of coupling loss between fiber links and free space devices can be eliminated.

Research (Wang et al., 2018) Focuses on a new optical approach that is highly efficient, compact, and compatible with fiber laser beam steering using dispersion in lattice fiber. The use of fixed diffractive optical devices to control the wavelength of the passive optical steering beam can be achieved. The Diffraction device diffracts optical rays of various wavelengths, moving them from one position to another. Therefore, the tuning wavelength is used to achieve mechanical free beam steering. This work aims to build a low-cost and compact fiber diffraction grating device based on 45 TFG which will address the real challenges for conventional dispersometry fibers, such as large dimensions, low diffractive efficiency, high costs, or significant loss in coupling with fiber optic links in the OWC (Optical Wireless Communication) system.

Research (J. Kim et al., 2020) discusses the characterization of IFoF links consisting of MHU and ROU-TRxs and examines the critical performance indicators of the IFoF system, e.g. gain flatness, EVM values, not only for evaluation purposes but also for the display of optimization processes of the link parameters, such as index modulation, Assessing the impact of integrating SMFs into a MIMO enabled IFoF link, The total RoF system which includes mmWave conversion modules, showing the DAS network in conjunction with OTA interfaced units Donor and 5G Baseband Units BBU.

Research (Al-Zubaidi et al., 2021) discusses how to overcome the impact on error vector number when putting a PoF signal into SMF, Analysis of the power levels in a modulation format concerning various links lengths, An analysis of nonlinear effects and HPL instability, Use of the SMF architecture for the implementation of CRAN's front-haul. Research (Vázquez et al., 2019) In the next generation of 5G radio access networks, integration of power over fiber is proposed to be a front haul solution using spatial division multiplexing and multicore fiber.

Research (Tian et al., 2020) The principle of a simultaneous RF and optical frequency requirement in the deployment of multiuser wavelength networks, as well as an excellent solution to provide robust and flexible Ultrastability Optical Frequency Network for Multi-User Deployment based on Frequencies Division Multiplexing techniques is demonstrated. Research (Liu et al., 2019) The signal transfer system over 100 km of complex urban fiber optic links in the Beijing area has been demonstrated to be stable point-to-point radio frequency RF.

Research (Schrenk, 2019) As it ignores the digitization and processing of radio signals at the front back of cellular optical communications, a RadioOverfiber Analog Scheme is proposed to avoid transmission overhead. Research (Umezawa et al., 2018) discusses the transfer of radio frequencies and energy over fiber, via a multicore fiber for multi-point access, and transmission of radio over fiber via multi-core fiber using utc single pad zero biased for access point to point. Research (Dixit, 2018) Optimizing the RoF networks for choosing subcarrier modulation schemes, cell interloper polling algorithms, and wavelength allocation algorithms to compare the performance of poll mechanisms with single polls is discussed.

Research (Gozzard et al., 2018) evaluates a technique to transmit radio frequency stabilized, using phase sensing optics and optical Phase actuation. Research (Zheng et al., 2021) A technique is proposed to prevent and order nonlinear distortions of long-distance microwave photonic links (MPL). Research (Tanizawa & Futami, 2020) proposes the technique of using asymmetric keys for direct data encryption. Research (Meng et al., 2020) HOM introduces a high-level mode with flexible outputs. Research (Hu et al., 2021) A stable radio frequency transfer system based on the dual drive Mach-Zehnder modulator is proposed for the optical link. Research (Muramoto et al., 2020) fabricated GI POF with mode-specific coupling. The GI POF's core diameter is 50 m and its numerical aperture is 0.2 as well as an exponent value of 2.0 for the GI profile. These values are roughly similar to the reference value for GI silica MMF. The attenuation and the bandwidth of GI POF are 60dB per km with a frequency range from 500 MHz to 1000 MHz.

Research (E. S. Kim et al., 2020) To efficiently extend the coverage of mmWave based 5G indoor networks, a multilevel distributed antenna system is proposed, Using radio over fiber techniques based on intermediate frequency overbear transmission techniques. Research (Li et al., 2020) created a D-band millimeter vector wave (mm-wave) signal propagation scheme using stepped intensity (IM) and in-phase / quadrature (I/Q) modulators. Research (Elwan et al., 2018) A system of radio over fiber based on an Optical Frequency Comb is proposed for 60 GH. Research (Endo et al., 2018) A system of radio signals over fiber is proposed that uses chromatic dispersion. Research (Jiang et al., 2019) discuss the feasibility of setting up a system with 1GHz frequency for transmission through fiber optic networks, verified by a set of propagation network frequencies. Research (Tsai et al., 2021) Through a fiber connection, delivers the longest distance millimeter wave, modulated with a beat frequency of 40 GHz and only one quad mode optical carrier mode to achieve optical single carrier modulation, 16-quadrature amplitude modulation data stream orthogonal frequency division multiplexing. Research (Bohata et al., 2020) discusses RoF with a 50 m long outdoor free space RF channel operating in the 25 GHz frequency band. The performance of EVMs has been tested using orthogonal frequency division multiplexed signals with 16 quadrature amplitude modulation (16-QAM) with long-term evolution signals. Research (Zeb et al., 2019) This article covers the creation of MMW photonic signals and mode division multiplexing WDM, along with wavelength division multiplexing WDM which is used to transport MIMO M MW signal in the optical field. Works in high capacity A-RoF fronthaul systems.

## III. METHOD

### A. Review Method

Systematic literature reviews have been used in this study. To answer specific research questions, the SLR process identifies, analyses, and interprets all available empirical evidence (Kitchenham et al., 2009). This method is used by researchers to analyze and select journals in a structured way that will follow the steps laid down for each process (Afsari et al., 2021). Retrieval of data sources was carried out using searches from indexed international reputable journal literature. There are 25 radio over fiber articles from reputable international journals selected as literature to be reviewed.

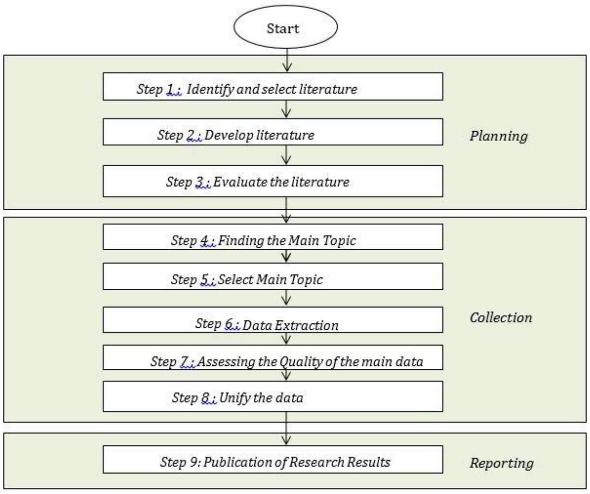

Figure 1. Steps for a systematic literature review

Systematic Literature Reviews have been carried out through three stages: Planning, Implementation, and Reporting. The first step is to define and comply with the requirements for a systematic literature review on this subject, such as interference between wireless networks at room level. The following steps are conducted under the SLR protocol to reduce the risk of bias in the study. It is, therefore, necessary to define the research question, a search strategy, selection study processes with inclusion and exclusion criteria, quality assessment as well as the process for data gathering and synthesis. The third step is to report the results of research carried out by literature that has been submitted using this protocol, discuss its findings and conclude.

### B. Research Question

This research question is to keep the SLR being carried out focused according to the stated goals. The research questions have been prepared based on guidelines, namely the criteria for Population (P), Intervention (I), Comparison (C), Outcome (O), and Context (C), which are abbreviated as PICOC (Kitchenham et al., 2009). The PICOC structure of research questions (RQ) on the radio over fiber systems in cellular communications is shown in Table 1.

Table 1. PICOC Summary

| | |
|---|---|
| ***Population (P)*** | Fiber Optic |
| ***Intervention (I)*** | Radio Over Fiber System |
| ***Comparison (C)*** | Sending signals on the radio over fiber systems on cellular communication systems |
| ***Outcome (O)*** | Comparing radio over fiber systems in cellular communications |
| ***Context (C)*** | There aren't any |

The table below shows the research questions (RQ) built into this study.

Table 2. Research Questions on Literature Review

| ID | Research Question | Motivation |
|---|---|---|
| RQ 1 | What journal has the most important information on the radio over fiber systems in cellular communications? | Identify the most significant journals dealing with radio over fiber in cellular communications |
| RQ 2 | Who is the most active and influential scientist in terms of systems over fiber for cellular communications? | Identify the most active and influential researchers about systems over fiber in cellular communications |
| RQ 3 | What topics and trends have researchers chosen about radio over fiber systems in cellular communications? | Identifying topics and trends which researchers have chosen for the deployment of radio over broadband systems in mobile communications |
| RQ 4 | What is the most used method for research in radio over fiber systems of cellular communications? | identification The most frequently used method of studying radio over fiber systems in cellular communications |
| RQ 5 | In cellular communications, what is the best way of transmitting radio via fiber optic cables? | Identification of the method of radio over fiber systems in cellular communications |
| RQ 6 | In cellular communications, what is the proposal for a method of radio over fiber? | In cellular communications, the method of radio over fiber systems has been identified. |
| RQ 7 | What are the frameworks proposed by researchers with a view to radio over-wire systems in cellular communications? | Identification of a framework for the radio over fiber communications system in mobile telecommunications |

The research question RQ 4 through RQ 7 represents the most significant issue of this systematic literature review. The radio-over-fiber system method in cellular communication will be extracted. Methods of implementing radio over fiber systems in cellular communications, frameworks, and data sets are analyzed to determine what is included and what is not. The research questions in RQ1-RQ3 are research questions that will assist researchers in evaluating the main study context. RQ 1-RQ 3, can provide information to researchers about a summary and synopsis of certain research areas about radio over fiber systems in cellular communications.

The identification of radio over fiber system methods in telecommunication networks, frameworks, and data streams used in the application of Radio Over Fiber systems in Telecommunications has been an important aim of this Systematic Literature Review. Figure 2 below shows the basic brain map generated by a systematic literature review:

Figure 2. SLR Mind Map on Radio Over Fiber System

## C. Search Strategy

The fourth step of a systematic literature review is the search strategy, which consists of several types of activities, such as the selection of digital libraries, establishment of databases, execution of searches, revision of database strings, and retrieval of lists of main studies through digital libraries to carry out appropriate and extensive research. Select data that are appropriate to find articles of particular interest before the commencement of the search. The databases used in the Digital Articles Search are IEEE Explore (https://ieeexplore.ieee.org/Xplore/home.jsp), ScienceDirect (https://www.sciencedirect.com/), SpringerLink (https://link. springer.com), Taylor and Francis (https://www.tandfonline.com/), Wiley (https://onlinelibrary.wiley.com/), Sage (https://journals.sagepub.com/), Emerald (https://www.emerald.com/), Oxford Academic Journal (https://academic.oup.com/). The identification of search phrases from PICOC is part of the keyword research in this systematic literature review, Search terms for research topics, the identification of search terms on titles, in particular from populations and interventions; Abstract, relevant keywords, the determination of synonyms, alternate words and anonyms from a search term, sophisticated string construction based upon known search terms like "AND" or "OR". (Optical Fiber Communication) AND (Optical Fiber Communication OR Radio Communication OR Radio Over Fiber) AND (Radio Over Fiber). To find the most articles that are relevant to a given topic for review, the objective of this keyword search shall be to get as much information as possible.

## D. Study Selection

Inclusion and exclusion criteria have been used for the selection of main studies, as shown in Table 3, during the design of this study.

Table 3. The inclusion and exclusion criteria for the SLR

| | |
|---|---|
| Inclusion criteria | *Research articles in the field of Radio Over Fiber in cellular communications. Research articles on the radio over the fiber that discuss and compare. Only articles from indexed journals in the Scopus database are included as research articles. Only the most complete and most recent data will be included for duplicate publications of the same study.* |
| Exclusion criteria | *Research that only focuses on Radio Over Fiber systems. Research that only focuses on radio communication systems* |

In managing search results and storing literature, researchers use reference management, namely Mendeley. Steps of the search process As shown in Figure 3, details and a list of studies were carried out at each stage.

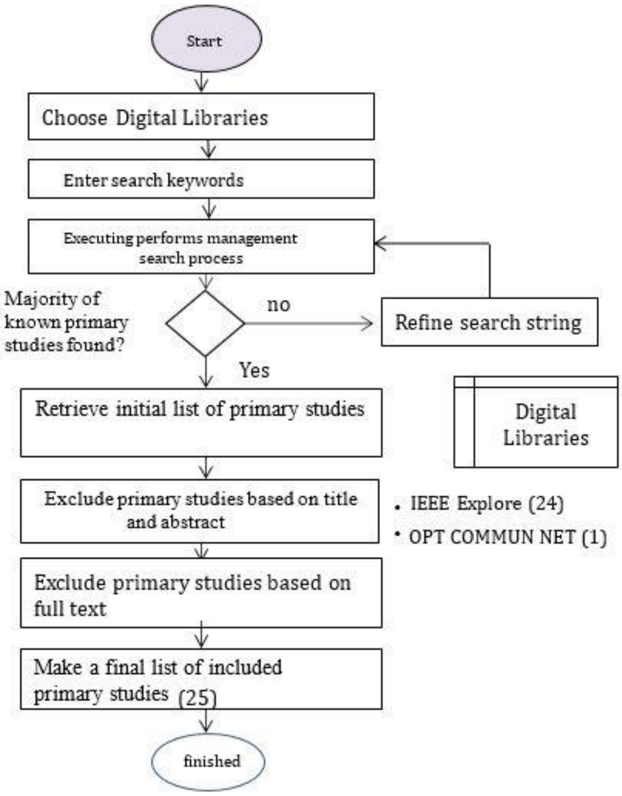

Figure 3. Main Study Search and Selection

## E. Data Extradition

This data extraction step involves retrieving information from the collected articles and systematically entering it into the extraction data summary table. Extracting the main studies by collecting data that will be used as answers to research questions (research question-RQ). Summary of data extraction identified through research questions and analysis conducted by researchers as shown in Table 4 below:

Table 4. Data Extraction

| Property | Research Question |
|---|---|
| Identification and publication | RQ1, RQ2 |
| Trends and research topics | RQ3 |
| Method | RQ4, RQ5, RQ6 |
| Framework | RQ7 |

## F. Study Quality Assessment And Data Synthesis

To determine the strength of conclusions to prevent bias, a quality assessment shall be carried out on studies to inform data synthesis. Data synthesis is intended for the collection of evidence from selected studies, to answer research questions. The use of the narrative method is the strategy used to synthesize these data. Several visual tools like bar charts and pie charts are used to determine the data consistently depending on the questions. Curves and tables to improve the presentation of the method distribution in use by transmitting radio signals over fiber systems into mobile communications.

## IV. RESULTS AND DISCUSSION

The results of the research that has been done are grouped into several discussions, including:

### *A. Significant Journal Publications*

In conducting this systemic review of the literature, 25 journals examine radio over fiber systems in cellular communications. The topic of system problems has been studied and discussed since 2017 and up to 2023 now, and the most recent studies were in the last 4 (four) years, 2018-2021. In Figure 4. Below is presented the distribution of researchers' interests in discussing and studying the topic of radio over fiber. Figure 4. This also shows that the field of research on radio over fiber is still very relevant today.

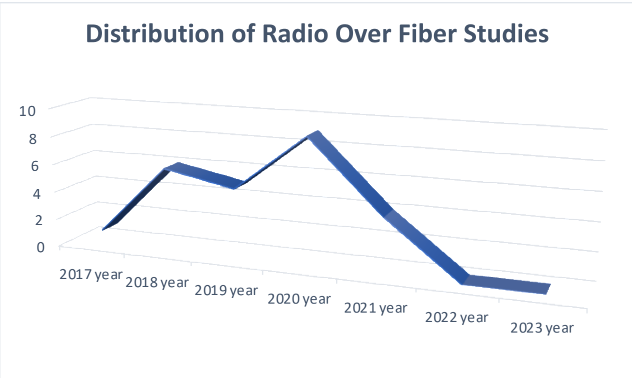


Figure 4. Distribution of Radio Over Fiber Studies

In Figure 5. Below shows the distribution of journal publications and selected studies.

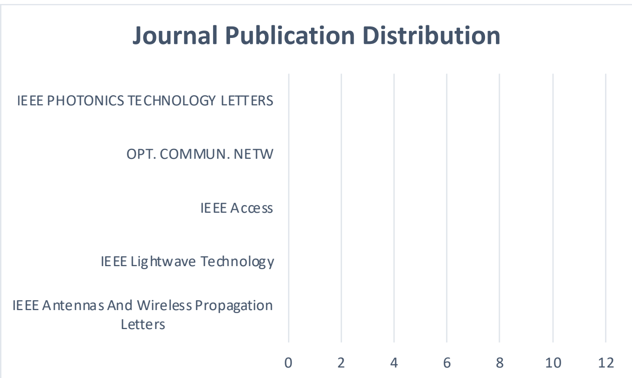


Figure 5. Distribution of Journal Publications and Selected Studies

Journal publications that discuss the field of Radio Over Fiber are arranged according to the Schimago Journal Ranking (SJR) value as shown in Table 5. Below.

Table 5. SJR Rating in Selected Journals

| No | Journal Name (Publication) | SJR | Category |
|---|---|---|---|
| 1. | IEEE Antennas And Wireless Propagation Letters | 2,020 | Q1 |
| 2. | IEEE Lightwave Technology | 1,514 | Q1 |
| 3. | IEEE Access | 0,926 | Q1 |
| 4. | OPT. COMMUN. NETW | 1,287 | Q1 |
| 5. | IEEE PHOTONICS TECHNOLOGY LETTERS | 0,776 | Q2 |

### *B. Most Active and Influential Researchers*

From the selected literature, researchers who discuss Radio Over Fiber have an active contribution to studying the problems, risks, and constraints. Figure 6. Shows active and influential researchers on Radio Over Fiber. From the selected data, it was found that the researchers who discussed Radio Over Fiber the most were Guoqing Wang, Joonyoung Kim, Minkyu Sung, and J. D. Lopez Cardona.


Figure 6. Influential Research and Number of Studies

### *C. Methodes Uses*

7 methods are often used in research, namely: descriptive analysis, comparative study, path analysis, model development, case studies, regression models, and literature studies.

## V. RESEARCH AGENDA

ROF channel modeling and analysis in the context of cellular communication: Developing a realistic ROF channel model to describe the optical and electromagnetic channel characteristics that affect ROF system performance in cellular communication. Analyze channel parameters such as loss, dispersion, noise, and interference, and consider factors such as distance, angle, and user mobility.

## VI. CONCLUSION

This systematic literature review will identify and analyze radio over fiber systems in cellular communications. 25 research articles on Fiber Optic Radio were selected based on the designed inclusion and exclusion criteria. The review process, which aims to identify, assess and interpret all the available research data that are intended to answer predetermined research questions, is known as a Literature Review Study (SLR). The existing radio over-fiber research is focused on research focus: Identifying problems and systems, Finding risks and efficiency of implementing radio over fiber. In radio over-fiber research 7 methods are often used, including descriptive analysis, comparative study, path analysis, model development, case studies, regression models, and literature studies.

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