A Brief Overview of Energy Efficiency Resources in Emerging Wireless Communication Systems

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Abstract: It is crucial to design new communication technologies to surmount the setbacks in RF communication systems. A suitable energy-efficiency scheme helps evade needless energy consumption in wireless communication. Appropriate choice of the most suitable energy-efficiency scheme aids in selecting the most energy-efficient equipment to minimize the expense of energy towards decreasing individual network element energy consumption without affecting their unique features. This review presents the energy efficiency challenges in wireless communication by employing different technologies. The emergence of visible light communication (VLC) provides an energy-efficient wireless communication system despite the various challenges inherent in its adoption that limit its physical realization. This work seeks to harness the potential of the transmission capabilities of VLC while providing an insight into novel practical implementation techniques. The work also addresses the energy consumption problem of low-active components and idle period of active components of base stations by using sleep modes for their systematic turning off and on. The high cost of power supply and the environmental emission of gases from base stations are also addressed by integrating a renewable energy resource into the conventional standalone diesel generators. Overall, the work provides an overview of information necessary for foundational research in energy-efficient resources applied to emerging wireless communication systems.

Keywords: energy efficiency; renewable energy resources; optical wireless communication; visible light communication; wireless communication systems; machine learning

1. Introduction

The COVID-19 pandemic is one of many factors that proves the tremendous rise in the use of wireless communication systems in recent times. By having to work or study from home, numerous organizations/schools were forced to increase their utilization of the internet for their operation, thereby making wireless communication more essential in today's world. One current primary concern in wireless communication is energy consumption. Therefore, an increase in the use of wireless communication implies that more energy is consumed. The question that then arises is, what technologies can be combined to produce an excellent energy framework in wireless communication? The deployment of enabling technologies has therefore become necessary [1].

Different technologies like Digital Subscriber Line (DSL), infrared communication, satellite communication, microwave transmission, Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE), etc., have been employed in the provisioning of wireless communication [2]. There has been difficulty in efficiently combining these different technologies to provide a faster and more

reliable communication system in the form of a heterogeneous network [3]. The adoption of small heterogeneous cells in future wireless communication is increasing because of its energy-saving features such as better handling of traffic in smaller areas, increased capacity and speed, etc. One crucial factor that brings about the need for heterogeneous networks is the limitation of sites for the commissioning of base stations [4]. Generally, telecommunication base stations consume so much energy, causing very high operational expenditure and a rise in the carbon emitted by the stations, which causes environmental hazards [5].

In 2015, research revealed that a tower that houses a single base station in Nigeria utilizing a 15–20 kVA diesel generator consumes an average of 50 L of diesel daily. Using this as an estimate for base stations in the country and assuming the generators run on average 17 h per day: for an estimate of 3000 generators working daily in the country, 1.5 million litres of diesel are consumed. At 140 naira per litre, a minimum of 210 million naira is spent daily on the energy consumption of telecommunication in Nigeria. Furthermore, it can be deduced that a telecommunication provider running five base stations would be spending a minimum of 0.98 million monthly on just energy consumption [6]. The grid power supply in Nigeria is still being improved for a constant supply. Therefore, telecommunication providers who require a continuous power supply have no other option but to depend hugely on diesel generators. Another identified disadvantage other than the very high operational cost is the harmful environmental influence caused by the increased CO_2 emission per kWh consumed [5]. The need for more utilization of renewable energy in Nigeria is becoming imminent. The mass integration of photovoltaic cells can be adopted to get an overall energy-efficient wireless communication framework [7].

An optimized optical wireless communication (OWC) system can be deployed to produce an energy-efficient framework for a wireless system. An optimized OWC system is a communication system that is both energy and spectrally efficient [8]. Energy efficiency implies that lesser power is consumed during the networking of signals. In contrast, spectrum efficiency indicates that maximum information is obtained from a given signal bandwidth at a particular period. With optical wireless communication, a world connected by light is realizable. Visible light communication (VLC) is an OWC network that operates from 380 nm to 750 nm [2]. Visible light frequency ranges from 430 THz to 790 THz, having a bandwidth of about 360 THz, being a significant advantage of the optical wireless communication system [9,10]. Another advantage of the larger bandwidth is the increased number of users connected to the network per time. Simultaneous illumination and communication are dual features offered by an optical wireless system, making it an alluring system widely adopted. It has numerous applications, such as street lights becoming internet access points, LEDs of driving cars having a real-time exchange of information which can help avoid overhead accidents, airplane cabin communication, etc. [11].

The constraining of energy at its nodes poses a need to integrate good performance alongside consuming less energy for each of its circuits/components. These components include the modulator, LED driver, photodetector, amplifier, and demodulator. They help to achieve an overall optimum energy consumption [12]. In constraining energy at nodes, a good modulation technique is needed. Modulation helps the constraining of signals to predetermined frequencies. An energy and spectrally efficient modulation technique in optical wireless communication systems is the orthogonal frequency division multiplexing (OFDM) and its variants [13–15]. The amount of information transmitted per unit of power and bandwidth in a communication system is defined as its energy and spectral efficiency. OFDM effectively fulfils these features by using different methods like the Fast Fourier Transform (FFT) to override several modulation restrictions [16].

One more effective method for achieving energy efficiency in a wireless network is sleeping modes. Sleep mode involves the selective turning on and off of different components of the base station. The selection is based on different factors chosen by the operator, which is how often the components are used per day. So, when some components are

turned off, less energy than usual is utilized, and therefore energy is saved. Utilizing this technique requires careful management of the sleep mode such that it is quick to respond to its function without oversleeping so as not to dwindle the effectiveness of the system [17]. By integrating the above-explained techniques, an energy-efficient framework can thus be formulated within a heterogeneous network.

Services that provide wireless communication will be utilized in a broader range in the future, which would cause a large consumption of energy [18]. Two important metrics for wireless communication are spectral efficiency and energy efficiency [19,20]. One major challenge in optical wireless communication is providing an energy-efficient, trusted, and guaranteed quality-of-service (QoS) [21]. The low price of light-emitting diodes, fast switching and their characteristic energy efficiency has enabled its widespread use for several purposes, such as car indicators, lighting systems, traffic data, and more [22,23]. One crucial factor to consider in LED lights is dimming [9]. An LED has a forward current, IF, which is the current that gets to the cathode coming through the anode of the LED light so that there can be enough current for powering the device in the forward bias [24]. Therefore, a linear relationship exists between the illumination of the LED and its forward current [25]. As such, LEDs are referred to as current-driven devices. Thus, dimming of LED lighting can be defined as controlling/influencing its forward current [26–30].

One method of dimming is a continuous modification of the current until half of the maximum current is achieved, which would give a 50% brightness. Pulse width modulation (PWM) is an alternative technique applied for dimming. Here, the brightening and dimming are done by increasing and reducing the pulse width, respectively, in which the amount of time the LED light is on is referred to as the duty cycle. Following the limited coverage distance of LEDs, to expand the coverage regions in an indoor VLC environment, holographic light shaping diffusers (LSDs) with suitable angles are utilized. This provides uniform power distribution and stands as a significant breakthrough in the design of VLC cellular systems [31].

In general, this review mostly examined recent literature on the proposed topic. In particular, publications indexed in major scientific research databases such as Web of Science, Scopus, ScienceDirect, etc., are included. However, a few works of literature that addressed the topic extensively, but are not currently indexed in the leading databases, were added. Specifically, keywords were used to limit the search scope, and peer-reviewed publications were included. The publication period considered is predominantly from 2012–2022, though a few older but highly relevant pieces of literature were captured. The papers included discussed the fundamentals and recent advances on the subject that meets the requirements of the current review. Overall, about a hundred works of literature were critically examined and included in the review.

The remainder of the article is organized as follows. Section 2 describes the research method, while Section 3 examines the energy efficiency strategies used in wireless communication networks. Section 4 discusses optical wireless communication schemes in greater depth. Section 5 provides an exhaustive discussion, and Section 6 gives a concise conclusion to the paper and outlines the direction for future work.

2. Method

Numerous innovative energy-efficient resource approaches in wireless communication networks have been presented in recent years, with an increasing emphasis on heterogeneous networks and resource allocation algorithms. The radio transmission technique has been optimized, low power circuit design has been developed, energy harvesting has been implemented, and green technology deployment has become a distinct research field. Others have also experimented with combining these approaches. A comprehensive framework for energy efficiency has been proposed in this review. This model incorporates all aspects of the wireless communication network's operation, from power generation to network infrastructure management to signal conditioning. The strategy proposes

implementing renewable energy resources within the wireless network's power generating module, as well as enforcing sleep mode infrastructure management techniques and deploying energy and spectrally efficient signal conditioning algorithms. The following sections of this review go into great detail about this method.

3. Energy Efficiency Techniques in Wireless Communication Systems

According to the authors of [32], the known categories of the approaches deployed for energy efficiency in wireless communication are either hardware-specific or quasi hardware/operation-specific. The hardware-specific techniques are the energy-efficient hardware component design and renewable energy resource deployment. The quasi hardware/operation-specific technique has to do with physical system architecture (heterogeneous network architecture), hardware conditioning (sleep mode technique) and system operation (energy-efficient transmission technique) [4]. Understanding these techniques will ensure the development of an integrated energy efficiency framework that will be robust enough to provide seamless services in the evolving and emerging communication architecture.

3.1. Energy Efficient Hardware Component Designs

Power amplifiers are used to increase the signal level of wireless communication for effective performance over the communication channel [4]. In [33], it was opined that using power amplifiers in base stations required certain conditions to be met. Requirements include the efficiency, linearity and expected output. The authors considered the Doherty power amplifier, envelope tracking (ET) power amplifier and linear amplification using non-linear components (LINC) power amplifiers. Advancements are still ongoing to improve the efficiency of power amplifiers in using sequential power amplifiers, good RF switching techniques, and smart antennas, among others [34,35].

3.2. Renewable Energy Resources

Renewable energy is a type of energy from natural resources like the sun, wind, etc. [36]. Part of the relevance of renewable energy is the supply of energy to areas with low or difficult accessibility to power grid sources [37]. By using renewable energy resource in wireless communication, a lower operational cost accrues to produce the same amount of energy that would have been provided if other means, like a diesel generator, were applied. Thus, equivalent information can be transmitted at a much higher operational cost when renewable energy is not used, resulting in energy inefficiency. Other relevance of renewable energy resources is environmental friendliness; renewable energy resources do not produce too many gas emissions compared to diesel generators [38]. Since less emissions are produced, most natural energy is transformed into useful electrical energy.

Different natural resources can be used as renewable energy technology. Some include hydropower, biomass, wind, hydrogen, geothermal, solar (photovoltaic and solar thermal), and ocean power [39]. Deploying large scale renewable technologies is challenging and has a high initial installation cost. Nevertheless, it has an optimum operational cost that outweighs the operational or running cost for the normal and frequently used energy supply (diesel generators) [40]. Factors affecting this are increased and unstable oil prices, air pollution, cost of transportation, epileptic energy supply, etc. [41]. British Columbia's transmission network deployed Bear Mountain Wind farm (BMW) as their first large-scale wind farm. Several communication devices were integrated with the wind farm, mainly wired technology. Communication availability can be enhanced, and also the maintenance effort can be reduced if the communication equipment is scalable and interoperable. The Bear Mountain Wind farm had thirty-four turbine generators which produced 102 MW [42]. Another interesting renewable energy source adopted is photovoltaic power systems [43,44].

A PV cell, usually encapsulated as a module, is used to harvest energy from the sun, converting it to electrical energy. To make an array meet the desired current or power, strings, a collection of PV modules, are interconnected. Strings have a series connection, thus, the greater the number of strings, the higher the voltage [45,46]. A typical representation of the cell, module, panel and array architecture of PV is shown in Figure 1 [47]. Utility, commercial and residential scales are the three classifications of grid-connected solar systems. Installations above 100 kW are designated as utility scales or solar farms/plants, and installations commonly found on the roof of a building with commercial capacity range from 10 kW to 100 kW [46]. The smallest type of installation found on private properties is the residential scale of less than 10 kW [46,48]. Cell ageing, soiling, partial shading, dust collection, and cell damage are examples of unavoidable non-optimal conditions that affect the power output of a photovoltaic array. Integrating a sensor that sends information data to the monitoring interface after sensing the temperature, voltage, and current is a way to track the solar module status. The major shortcomings of a photovoltaic cell system are troubleshooting failed panels and minimizing power dissipation losses [42].
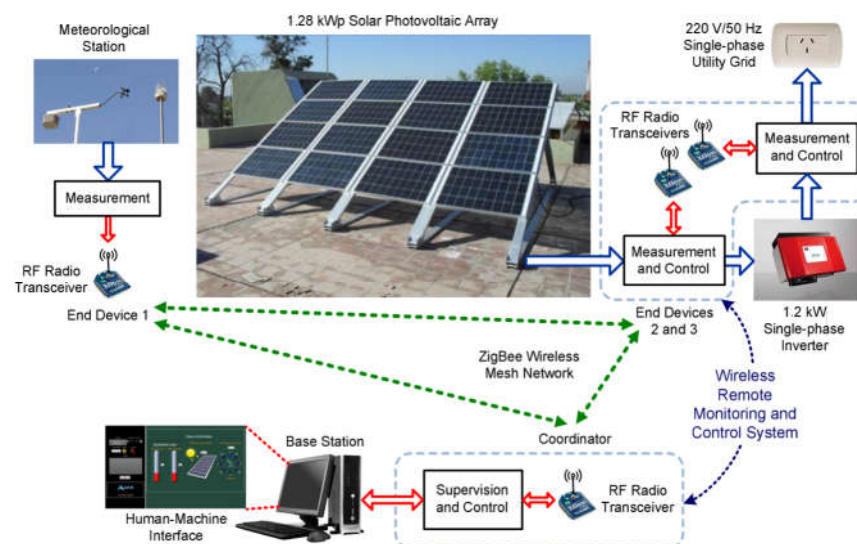

Figure 1. Photovoltaic cell, module, and array for various applications.

3.3. Heterogeneous Networks

A developing and encouraging means to solve the shortcomings in future electronic communication is the deployment of heterogeneous networks, which keeps up with the most significant amount of future system performance gains, considering the insufficiency in existing wireless networks, and the integration of supporting technologies within the network.

To enhance the wireless communication systems, heterogeneous network modelling of the framework shown in Figure 2 [19], the picocells, femtocells, microcells, etc., would have to work together for better performance [49]. A femtocell is a small, low-power base transceiver station situated in homes or small businesses. Figure 3 depicts femtocells configuration, showing dead zones in wireless networks [50]. Figure 4 describes femtocell–consumer installed wireless data access points inside homes [51]. Figure 5 depicts microcells installed cell towers, which improve coverage in environments with limited signal reception [50].
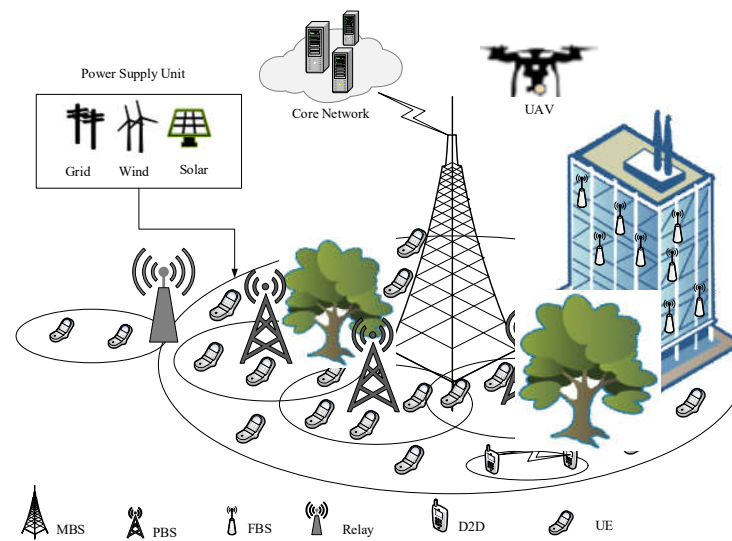
Figure 2. Heterogeneous wireless network support various wireless applications.

The internet service providers connect to the femtocell via network cables or digital subscriber lines (DSL) [49]. The range of a femtocell is around 10 m; a picocell is around 200 m or less; while microcells are less than two kilometres wide [52]. A picocell is a small base transceiver station that covers small areas such as offices, stores, banks, etc., to increase the network capacity in those areas where it would have been difficult for macrocell to reach [49,53].
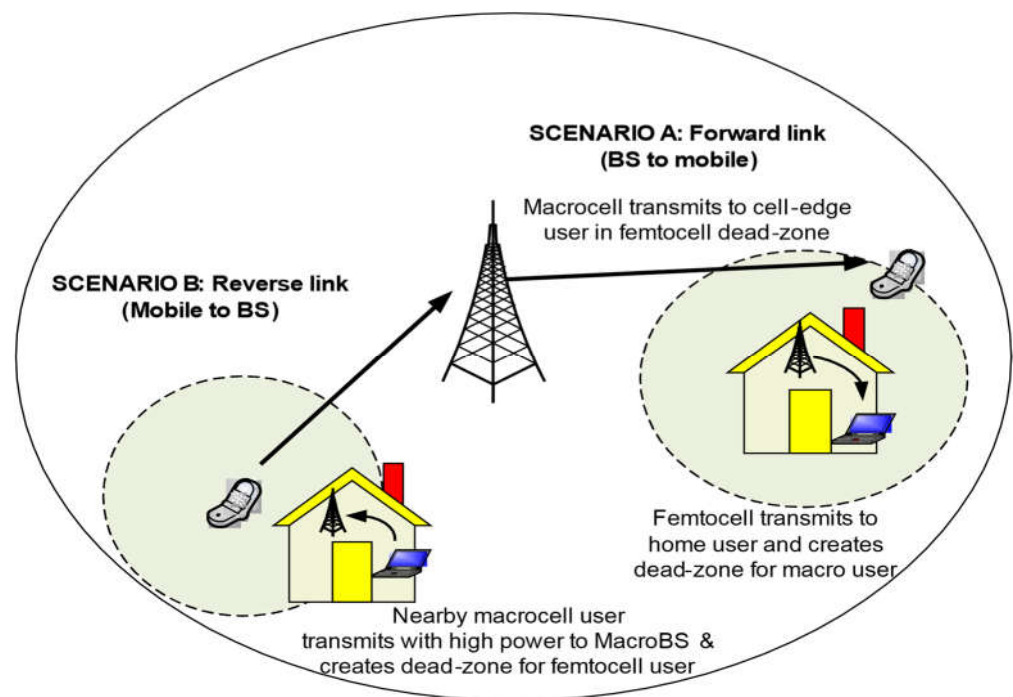

Figure 3. Femtocells configuration showing dead zones in wireless networks.
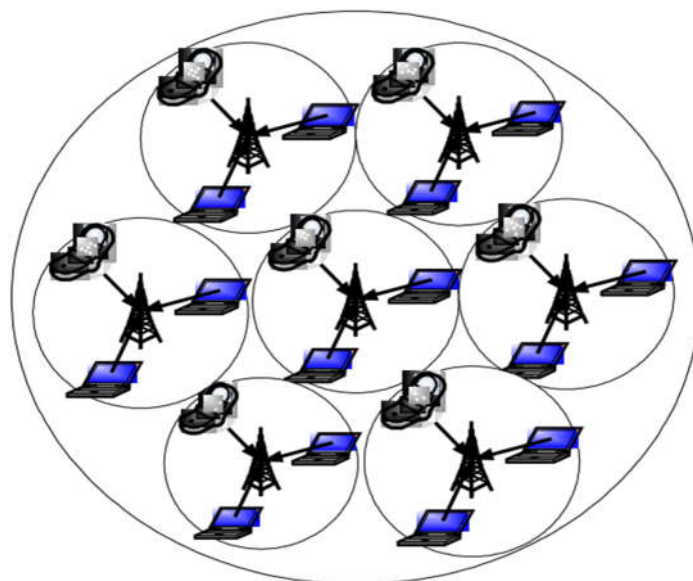
Figure 4. Femtocell: Consumer installed wireless data access points inside homes.
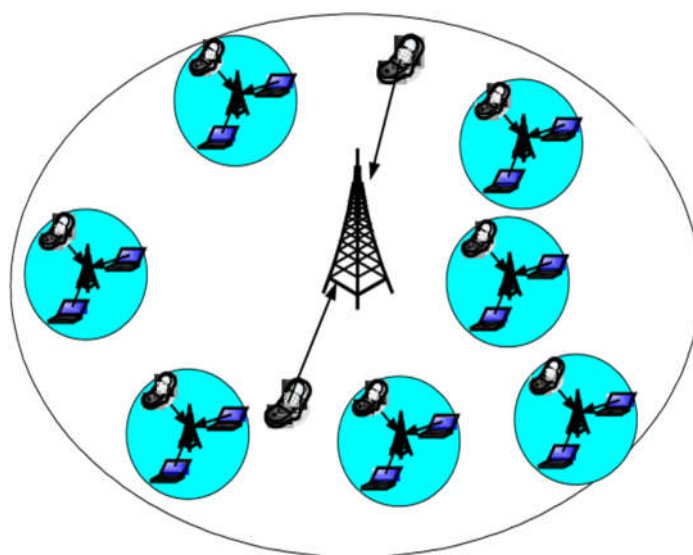

Figure 5. Microcells installed cell towers, which improve coverage in environments with limited signal reception.

3.4. Energy-Efficient Transmission Techniques

The growth of future wireless systems will be impeded by the accumulation in the radio frequency (RF) range (3 kHz–300 GHz), except more parts of the spectrum are accessible. There is an alluring technology that has a broader frequency range compared to the RF spectrum. It has a lot of uses, such as lighting facilities in buildings for advanced speed data communication, aeroplane cabins having higher communication speeds, vehicle to vehicle communication, trains, and underwater transmission and reception. The system is called a visible light communication system [54]. It can serve the purpose of both communication and illumination, therefore taking away additional transmission power that would have been used. Direct detection and intensity modulation are utilized mainly by OWC systems [54]. A leading research university in Japan, Keio University, partnered with Nakagawa laboratory, was the first to propose the first VLC system [55]. The desire for advanced network provisioning has waxed stronger; VLC techniques can solve these demands. Several issues surround VLC systems, including uplink connectivity, optimum multiple access approaches, optimum modulation technique, mobility, mitigating ISI

standardization, dimming control and illumination [56,57]. Multicarrier modulation, multicolour, and baseband modulation can be applied in OWC [11]. Multiplexing techniques most widely considered are WDM and OFDM [11].

Recent Advances in Energy-Efficient Transmission

The authors in [58] used a minimal abstraction layer to demonstrate the essential working parts of a wireless communication system for efficiency, which reduces the delayed/prolonged transmission time rate between several nodes, thereby saving power. The limitation to its use is the standardization of existing communication protocols. In [59], Sahaly and Christin proposed a technique for load balancing by a methodical apportioning of data traffic to links available in a wireless communication network. Its inadequacy was the inability to be carried out in real life and its consideration of only the local parameters of each node.

The authors of [60] demonstrated a technique that accommodated low power consumption, low latency, and high reliability with simplicity in wireless communication, which was achieved using non-orthogonal multiple access (NOMA). In OFDM, signals are transmitted at discrete frequencies, while NOMA uses the same frequency spectrum but has distinct power measures. The advantage of NOMA is that it has high spectral efficiency, as the same frequency spectrum can be utilized several times. This technique permits multiple connections to the identical frequency spectrum. An evaluation of some precoding techniques was carried out in the work. One benefit of the technique is the reuse of frequency. A significant setback to this technique is the difficulty of maintaining the BER functionality by giving a good estimation algorithm.

The authors in [61] analyzed that using the Kalman filter could measure the fastest path in a wireless sensor network and the input data noise. The Chinese remainder theorem (CRT) could split the nodes with the Kalman filter. Procuring a threshold for the CRT components is a drawback of this technique. The Kalman filter addressed energy efficiency because imperfections and unwanted signals are removed at the receiver end by producing an optimum from consideration of a group of them.

The work in [32] showed a promising and remarkable method for reducing the overall consumption of energy by using sleep mode techniques. The advantage is the automatic energy-saving of base stations at non-peak hours; as such, the energy is not wasted, thus causing energy efficiency. The limitation is that the technique was restricted to only cellular networks. Table 1 provides relevant requirements of the RF/Optical wireless communication techniques [11].

Table 1. Comparison between RF and optical wireless systems.

Feature	RF Communication	Optical Wireless Communication
Power consumption	Medium	Relatively low
Cost of technology	High	Low
Noise Sources	Similar frequency	Near external light sources
Multipath signal diminishing	Yes	No
Radio frequency electromagnetic interference	Yes	No
Data speed	Mbps	Gbps
Bandwidth	Regulated	Not regulated
Safety	Poor	Good
Passes through walls	Good	Cannot
Direction of Beam	Fair	Average
Usable bandwidth	Small	Quite large

3.5. Renewable Energy Resources

In Benin city, Nigeria, an on-grid and a standalone PV system for a telecommunication base station were analyzed and compared [62]. The operational expenditure for an on-grid system was lower than the standalone PV system. It was suggested that an on-grid system is a very cost-efficient scheme in areas with an adequate electricity supply. Later in 2016, a standalone PV system was also analyzed in South Korea. The authors in [63] highlighted that it would be impossible to adopt this system in areas with extremely low solar irradiation. This opinion agrees with the work done in [64] earlier in 2015 in Malaysia, which was compared with another site in Germany that solar irradiation is an important factor to be considered if a PV system is to be utilized because it affects the overall effect cost and gas emissions. A PV/DG system was considered, unlike the work done in [55,56] that thought of just standalone PV systems. In 2019, another PV/DG system [65] proved to be a more considerable system that should be adopted in Nigeria as opposed to an on-grid system suggested in [62] because most base stations in Nigeria run almost totally on diesel generators because of the power supply problem in Nigeria. So, integrating a PV with the conventional DG system would reduce the overall expenditure and environmental emissions caused by several base stations in Nigeria. A similar analysis in [66] had earlier been done in 2018 in Nigeria to show that PV systems should be added to the conventional DG system. The work added an analysis indicating that it is better to have an optimized generator scheme for maximum utilization of the PV resource. All the authors used HOMER as the simulation software, except those that used PVSYST6.0.7 [62]. Further improvements in the proposed models are achievable by incorporating the right software metrics into the simulation software [67]. However, the additional software metrics will be at the expense of the desired efficiency level within the governing ethics and standards [68,69].

4. Optical Wireless Communication Schemes

In 2017, a general standard was researched and formulated to develop new products in VLC-IEEE 802.15.7. They considered three separate VLC system applications: infrastructure, vehicle, and cellular applications. The standard aims to specify the speed of communication, modulation and error correction schemes, providing immunity against electromagnetic interference, providing connection to several hundred THz bands, etc., [70–72]. It showed high feature bandwidth, making VLC an attractive technique for future communication and a promising field for further research. It was investigated that combining RF and VLC would be a better communication scheme as it is better to support RF with VLC systems than just eliminating RF.

Work on the concept described had been earlier carried out in 2016. The authors in [73] carried out an optimized energy-efficient scheme that incorporated both an RF and a VLC system. A VLC system model was proposed with a single-user transmitter and receiver. The derivation of algorithms obtained allocations for the power and bandwidth of the system. Throughput improvement of the system and energy efficiency optimization was achieved. None-Line-of-Sight VLC transmissions were not considered; therefore, their transmission was unsuccessful. One factor that contributed to the transmission failure was that the network and the varying position of the users were not analyzed.

In [74], the authors proposed a system analyzing the relationship between the position of the network and users. An amorphous structure was used instead of the normal conventional structure. A proposed system-level energy-efficient maximization algorithm for the initial algorithms was simulated to prove that it had a higher energy efficiency per user for different angles of its field of view. Only the transmission power was considered as the source of power consumption. An open issue that was not addressed was how the VLC energy consumption is measured. Other sources of power consumption included signal processing costs, backhaul power consumption, etc. Additionally, the proposed algorithms were strictly for indoor cases and did not permit the mobility of users.

Unlike [74], which used an amorphous setup, the work in [75] used a user-centric design philosophy to show a concept whereby VLC was integrated into the radio frequency (RF) heterogeneous network environment. It reviewed answers to problems like multi-user signal processing, scheduling and resource management. The survey in this paper proposed a system-level VLC network substituting network-centric design for a user-centric design philosophy, taking significant cognizance of minimizing interference.

Research in 2020 [76] showed the connection between user association performance in a visible light cell where the user association was studied in a multicell non-orthogonal multiple access (NOMA) VLC network. The research was carried out because of the difficulty in obtaining optimal strategies for how users in a multicell NOMA-VLC network relate, which led to the study of their relationship using the proximity access principle. Shannon's mathematical model theory was used to depict the basic system model. In order to prove the theoretical analysis, the MATLAB program software and the Monte Carlo simulation methods were utilized. The simulation results showed that the Virtual Power Purchase Agreements (VPPA) improved rate response based on sufficient conditions than the proximity access principle. The authors did not include the study of how a multi-cell NOMA-VLC network allots power and assembles its users.

The authors in the article [77] proposed a full-duplex VLC system with several users who can handle different devices. The system was separated into downlink and uplink sections. Other modulation schemes were employed in the system. The cost and power consumption analysis were carried out concerning the data throughput. The system proved to be both power efficient and cost-efficient; though the initial cost was high, the operational cost was lesser. The problem of assembling several users was not directly settled.

In 2018, through the notion of cell-free massive MIMO [78] and encouraged by the dense-luminaries' facility, a dense VLC system enabled by densely distributed LEDs was proposed. In order to provide for several users simultaneously, dense VLC is used to fit the beam spots according to the system dynamics. The complicacy in adaptation was dwindled by designing a heuristic algorithm which was a proposal to make NLOS VLC harmonize with the distributed transmitters. In order to optimize the system throughput, an optimalo5 policy was formulated for the power allocation among the distributed LEDs. While keeping up with the specifications for uniform illumination, the outcome proves that dense VLC can enhance the rate at which data are transmitted and the efficiency of the power [79].

Many works have been done around optical wireless communication, but much work has not been concentrated on the best modulation technique with spectral and energy efficiency [4,19]. One of the best modulation techniques in wireless communication is orthogonal frequency-division multiplexing (OFDM) [80–83]. OFDM has remarkable features like optimum transmission channel management, low intercarrier interference (ICI), minimal intersymbol interference (ISI), etc. In July 2010, the authors of [84] analyzed the impact of OFDM on an OWC system. It helped to see the effect of clipping in the LED transmitter front-end and the relationship between the modulation order and SNR degree, which are two important factors to consider when using OFDM in an OWC system [25,85]. A variant of OFDM for optimal spectral and energy efficiency was presented in [8]. Another remarkable modulation technique [86] for OWC was introduced just the next year, 2011—spatial modulation. Spatial modulation complements the drawback of a reduced data rate in OFDM, which was investigated previously to efficiently manage sub-carriers positioning for maximum spectral performance [87]. Subsequently, OFDM and spatial modulation have combined OWC [88] and MIMO [89].

In 2017, spatial modulation for the VLC system in MIMO-OFDM was first analyzed by authors in [90], which provided a better data rate than other schemes. The work helped to minimize spectral attenuation that has largely been previously encountered. A slight improvement, an improved detection algorithm, was added in the following year [91], which further improved the overall efficiency of the system. One drawback in the last two

investigations is that the configuration of the transmitter and the receiver were limited to a 4 × 4 setup and a multiple of it. In 2019, a polar form was analyzed [92] for the same modulation configuration improved SNR saving. In that same year, the authors improved on the drawback of the setup configuration in their work [93]. The most recently improved work [94] on this technique by the same authors was done in 2020.

One major problem envisaged in VLC is the security of critical user information. The key challenges in physical layer security for VLC are outlined in [95]. Figure 6 shows a typical illustration of a scenario where an eavesdropper appears to narrow its FoV in an attempt to wiretap an information-bearing signal. This scenario tries to minimize the reception of jamming signals [96]. Here, a typical VLC system with a jamming strategy is demonstrated. The electron device (ED) is boosted with a narrow field-of-view (FoV) photodiode (PD) and oriented directly toward the information LED transmitter, as described in Figure 6 [95]. As seen in Figure 6, the LEDs assume a uniform distribution on a square lattice. Specifically, one legitimate user and one eavesdropper could be positioned in the region under investigation. The nearest LED to the legitimate user is selected to transmit the information-bearing signal. In this case, the other LEDs pretend to be jammers. Another assumption made is that the transmitters know the channel state information of the real and malicious users. In real applications, the jammers can derive the precoding matrix through the design of an optimization problem, which can maximize the jamming signal reception at the eavesdropper. It does this by aligning it to the null space of the legitimate user's channel [97]. Afterward, the jammers can multiply a random noise signal by the precoding matrix and transmit it to stop information reception at the eavesdropper site [95].
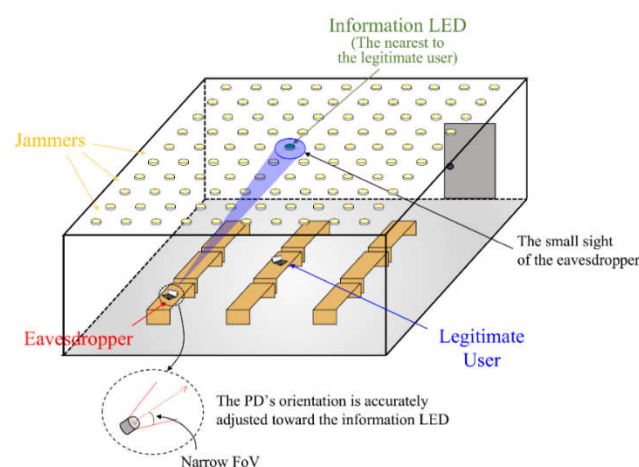

Figure 6. Diagrammatic illustration of artificial jamming in VLC applications.

In 2022, an optical HARQ-based LEO-to-ground downlink with power allocation was proposed to enable reliable and energy-efficient transmission under weak turbulence circumstances. With a maximum transmitted power constraint and a target outage probability constraint, the system's energy efficiency and reliability were maximized by minimizing the average power consumption [98]. The authors in [99] contributed to the ongoing development of a next-generation optical wireless communication standard from a European perspective and proposed Li-Fi as a candidate technology for 5G. The IEEE 802.15 working group was deemed the best fit for the bottom-up development of the Li-Fi idea in Europe, America, and the world. The IEEE 802.15.7-2011 standard for visible light communication has been revised and is now known as 802.15.7r1. While the change addresses low data rate communication using imaging sensors, it also allows for establishing high data rate mobile communications using an optical wireless standard. Tables 2 and 3 provide a comprehensive review of renewable energy and optical wireless communication techniques deployed in energy-efficient networks.

Table 2. Summary of related work utilizing renewable energy systems in base stations.

S/N	Author	Country	Hybrid System	Cases Considered	Simulation Software	Achieved Results		Remarks
1	Dike et al., 2014 [62]	Nigeria	PV.	Comparing powering options of the grid and off-grid sites	PVSYST6.0.7	- -	The cost of the grid/PV system was lower than the off-grid PV system. OPEX for the grid system was €0.24/kWh while the PV system was €1.08/kWh.	A grid system is better for locations with a very good grid supply.
2	M. H. Alsharif et al., 2015 [64]	Malaysia	PV/DG	Decreasing OPEX and environmental emissions.	HOMER	- -	System OPEX savings were 43% to 47%. Malaysia's greenhouse condition was a better choice of location for the proposed hybrid system than Germany.	The rate of solar irradiation determines the reduction in OPEX and gas emissions.
3	Alsharif et al., 2016 [63]	South Korea	PV.	Decreasing OPEX and environmental emissions.	HOMER	- -	System OPEX savings got to 48.6%. It was shown that a PV system does not necessarily need a battery bank to operate.	It would be impossible to adopt this system in extremely low solar radiation areas.
4	P. Oviroh, T. Jen, 2018 [66]	Nigeria	PV/DG	Analyzing the cost of a hybrid system with three generator schemes checking for the best scheme.	HOMER	- -	With an 8 kW load, an average cost of $0.156/kWh to $0.172/kWh of valuable energy was produced. The optimized generator was shown to be the best combination with the hybrid system, maximizing the renewable energy resource.	In adopting a hybrid system, optimization of the generator should be carried out for the better performance of the whole system.
5	Babatunde et al., 2019 [65].	Nigeria	PV/DG	Investigating operational expenditure and gas emissions at two diesel prices.	HOMER	The hybrid system was more cost-efficient than the usual standalone diesel generators.		A very high initial price for the PV array would affect the adoption of such a system in the country.

Table 3. Summary of work utilizing different optical wireless communication modulation schemes.

S/N	Author	Focus/Main Contribution	Results	Limitation/Drawback
1	R. Mesleh et al., 2010 [84]	The work analyzed the impact of OFDM in an OWC system showing the relationship between the modulation order and the degree of SNR.	System quality depended on the order of the modulation and how the LEDs were clipped.	The system needs improvement because it has a low data rate.

2	T. Fath et al., 2011 [86]	The work introduced the use of spatial modulation in OWC.	It provided a better data rate than previous schemes.	More work still needs to be done on the technique.
3	Zhang et al., 2016 [74]	An amorphous setup to provide spectral efficiency in a VLC network.	Higher energy efficiency per user was obtained using A-cells compared to the conventional cell formation for the different practical field of views (FOVs) angles.	Strictly for indoor cases and does not permit user mobility. Furthermore, the non-linear clipping distortion effect for the capacity expression of DCO-OFDM was not considered.
4	M. Kashef et al., 2016 [73]	Derived and formulated allocation algorithms to maximize the energy efficiency of a heterogeneous network that had both RF and VLC.	It was shown that the proposed network would produce more benefits than using just an RF network.	None-line-of-sight VLC transmission was not considered; therefore, their transmission was unsuccessful.
5	LU. Khan, 2017 [70]	Survey of VLC standardization, modulation techniques, potential applications, architecture, and open research.	Numerous features like high bandwidth have made VLC an attractive technique for future communication.	It did not provide a feasible model for an energy-efficient VLC system.
6	M. T. Niaz et al., 2017 [77]	The work utilized AC0-OFDM for downlink transmission and OOK and PAM–OOK for the proposition of multiple connected VLC networks.	The system's performance met data transmission requirements for an indoor environment. However, it had a high initial cost but a lesser operational cost, making it cost-efficient. It was also power-efficient.	It had a low data rate
7	Yesilkaya et al., 2017 [90].	The work proposed an LED index modulation method for MIMO-OFDM based VLC system.	Using spatial multiplexing and LED index modulation, spectrum efficiency losses were eliminated by time and frequency domain shaping in OFDM signals.	It can only be applied to a system with a multiple of four transmit LEDs
8	J. Beysens et al., 2018 [79].	The work proposed a dense VLC system that serves several users simultaneously using a cell-free massive multiple input multiple output (CFM-MIMO) system.	Dense VLC enhanced the rate at which data were transmitted and the power efficiency compared to traditional means. A heuristic model was designed to harmonize non-line-of-sight VLC with distributed transmitters.	Enhanced modulation techniques such as OFDM in VLC were not exploited to achieve better results. Unplanned receivers can experience interference from transmitters if their placement is not adequately coordinated.
9	M. Tran, S. Kim, T. Ketseoglou et al., 2018 [91]	Analyzed LEDs domain positioning for a MIMO-OFDM as a multiple of four transmit LEDs, formulating a scheme that had a reduced detection complexity compared with the one in [59]	The scheme obtained was better than the one in [59]	It can also be applied to a setup with multiple four transmit LEDs

10	M. Obeed et al., 2019 [75].	Integrating VLC into the RF heterogeneous network environment using a user-centric design philosophy. Reviewing optimization techniques proposed to improve VLC network performance.	Reviewed and proposed different system models for NOMA-VLC. A hybrid VLC/RF network was shown to have a better performance than VLC or RF standalone networks and evaluated energy harvesting in VLC systems.	No hybrid NOMA techniques in the VLC system have been investigated. There are still challenges in harvesting energy in VLC systems.
11	H. Hussein, 2019 [92].	In resolving the shaping issues of OFDM signals, the conventional signal for OFDM was changed to a polar form to realize an efficient VLC scheme.	Compared with [59], this technique allows just two transmit LEDs to operate with a better SE, enhancing BER and data rate. It saves 6.25 dB SNR than [59].	The spatial domain could still be exploited more than how it was done in [62].
12	Hussein et al., 2019 [93].	The authors worked on the scheme in [59] by proposing an improved scheme with an increased spatial index modulation.	It used fewer transmit LEDs to produce more spectral efficiency than the work [59], giving a better data rate. It saved 8 dB SNR than [59].	The spatial domain could still be exploited more than how it was done in the journal [63].
13	S. Tao et al., 2020 [76].	The work analyzed the user-association performance of a visible light cell in a multicell non-orthogonal multiple access (NOMA) VLC network.	The violation of the principle of proximity access (VPPA) was formulated, which showed a better signal response than the PPA.	The arrangement of users and power allocation was not considered.
14	Hussein et al., 2020 [94].	Improved on the scheme of [63]. Proposed a scheme that maximized the LEDs indices spatial domain to avoid the optical OFDM shaping issue and expand the domain.	The proposed scheme proved to be better than the generalized LED index modulation scheme in [63], having a higher bit error rate and data rate. It saved 5.2 dB SNR compared to [59] and 3.7 dB SNR compared to [63].	It can only be applied to a system with three or more transmitters.
15	Cogalan, T. Haas, H. Panayirci, E., 2020 [100].	Presented a scheme for transmission in spatial modulation (SM) optical MIMO system that manipulates the transmitter domain to enhance the effective functioning of several users while removing some components of the receiver section that would have been there normally.	It used an M-ary PAM to derive a model for an increase in BER for any number of transmitting LEDs. The work formulated a scheme for the different spatial arrangements of LEDs by maximizing the domain of the transmitter.	The scheme was analyzed for a 2 × 2 and a 4 × 4 LED structure. It cannot be concluded that the same performance can be recorded for a structure more than that mentioned above due to increased complexity.
16	M. Gismalla et al., 2019 [101]	Optimizing the power received and SNR of an indoor VLC system by proposing an optical attocell network configuration with five attocells.	24.9% of power transmitted was saved, as seen in the simulation results. SNR and power received were optimized.	It considered only line-of-sight links

5. Discussion

This review categorizes the energy efficiency framework for wireless communication networks as both hardware and operations based. The hardware distribution was analyzed, including high-power generation and consumption components, including power amplifiers and energy generating sources. It was suggested that the non-linearity caused by power amplifiers might be reduced by utilizing power amplifiers with non-linear components and deployable investigated technologies. Cost-effective and reliable renewable energy resources could be used rather than relying on heavy-duty diesel generators to power transmission base stations in areas where power outages are still common. Despite the large initial capital investment in renewable resources, the long-term minimal operating cost is a significant tradeoff compared to the high operating cost of diesel generators. Solar and wind are two renewable resource options that, depending on the geographical variables, may favour one over the other in the deployment area. The energy-efficient framework's operation-based or quasi-hardware component deals with the physical topology of the wireless network, component conditioning, and transmission mechanisms. According to this review, the heterogeneous network, which must be backwards compactable with developing technologies, is an increasingly evolving component of the energy-efficient framework. The base stations might be set to run on demand by enabling the sleep mode approach. The deployment of low power consumption cells in hotspot zones is a critical component in the evolution of the heterogeneous network. With the advent of light-fidelity networks, the integration of attocells into current topologies has become critical in pursuing entirely green and sustainable technology. While the introduction of enhanced data rate low power consumption visible light technology does not imply a complete replacement, its complimentary properties in high-speed traffic backhauling guarantee a smooth implementation of the future generation of wireless communication technology. Optimized signal conditioning strategies have been proposed to improve the energy efficiency of the transmission process even more. Following the development made so far, novel techniques are still sought by investigating variants of the existing optical multicarrier techniques. An excellent optical multicarrier solution will combine spectral and energy efficiency performance features.

6. Conclusions and Future Work

The global population growth and increased demand for improved data rate and bandwidth have necessitated a reduction in power consumption and the development of better transmission communication models to meet the escalating demand. This article has provided relevant first-hand information on energy efficiency while covering renewable energy resource deployment, heterogeneous networks, efficient transmission techniques and emerging optical wireless communication technologies. An integrative energy efficiency approach is anticipated to be deployed in wireless communication networks with smart innovations that will encompass the automation and synchronization of all the energy-consuming components of the wireless communication infrastructure. This approach will entail the integration of an energy efficiency framework that will enable low power consumption spanning from the energizing of the base stations to the transmission and reception of extremely low power signals. Diverse energy and spectrally efficient modulation techniques will have to be deployed. At the same time, optical attocell network configuration can be modelled to cover hotspots, thereby producing extremely low optical transmission power. While the future landscape is promising, it is noteworthy that energy-efficient schemes can only be achieved at the expense of optimized hardware and software resources, and fast processing platforms. Currently, artificial intelligence is gaining widespread popularity in the deployment of learning-based models for energy efficiency and spectral gains in wireless communication systems. Future works would focus on leveraging machine learning and artificial intelligence toward achieving cost-efficient

energy resources with fast computational processing capabilities for emerging wireless communication systems.

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