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RESEARCH PAPER

Review of "Radio-Over-Optical-Fiber-Networks" by Yu, J., *et al.*, (2009)

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ABSTRACT

The review below describes or analyses the content, style and merit of the research article on Review of "Radio-Over-Optical-Fiber-Networks" by Yu, J., et al., (2009) in the context of latest developments in the area. The phenomenal growth in the use of smart phones, tablets, wearables, other mobile data consuming devices, and Internet of things (IoT), etc., combined with advanced applications, now requires high capacity heterogeneous wireless networks. Optical Fiber communication has enabled telecommunications link to be made over greater distance and with lower levels of losses in transmission medium. Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. In the Radio over Fiber (ROF) links, the radio frequency (analog) waveform (with embedded base band information) continuously modulates the light wave. The architecture for ROF is when the optical fibers transmit the RF signal between central-base station (CBS) and low power Radio Access Point (RAP). The IEEE802.16 or WiMAX standard has now been established to bridge the last mile though mobile and fixed wireless access to the end user at frequencies between 2 and 66 GHz.

Key words: *Network, Feature Issue, Yu, J., et al.*

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ANALYTICAL EXPOSITION

The phenomenal growth in the use of smart phones, tablets, wearables, other mobile data consuming devices, and Internet of things (IoT), etc., combined with advanced applications, now requires high capacity heterogeneous wireless networks. The essay or review below describes or analyses the content, style and merit of the research article on Review of "Radio-Over-Optical-Fiber-Networks" by Yu, J., *et al*., (2009) Convergence of wired and wireless services is dependent upon the progress made by the next-generation access networks. The broad-band evolution coupled with the phenomenal growth in the Internet has precipitated intense traffic patterns in access networks (Yu, J., *et al*, 2009). The high-speed, symmetric, and guaranteed bandwidth demands for future video services have also contributed to the convergence of wired and wireless services provided by the next-generation access networks. A unified networking platform for fixed and mobile users is now clothed with mobility features that deliver voice, data, and video services (Yu, J., *et al*, 2009). The IEEE802.16 or WiMAX standard has now been established to bridge the last mile though mobile and fixed wireless access to the end user at frequencies between 2 and 66 GHz. The cost of system installation and maintenance of such systems is drastically reduced by making use of simple radio antenna units. Yu *et al* (2009) advises that this can be achieved by consolidating the radio carrier generation and data signal processing functions at a centralized head end where the modulated signals are distributed over fiber to the antennas. Radio-over-fiber (RoF) is the technique by which light signal is modulated by a radio signal (Singh, *et al,* 2017).

Telecommunications is the electronic transmission of all forms of information (voice, fax, data, text, sound, and video) from one location to another over some type of network, whereas Data communications describes the transmitting and receiving of data over the communications line. Optical Fiber communication has enabled telecommunications link to be made over greater distance and with lower levels of losses in transmission medium. Fiber optical communications are enabled to designed to accommodate much higher data rates. Digital information modulates the light signal in binary(on/off) or M-ary manner. Optical communication is any form of telecommunication that uses light as the transmission medium. An optical communication system consists of a transmitter, which encodes a message into an optical signal, a channel, which carries the signal to its destination, and a receiver, which reproduces the message from the received optical signal. The transmitters in optical fiber links are generally light-emitting diodes (LEDs) or laser diodes. Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies. The process of communicating using fiber-optics involves the following basic steps of creating the optical signal involving the use of a transmitter, which is shown in the figure below, Figure 1:

1. Relaying the signal along the fiber
2. Ensuring that the signal does not become too distorted or weak.
3. Receiving the optical signal.
4. Converting it into an electrical signal.

The diagram below shows how a signal from a transmitting device can enter into the fibre-optic cable and comes out through a photo-detector on the receiving end.

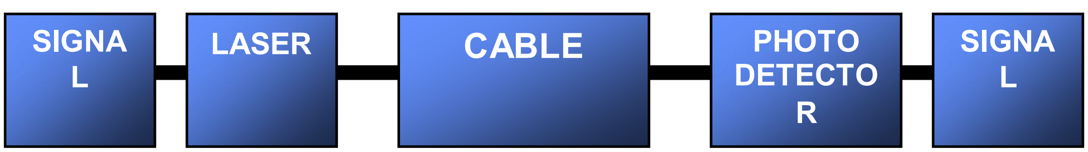

Fig. 1: Fiber optic transmission

Fiber provides huge bandwidth and connectivity which can be used together with the mobility feature via wireless links to offer a solution to the increasing capacity and mobility. This inevitably reduces power consumption and costs in the access network. Yu *et al* (2009) argues that the future broadband access networks based on radio-over-fiber technologies have emerged as an alternative solution in multi-user public environments. The feature article presents enabling techniques inclusive of novel architectures and optical millimeter-wave generation for radio-over-fiber networks. Optical fiber communication is the fastest and secure telecommunication technology to achieve consumer needs and reliabilities, and is reliable in handling and transmitting data through hundreds of kilometers with low bit error rate (Singh, R., *et al,* 2017). The structure of fiber is shown below on Fig. 2.

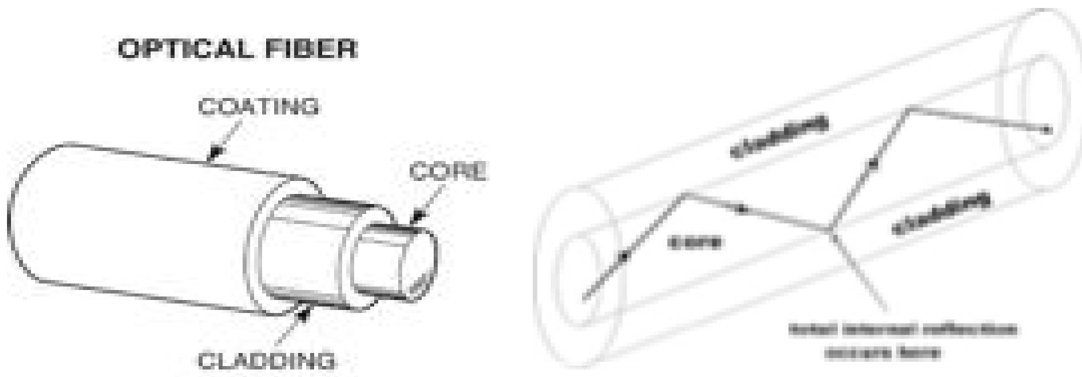

Fig. 2: Fiber structure and cladding

Most current networks such as SONET, Ethernet, GPON, EPON are digital. In the Radio over Fiber (ROF) links, the radio frequency (analog) waveform (with embedded base band information) continuously modulates the light wave. Radio over fiber (RoF) or RF over fiber (RFoF) refers to a technology whereby light is modulated by a radio frequency signal and transmitted over an optical fiberlink. The architecture for ROF is when the optical fibers transmit the RF signal between central-base station (CBS) and low power Radio Access Point (RAP). The RAP then transmits/receive the RF signal to customer units over the air. The RAPs only implement optical to RF conversion and RF to optical conversion. To enlarge the coverage of the wireless millimeter-wave signals, hybrid systems combining fiber and radio technologies, called Radio over Fiber (RoF), are discussed. The RoF is focused on the optical transmission and it does not include necessarily a wireless one. RoF transmissions can be used for multiple purposes such as the television distribution in the access network and inside the home or the transport of cellular signals between a base station and the remote antennas. The Wavelength Division Multiplexing (WDM) technique is the most preferred way to increase the information transmission capacities of a fiber system. Optical communications systems are widely employed for application ranging from major telecommunications backbone infrastructure to Ethernet systems, broadband distribution and general data networking. As a principle of ray propagation, the light ray enters the fiber core from a medium and strikes the core-cladding interface at such an angle that it is totally internally reflected, and is passing through the axis of guide after each reflection.

The development of a cost-effective Base Station (BSs) is guaranteed by Radio-over-fiber (RoF) technology, which involves modulating the radio frequency (RF) subcarrier onto an optical carrier for distribution over a fiber network (Zin, A.M., 2010). Optical fibers are attractive for RoF systems due to the following characteristics: very high bandwidth, low loss, immune to EMI, light weight, small cross section, low cost, and high flexibility. Current trends for future provision of broadband, interactive and multimedia services over wireless media in both mobile and fixed cellular networks are purposed to (Zin, 2010):

1. reduce cell size to accommodate more users and
2. operate in the microwave/millimeter wave (mm-wave) frequency bands to avoid spectral congestion in the lower frequency bands.

Radio over fiber (RoF) is the solution to the problem many base stations (BS) capable of handling a huge number of mobile-cellular telephone and broadband internet traffic since can operate a lot of BSs that are connected to central station (CS) by using optical fiber, as well as offering cost-effective solution (Sainawi and Ismail, 2017). Optical communication system consists of a transmitter, channel and a receiver. The transmitter will encode a message into an optical signal, the channel will carry the signal to its destination, and the receiver will reproduce the message from the received optical signal. Radio over fiber (RoF) is a technology where RF signal modulates light and then transmits it over an optical fiber link (Sainawi and Ismail, 2017). RoF is cost effective and saves on power consumption.The RoF lets the electrical signal modulates the optical source and after that the optical signal will travel along the optical fiber to the remote station. When the RF signal is modulated straight to the optical link, the power consumption drops while the antenna side has high frequency radio carriers. Sainawi and Ismail (2017) explained the cost reduction in RoF technology in two ways. The first one is the central station (CS), which provides resources that can be shared by a variety of base stations (BS), and secondly, the BS only executes a simple function. Furthermore, the BS is in a small size and less cost consuming. RoF is an ideal technology for the future generation, as it provides low attenuation and broad bandwidth. It is also immune to electromagnetic interference (EMI), which is a radio-frequency interference where disturbance generated by an external source that affects an electric circuit by electromagnetic induction, coupling or conduction.

According to Ng'oma (2005, Radio-over-Fibre (RoF) technology entails the use of optical fibre links to distribute RF signals from a central location (headend) to Remote Antenna Units (RAUs). In narrowband communication systems and WLANs, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing, are performed at the BS or the RAP, and immediately fed into the antenna. RoF makes it possible to centralise the RF signal processing functions in one shared location (headend), and then to use optical fibre, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs (Ng'oma, A., 2005). However, RoF has limitations since it involves analogue modulation, where detection of light is fundamentally an analogue transmission system. Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, are important in RoF systems as well. These impairments tend to limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links (Ng'oma, 2005). According to Ng'oma (2005), the noise sources in analogue optical fibre links include the laser's Relative Intensity Noise (RIN), the laser's phase noise, the photodiode's shot noise, the amplifier's thermal noise, and the fibre's dispersion. In Single Mode Fibre (SMF) based RoF, systems, chromatic dispersion may limit the fibre link lengths and may also cause phase de-correlation leading to increased RF carrier phase noise. It was observed by Ng'oma (2005) that in Multi-Mode Fibre based RoF systems, modal dispersion severely limits the available link bandwidth and distance. The use of Wavelength Division Multiplexing (WDM) for the distribution of RoF signals has become popular, as WDM enables the efficient exploitation of the fibre network's bandwidth. However, the transmission of RFoF signals is considered inefficient in terms of spectrum utilisation, since the modulation bandwidth is always a small fraction of the carrier signal frequency (Ng'oma, 2005).

We are now living in the era of ubiquitous connectivity or "communication anytime, anywhere, and with anything". Next generation access networks are expected to support an increased numbers of users, increased bandwidth demand and longer-range coverage. The new notion of ubiquitous connectivity has increased the importance of in-building coverage for all wireless communication systems. Optical fiber as the prevailing solution for next generation ion fixed access network has been adopted and deployed worldwide. Radio over fiber as the enabling technique bridges the wireless and optical world.

CRITICAL CONTEXT

An *internetwork* is a collection of individual networks, connected by intermediate networking devices, that functions as a single large network. Internetworking refers to the industry, products, and procedures that meet the challenge of creating and administering internetworks. Figure 3 illustrates some different kinds of network technologies that can be interconnected by routers and other networking devices to create an internetwork.

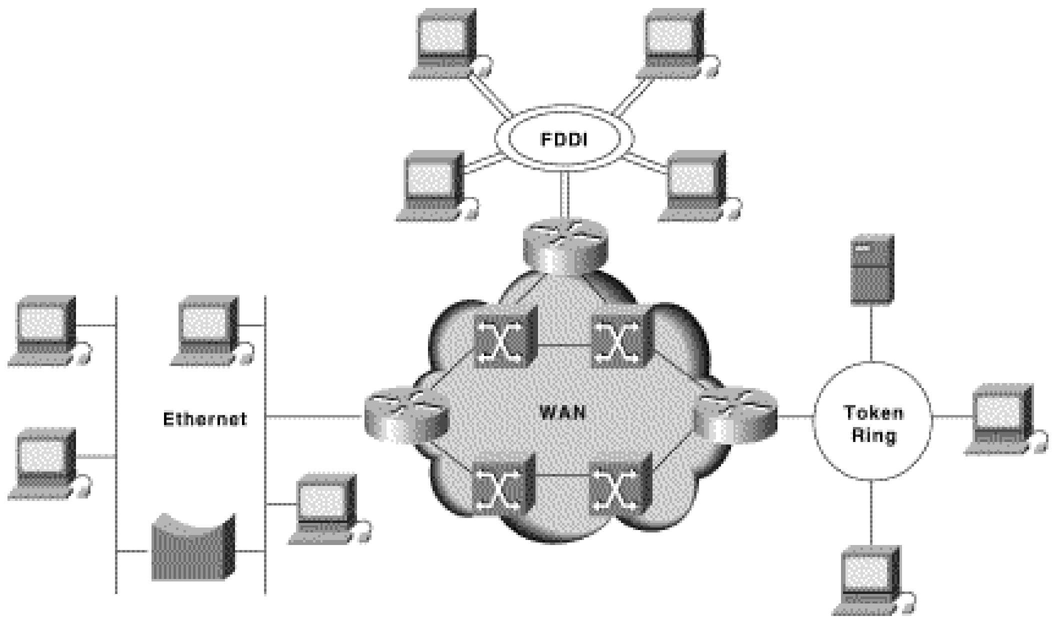

Fig. 3: Different Network Technologies Can Be Connected to Create an Internetwork

Today, high-speed Local Area Networks (LANs) and switched internetworks are becoming widely used, largely because they operate at very high speeds and support such high-bandwidth applications as multimedia and videoconferencing. Internetworking evolved as a solution to three key problems:, viz. isolated LANs, duplication of resources, and a lack of network management. Isolated LANs made electronic communication between different offices or departments impossible. Duplication of resources meant that the same hardware and software had to be supplied to each office or department, as did separate support staff. This lack of network management meant that no centralized method of managing and troubleshooting networks existed. The metropolitan networks perform a key role in tripleplay service provision in delivering the service traffic to a multiplicity of access networks that provide service coverage across a clearly defined geographical area such as a city over fiber or wireless technologies infrastructure. The core networks or long haul networks are those parts of the end-to-end communication network that interconnect the metropolitan area networks. The core network infrastructure includes optical routers, switches, multiplexers and demultiplexers, used to deliver triple play service traffic to the metropolitan networks and route traffic from one metropolitan network to another (Abdollahi, *et al,* 2012).

Kettani and Rachidi (2010) made an enlightening comparison between fiber and wireless technologies for the implementation of a Metropolitan Area Network (MAN) of Fes in Morocco. A metropolitan area network (MAN) is a large computer network that usually spans a city or a large campus. A MAN usually interconnects a number of local area networks (LANs) using a high capacity backbone technology, such as fiber-optical links, and provides up-link (also called backhaul in the context of a wireless network) services

to wide area networks and the Internet (Kettanii, and Rachidi, 2010). Usually, a MAN is optimized for a larger geographical area than a LAN, ranging from several blocks of buildings to entire cities depending on the communications channels of moderate-to-high data rates and whether the MAN is owned and operated by a single organization. Two major wireless solutions/technologies are available today for building Wireless MANs (WMANs), and these are WiMax802.16d (fixed WiMax) and the Long range Wireless Fidelity (LR Wi-Fi). Other Wireless technologies, such as 60GHz links and Microwave links, were not appropriate for city MANs because of their limited range which usually does not exceed 800m owing to signal decay, and the link type used which is point to point rather than point to multipoint (Kettani and Rachidi, 2010). Wi-Fi is the trade name for the popular wireless technology used in home networks, mobile phones, video games and other electronic devices that require some form of wireless networking capability.
Worldwide Interoperability for Microwave Access (WiMAX) is a standard-based telecommunications technology that provides wireless transmission of data using a variety of transmission modes including point-to-multipoint. WiMAX is a technology also called Broadband Wireless Access which provides up to 10 Mbit/s broadband speed without the need for cables, and is based on IEEE 802.16-2004, IEEE 802.16d, or "fixed WiMAX" standard (Kettani, D., and Rachidi, T., 2010, p.8). The Fixed WiMax systems are meant to provide network access to homes, small businesses, and commercial buildings as an alternative to traditional wired connections. The following table, Table 1, summarizes the strengths and weaknesses of WiMax technology.

Table 1: WiMAX strengths and weaknesses (Source: Kettani and Rachidi, 2010)

WiMAX strengths	**WiMAX weaknesses**
• Point to Multipoint: A singleWiMAX station can serve hundreds of users	• Line of site is needed for (+10km) links
• Much faster deployment of new users comparing to wired networks	• Weather conditions like rain could interrupt the signal
• Speed of 10 Mbps at 10 kilometers with line-of-site	• Other wireless equipments could cause interference
• Supports Non line of Sight	• Multiplied frequencies are used
• It is standardized, and same frequency equipment should work together	• WiMAX is very power intensive technology and requires strong electrical support
• Short delay	• Big installation and operational coast

The following table, Table 2, is a summary of fixed-WiMAX vs LR Wi-Fi technologies in terms of the 4 requirements and their sub-criteria.
Optical fiber can be bundled as cables and used as a medium for telecommunication and networking. With Wavelength Division Multiplexing (WDM), each fiber can carry many independent channels, each using a different wavelength of light. For short distance applications, such as creating a network within an office building, fiber-optic cabling can be used to save space in cable ducts. This is because a single fiber can often carry much more data than many electrical cables, such as Cat-5 Ethernet cabling (Kettani, and Rachidi, 2010). According to Kettani and Rachidi (2010) fiber is also immune to electrical interference; there is no cross-talk between signals in different cables and no pickup of environmental noise. Both multi-mode and single-mode fibers are used in communications, with multi-mode fiber used mostly for short distances, up to 550 m, and single-mode fiber used for longer distance links. “Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information e.g. generated by computers,

telephone systems, and cable television companies", (Kettani and Rachidi, 2010). The following table, Table 3, summarizes the advantages and disadvantages of fiber optics.

Table 2: A comparison between fixed-WiMAX and LR Wi-Fi in terms of the 4 requirements and their sub-criteria (Source: Kettani and Rachidi, 2010, p.15)

Requirement	Sub-criteria	LR Wi-Fi	WiMAX 16d
Application Requirements	Support for Real time applications and QoS	No support MAC is best effort	QoS built in MAC
Wireless Requirements	Supported Topology	Point to point, not scalable	Point to multipoint. Very scalable
	Support for NLOS	No support for NLOS	Support for NLOS up to 10Km
	Power Consumption	Depend on Product	Depend on Product
	EIRP	Built in	Built in
	Antenna Gain and beamwidth, and Antena Diversity	Depend on Antenna device	Depend on Antenna device
	SNR		
	Frequency of operation		
	Dynamic Frequency Steering (DFS)		Usually built in
	Transmitted Power Control (TPC)		Usually built in
	Achievable Bandwidth in a MAN type of Network	2 Mps	10s Mps
Policy Requirements			
	Frequency		
	Interoperability	No	Yes
	Openess	No	Yes
	Certification	No	Yes
CAPEX and OPEX Requirements			
	CAPEX	low	High: More expensive than LR-Wi-Fi
	OPEX	lo	High as management requires advanced skills

From the above table 2, it is clear that Fixed -WiMAX is the better option for a large MAN. The Optical based network technologies use SONET/SDH as a transport protocol that transparently manages the optical transmission. Synchronous Optical Networking (SONET) or Synchronous Digital Hierarchy (SDH) are standardized multiplexing protocols that transfer multiple digital bit streams over optical fiber using lasers or light-emitting diodes (LEDs).

SONET and SDH, which is basically the same, were originally designed to transport circuit mode communications (e.g., T1, T3) from a variety of different sources. SONET/SDH is not itself a communications protocol per se, but a transport protocol (Kettani, D., and Rachidi, T. 2010, p.19).

Abdollahi, *et al* (2012) explained the fiber optic link transmission as follows. "The signal that is transmitted over the optical fiber can either be originally an RF, intermediate frequency (IF) or baseband (BB) signal. For the IF and baseband (BB) transmission cases, additional hardware for up converting the signal to the RF band is required at the BS. At the optical transmitter, the RF/IF/BB signal can be modulated onto the optical carrier by using direct or external modulation of the laser light. In an ideal case, the output signal from the optical link will be a copy of the input signal. However, there are some limitations because of non-linearity and frequency response limits in the laser and modulation devices as well as dispersion in the fiber. The transmission of analog signals puts certain requirements on the linearity and dynamic range of the optical link. These demands are different and more exacting than requirements placed on digital transmission systems".

Table 3: Optical fiber advantages and disadvantages (Source: Kettani and Rachidi, 2010, p.18)

Advantages of Optical Fiber	Disadvantages of Optical Fiber
➢ System Performance ➢ Greatly increased bandwidth and capacity ➢ Lower signal attenuation (loss) ➢ Immunity to Electrical Noise ➢ Immune to noise (electromagnetic interference [EMI] and radio-frequency interference [RFI] ➢ No crosstalk ➢ Lower bit error rates ➢ Signal Security ➢ Difficult to tap ➢ Nonconductive (does not radiate signals) ➢ Electrical Isolation ➢ No common ground required ➢ Freedom from short circuit and sparks ➢ Size and Weight ➢ Reduced size and weight cables ➢ Environmental Protection ➢ Resistant to radiation and corrosion ➢ Resistant to temperature variations ➢ Improved ruggedness and flexibility ➢ Less restrictive in harsh environments ➢ Overall System Economy ➢ Low per-channel cost ➢ Lower installation cost	**1.** Fiber optic components are expensive because of the relative newness of the technology **2.** Fiber optic transmitters and receivers are still relatively expensive compared to electrical interfaces **3.** The lack of standardization in the industry **4.** Many industries are more comfortable with the use of electrical systems and are reluctant to switch to fiber optics

Depending on the requirements and features of the end users in terms of latency, quality of service (QoS) or service layer agreements (SLA), optical access networks have evolved in different directions with high capacity at low price which is supported by passive optical networks (PON) while quality assurance and security are supported by active optical networks (AON) (Olmos, 2012). Passive optical networks (PON) systems have become increasing popular because they offer both low capital and operational expenditures, which are critical factors in access networks. However, PON efficiency is low in terms of bandwidth utilization and power budget issues limit the splitting ratio and the attainable link length. The intrinsic nature of the distribution approach (point-to-multipoint multicast) may raise concerns in terms of security, especially in industrial or business environments (Olmos, 2012). In AON, data can be effectively managed at a traffic engineering level (i.e., path control, bandwidth reservation, prioritization, etc.), while ensuring secure unicast distribution and simple and flexible designs. When considering AON networks, in the context of wireless systems, the advantages are clear in that we can better handle data distribution while preserving the mobile nature of the end users.

INTEGRATIVE CONCLUSION

The essay or review described or analysed the content, style and merit of the research article on "Radio-over-optical-fiber Networks: Introduction to the feature issue" by Yu, J., *et al* (2009). The article presented a foundation on the innovative developments in the field of telecommunications and in particular in the mobile phone communications industry. The phenomenal growth in the use of smart phones, tablets, wearables, other mobile data consuming devices, and Internet of things (IoT), etc., combined with advanced applications, now requires high capacity heterogeneous wireless networks. Fiber optical communications are enabled and designed to accommodate much higher data rates. Radio-over-fiber (RoF) is the technique by which light signal is modulated by a radio signal (Singh, *et al*, 2017). The broad-band evolution coupled with the phenomenal growth in the Internet has precipitated intense traffic patterns in access networks (Yu, J., *et al*, 2009).

An optical communication system consists of a transmitter, which encodes a message into an optical signal, a channel, which carries the signal to its destination, and a receiver, which reproduces the message from the received optical signal. A unified networking platform for fixed and mobile users is now clothed with mobility features that deliver voice, data, and video services (Yu, J., *et al*, 2009). Optical communication is any form of telecommunication that uses light as the transmission medium. Optical Fiber communication has enabled telecommunications link to be made over greater distance and with lower levels of losses in transmission medium. The cost of system installation and maintenance of such systems is drastically reduced by making use of simple radio antenna units. Convergence of wired and wireless services is dependent upon the progress made by the next-generation access networks. The high-speed, symmetric, and guaranteed bandwidth demands for future video services have also contributed to the convergence of wired and wireless services provided by the next-generation access networks. Yu *et al* (2009) advises that this can be achieved by consolidating the radio carrier generation and data signal processing functions at a centralized head end where the modulated signals are distributed over fiber to the antennas.

Telecommunications is the electronic transmission of all forms of information (voice, fax, data, text, sound, and video) from one location to another over some type of network, whereas Data communications describes the transmitting and receiving of data over the communications line.

The transmitters in optical fiber links are generally light-emitting diodes (LEDs) or laser diodes. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies. The IEEE802.16 or WiMAX standard has now been established to bridge the last mile for mobile and fixed wireless access to the end user at frequencies between 2 and 66 GHz.

According to Wikipedia (https://en.m.wikipedia.org/wiki/Radio_over_fiber), Radio over fiber (RoF) or RF over fiber (RFoF) refers to a technology whereby light is modulated by a radio frequency signal and transmitted over an optical fiber link. The main technical advantages of using fiber optical links are lower transmission losses and reduced sensitivity to noise and electromagnetic interference compared to all-electrical signal transmission. The common applications of RoF range from the transmission of mobile radio signals (3G, 4G, 5G and WiFi) and the transmission of cable television signals (CATV) to the transmission of RF L-Band signals in ground stations for satellite communications. Signals transmitted on optical fiber attenuate much less than through other media like metal cables or wireless media. By using optical fiber, the radio signals can gap larger transmission distances, reducing the need of additional repeaters or amplifiers.

Radio signals are carried over fiber-optic cable, where a single antenna can receive any and all radio signals (5G, Wifi, cell, etc..) carried over a single-fiber cable to a central location where equipment then converts the signals. In contrast in the traditional way, each protocol type (5G, WiFi, cell) requires separate equipment at the location of the antenna. Although radio transmission over fiber is used for multiple purposes, such as in cable television (CATV) networks and in satellitebase stations, the term RoF is usually applied when this is done for wireless access. In RoF systems, wireless signals are transported in optical form between a central station and a set of base stations before being radiated through the air. Each base station is adapted to communicate over a radio link with at least one user's mobile station located within the radio range of said base station. The advantage is that the equipment for WiFi, 5G and other protocols can be centralized in one place, with remote antennas attached via fiber optic serving all protocols. This greatly reduces the equipment and maintenance cost of the network. Hence, RoF technology enables convergence of fixed and mobile networks. (Wikipedia, https://en.m.wikipedia.org/wiki/Radio_over_fiber).

Mobile network is an important application area of RoF technology. The ever-rising number of mobile subscribers coupled with the increasing demand for broadband services have kept sustained pressure on mobile networks to offer increased capacity. Therefore, mobile traffic (GSM or UTS) can be relayed costs effectively between the SCs and BSs by exploiting the benefits of the technology (Kaur and Kaler, 2007).

A fiber-radio network comprises two distinct domains, one optical and one wireless. In the optical domain, Wavelength Division multiplexing (WDM) can be use to combine several wavelengths together to send them through a fiber-optic network, greatly increasing the use of the available fiber bandwidth and maximising total data throughput that in order to meet future wireless bandwidth requirements, a single CO feeds each remote radio BS and has access to a separate optical wavelength. Note that each BS is allocated a separate optical wavelength in the downlink (from CO to BS), which can be re-used in the uplink direction (from BS to CO). Using the same wavelength in both directions is not a requirement, since a channel offset scheme can be used or downlink and uplink channels can be interleaved. One of the main factors that determines the nature of the optical network and the equipment used at the CO and BSs is whether or not data destined for BSs is sent at baseband or at an intermediate- or radio-frequency (IF or RF). WDM involves multiplexing multiple wavelengths and transporting them in a single fiber. Current technology allows one to two hundred channels to be transported in a single fiber, achieving Tb/s total capacity If WDM is used in a fiber-radio network, then each BS can be assigned a single wavelength (Kaur and Kaler, 2007).

REFERENCES

1. Abdollahi S.R., Al-Raweshidy H.S., and Owens T.J. (2012): Super-Broadband Wireless Access Network, Book Chapter 19 in the Book "Wireless Communications and Networks- Recent Advances", InTech Publications, 2015, pp.493-450, ISBN: 978-953-51-0189-5, InTech, Available from: http://www.intechopen.com/books/wireless-communications-and-networks-recent-advances/super-broadband-wireless-access-network.
2. Kaur P. and Kaler R.S. (2007): Radio over fiber networks, Proceedings of National Conference on Challenges & Opportunities in Information Technology (COIT-2007) RIMT-IET,Mandi Gobindgarh, India, March 23, 2007, https://www.researchgate.net/publication/228941946_Radio_over_Fiber_Networks
3. Kettani D. and Rachidi T. (2010): Comparison of Fiber and Wireless Technologies for the implementation of the administrative MAN of FES, Morocco, Alakhawayn University in Ifrane, Morocco, 08/03/2010, (cc) Creative Commons Share Alike Non-Commercial Attribution 3.0.
4. NG'OMA A. (2005): Radio-over-fibre technology for broadband wireless communication systems Eindhoven: Technische Universiteit Eindhoven DOI: 10.6100/IR592332.
5. Olmos V. J.J., Rodes G. and Monroy T.I. (2012): Optical Switching for Dynamic Distribution of Wireless-Over-Fiber Signals in Active Optical Networks. Journal of Optical Communications and Networking, 4(8), 622-627. DOI: 10.1364/JOCN.4.000622.
6. Sainawi L. and Ismail K. (2017): Receiver Performance Improvement in Radio over Fiber Network Transmission, Optical Fiber and Wireless Communications, June, 2017, DOI: 10.5772/intechopen.68583, https://www.intechopen.com/books/optical-fiber-and-wireless-communications/receiver-performance-improvement-in-radio-over-fiber-network-transmission
7. Singh R., Ahlawat M. and Sharma D. (2017): A Review on Radio over Fiber communication System, International Journal of Enhanced Research in Management & Computer Applications, ISSN: 2319-7471, Vol. 6, Issue 4, April-2017.
8. Yu J., Chang G.K., Kooning A.M.J. and Ellinas G. (2009): *Radio-over-optical-fiber Networks: Introduction to the feature issue*, Journal of Optical Networking, Vol. 8, No. 5, May 2009.
9. Zin A.M., Bongsu M.S., Idrus S.M. and Zulkifli N. (2010): An overview of radio-over-fiber network technology. International Conference on Photonics 2010, Langkawi, pp. 1-3.