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INVESTIGATION OF FIBER-WIRELESS (Fi-Wi) NETWORK: TRENDS AND FUTURISTIC

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ABSTRACT

In the present scenario, we need a technology which can support high bandwidth and seamless communication for both fixed and mobile clients under the single infrastructure. Fiber-Wireless (Fi-Wi) technology is a solution for the above said requirement. This technology converge various optical and wireless technologies under a single infrastructure so that we can get the benefits of high bandwidth (of the order of up to Gbps) and less cost. This paper reviews various developments carried out in the field of Fi-Wi Technology specifically, on Radio-and-Fiber (R&F) network integration. Future research challenges that should be explored in order to achieve a feasible Fi-Wi R&F architecture are also discussed.

Keywords: Fiber -Wireless (Fi-Wi), ONU, R&F

1. INTRODUCTION

It is the technology evolution, which give rise to new demanding applications, support and services. For these new demands, copper based access networks were not capable to support efficiently. Few examples of such requirements are IPTV (HD IPTV), Video-on-Demand (VoD) and Online Interactive Gaming, which require data rates up to tens of Mbps per client. This led many providers to seek alternative medium and infrastructure that would be able to provide such large bandwidth requirement. Since Optical Technology provides the high bandwidth, therefore many providers opted to use this technique. On the other hand, there was another technique in which wireless broadband access networks had attracted researchers due to its flexibility, mobility support and low implementation cost.

Optical networks offer a huge bandwidth capacity with the compromise in cost, whereas wireless networks offer mobility and ubiquity with the compromise in data integrity due to error-prone channels. Two approaches had been investigated the integration of Optical and Wireless Network; Radio-over-Fiber (RoF) and Radio-and-Fiber (R&F) [1]. The research work on RoF had been started since 1984 by the Military Electronics Division, of the TRW Electro Optics Research Center in California [1]. On the other hand, research on R&F Network started during the last decade.

In RoF Systems, RF signals modulate optical carrier signal in a Central Office (CO) are being propagated over an analog fiber link to Remote Antenna Units (RAUs) and are then transmitted to clients through the air as shown in figure 1.

Implementation of RoF is quite easy and cost effective because RAUs contain fewer components due to their simpler functionality. The

advantages of Fi-Wi network over other broadband access network are as follows:

1) Compare to Passive Optical Network (PON), Fi-Wi can provide wider coverage and better flexibility by Wireless Mesh Network (WMN) front-end which reduces the deployment cost.

2) Compare to WMN, Fi-Wi can provide higher bandwidth capacity and better stability by PON back-end and also reduces packet loss and interferences.

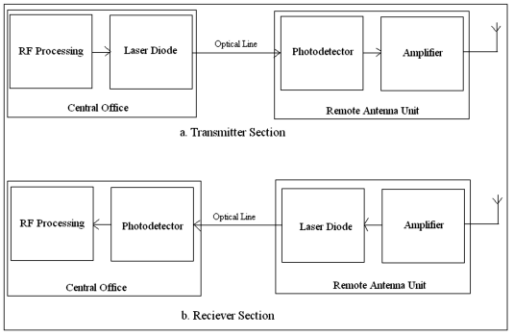


Fig.1 Radio-over-Fiber Transceiver Fi-Wi concept [1]

2. FI-WI Architecture & Technologies

Fi-Wi network has the tree-mesh architecture as shown in Figure 2. It has two ends, PON at back-end whereas WMN at front-end. In back-end, single Optical Line Terminal (I) drives various ONUs via feeder fiber, distribution fiber and Remote Node (RN). From ONU a wireless gateway is connected through wire. Various users located at premises and buildings in the front-end, can be connected to network through wireless router. If user wants to access internet the following steps are required to perform. First they sends packet to its nearby wireless router then router sends packet to its primary ONU via wireless gateway. ONU sends this packet to OLT via feeder fiber, distribution fiber and remote node. Finally OLT inject packet to internet backbone. In this fashion Fi-Wi provides user to access network with higher bandwidth capacity and better flexibility [2].

Fi-Wi access networks or Wireless-Optical Broadband Access Networks (WOBANs) integrate technical merit of both PON and WMN technologies [4]. Figure 2 shows the connectivity between various components like OLT, splitter, ONUs, wireless routers and user-end device in a Fi-Wi access network.

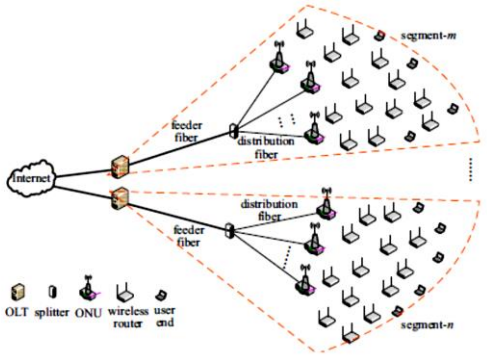


Figure 2: Fiber-Wireless Access Network [4]

A PON is a communication network in which single optical fiber is used to serve multiple premises achieved by the splitting action of splitters which do not require any external power for its working. It comprises with an OLT situated at the central office and a number of ONUs in premises of end users. In this way, PON reduces the amount of fiber required resulting in a less number of equipment requirement at CO. ONU reduces the work of central office in the network [3]. While, the WMN is a combination of various nodes like laptops, cell phones, etc. It is reliable and it also provides redundancy to the overall system.

3. Wireless-over-Fiber technology

Wireless-over-Fiber technology is the old technology which is implemented with different wireless signals transportation on optical link according to which it is called as RF-over-Fiber, IF-over-Fiber , Baseband-over-Fiber & Free Space Optical (FSO) [5,6]. The comparison of all four for signal-over-fiber transportation on the basis of quality, connectivity, advantages & limitations is shown in Table 1.

In PON, an OLT can connect up to 32 ONUs via Passive Splitter and one ONU connects several 802.11 Wi-Fi Access Points of end users, 802.16 WiMAX Base Station or both of them. A single fiber cable is required from OLT to the Splitter which is further spread up to 32 sub-cable connected to ONUs as shown in figure 3. This figure depicts the complete architecture of Fi-Wi Network [10].

Depending on the needs of the end user Service Provider choose the location of ONUs. In addition, Optical Network Terminal (ONT) is used as customer premises if Fiber to the Building (FTTB)

and Fiber to the Home (FTTH) Fi-Wi implementation type is chosen [10]. ONT is a device that interconnects the sub-cable of fiber coming from the ONU to coaxial cable that connects the Access Point.

Table1: A detail comparison of Wireless-over-Fiber Technologies

Wireless-over-Fiber Architectures / Parameters	**RF-over-Fiber [5]**	**IF-over-Fiber [5]**	**Baseband-over-Fiber [5]**	**Microwave-over-Fiber [9]**	**Free Space Optical (FSO) [6]**
Definition	In this technique, wireless signals are transported by an optical fiber network without any frequency translation at the remote Base Station (BS). It's having centralized control to CO.	In this technique, the signal transmission over fiber has been done by the down conversion of signal to the lower Intermediate Frequency (IF) at CO, before the transmission.	The scheme transports signal over fiber as baseband signal only & then up-converts it to the radio frequency needed at the BS antenna. Due to air interface dependency it requires additional hardware at CO.	In this, modulation of wireless signal is done using an optical carrier frequency. In this, two types of subcarriers are used one is wireless subcarrier which is on another subcarrier called as optical sub-carrier. This technique mainly used for PON & Wi-MAX system integration.	This provides point-to-point communication i.e. direct line of sight (LOS) optical communications for modulating visible as well as IR beams. Its less used technique compared to others.
Quality	Normal as it is a simple technique	Good	Good	Good	Good for LOS
Connectivity	Point-to-point & point-to-multi point communication in full duplex mode	Point-to-point & point-to-multi point communication in full duplex mode	Point-to-point & point-to-multi point communication in full duplex mode	Point-to-point & point-to-multi point communication in full duplex mode	Point-to-point communication in full duplex mode
Advantages	Simple, air-interface independency	Overcome chromatic dispersion, use low speed optoelectronics devices [7]	Use low cost optoelectronics devices	Simplified handover operation, used with digital optical link which makes it cost effective [8].	High bandwidth over short distances
Limitations	Suffers from chromatic dispersion [7] & slow in speed	BS complexity, reconfiguration issues	Air-interface dependent, BS complexity	Crosstalk problem in the subcarriers and interference issues in the optical subcarriers	Less number of users can be serviced, only for small distances (around 10km)

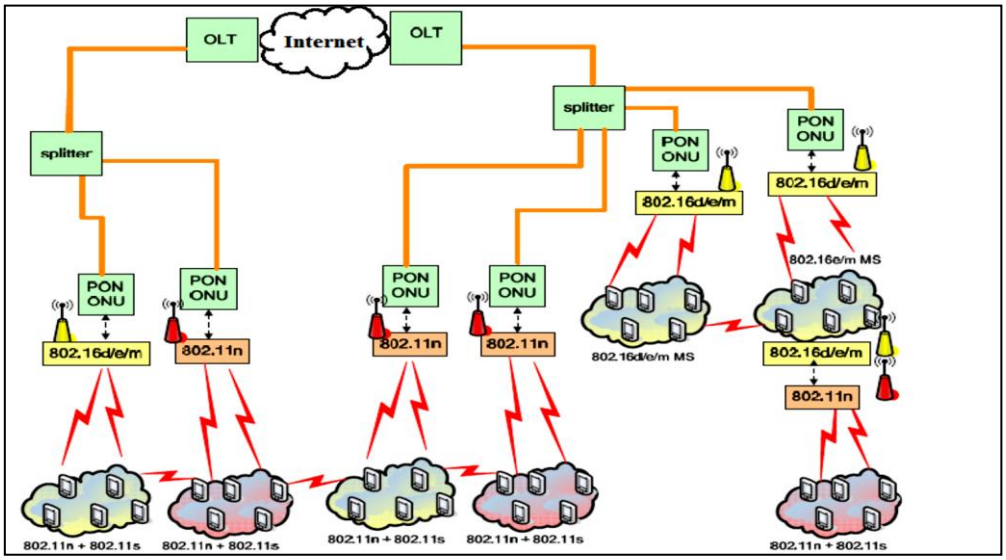


Figure 3: FiWi Network: Complete Architecture [10]

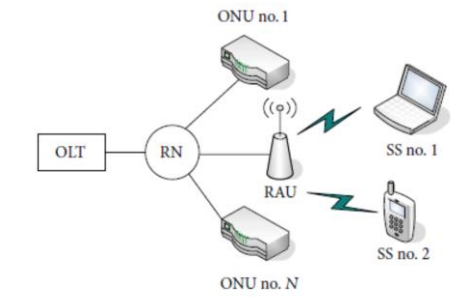
4. **Wireless-and-Fiber Technology**

The Wireless-and-Fiber technology is the R&F Technology, which is the most useful and widely used technology as it is highly suited for Fi-Wi architecture for high coverage [16]. The R&F technology is the latest one which uses the concept based on decentralization with the use of ONU. It basically uses two different MAC protocols for the PON & WMN separately, which overcomes the problem of high traffic on CO arrived in RoF [17]. The ONU-BS reduces the working of CO by performing the protocol translation resulting in reduction of traffic load by the user on CO [3]. It also provides the survivability during the failure of the optical link [1]. This benefit is very advantageous. Further it is advantageous in terms of reduced Complexity of CO because in the presence of ONU-BS, there is no need to transport wireless MAC frames always via the optical link to CO for Communication. It just has to pass through the access point related with it. Besides with the use of two MAC protocols, R&F also have distributed processing with storage capabilities and can perform additional functions which are not possible with RoF. It is advantageous to implement R&F technology with the use of ONU-BS, but it increased the overall cost of the system. Therefore many researchers are engaged in the research work, where they are exploring the possibility of reducing the cost of the system by best suitable placement of ONUs. Proper placement of ONU may reduce the required number of ONU resulting in a cost reduction.

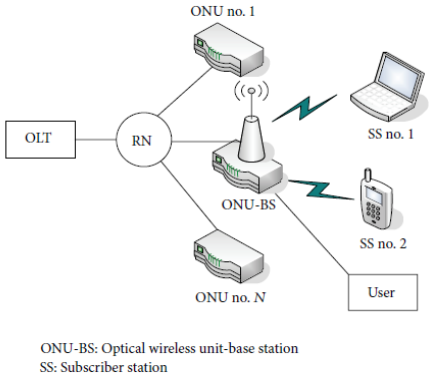
The comparison between the two leading technologies used in Fi-Wi networks i.e. RoF and R&F is shown in Table 3. The comparative architectural view of both the technologies is shown in figure 4.

Table 2: Comparison between RoF and R&F

Architecture	Service Quality	Advantages	Limitations
Radio-over-Fiber (RoF)	Good	Low attenuation loss at fiber end, Low power consumption, Cost efficient	Low network performance due to fiber propagation delay
Radio-and-Fiber (R&F)	Enhanced quality over RoF	Less propagation delay, extended network coverage	Cost of ONU is very high



(a)



(b)

Fig. 4: (a) Radio-over-Fiber (b) Radio-and-Fiber [17]

5. Passive Optical Network (PON)

PON Network has two major types that can be combined with Wireless Networks which are EPON and GPON. Below are the two types of PON with small description for each.

Ethernet Passive Optical Networks (EPON)

EPON is standardized by IEEE 802.3ah EFM in 2001 and ratified in 2004 [15]. All packets travelling in EPON are encapsulated in Ethernet frames. The maximum distance it can reach is 20 km [14]. In addition, several different configurations are allowed in EPON network such as Tree, Ring, and Bus Topologies. EPON can support downstream and upstream rates up to 1000 Mbps [14].

Gigabit Passive Optical Networks (GPON)

GPON is standardized by ITU-T G.984.1 in March 2003 [1]. It can support different types of data (ATM, Ethernet, and TDM) which results in providing downstream rate of 1.25 / 2.488 Gbps and upstream rate of 155/622/1244/2488 Mbps [14]. The logical distance that GPON can reach is 60 km but physically the maximum distance is 20 km [14]. Table 1 shows the features of EPON and GPON briefly.

Table 3: Features of EPON and GPON [14]

	EPON	**GPON**
Standard	IEEE802ah	ITU G.984
Data Packet Cell Size	1518 byte	53 to 1518 bytes
Maximum Downstream Line Rate	1.2 Gbps	2.4 Gbps
Maximum Upstream Line Rate	1.2 Gbps	1.2 Gbps
Downstream wavelength	1550 nm	1490 nm and 1550 nm
Upstream wavelength	1310 nm	1310 nm
Traffic Modes	Ethernet	ATM Ethernet or TDM
Voice	VoIP	TDM
Video	1550 nm overlay/ IP	1550 nm overlay/ IP
Maximum PON Split	32	64
Maximum Distance	20 Km	60 Km
Average Bandwidth per User	60 Mbps	40 Mbps

6. **Downstream and Upstream Traffic of PON in Fi-Wi Network**

In PON networks, the upstream and downstream traffic travels through the feeder single fiber cable as shown in figure 5. The Downstream Traffic is Point-to-Multipoint whereas the Upstream Traffic is Multipoint -to-Point. It means that in case of the Downstream Traffic the data flow from OLT to ONUs where each ONU manages the bandwidth of its sub-fiber cable connected to Passive Splitter towards OLT. For Upstream Traffic, the data flow from different users through ONUs towards OLT. However, an ONU is unable to detect other ONU's transmission which

leads to data collision [11]. This problem is sort out by using Time Division Multiplexing (TDM) scheme which is a channel separation mechanism to share the bandwidth properly [1].

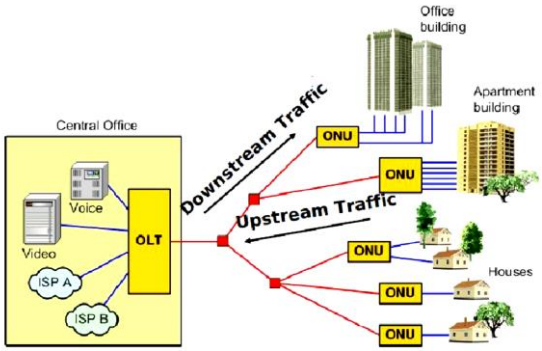


Figure 5: Downstream and Upstream of PON [12]

For Downstream Traffic, all ONUs receive broadcasted downstream traffic and then each ONU filters the data frames by destination addresses [13]. OLT divides traffic into time slots using TDM as it can be shown in figure 6.

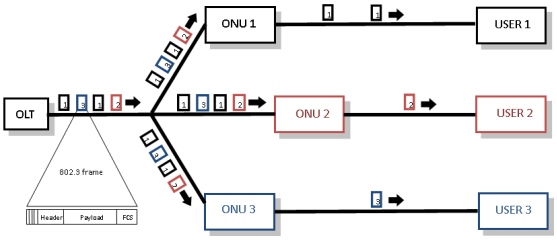


Figure 6: Downstream Traffic in PON [13]

For Upstream Traffic, all ONUs connected to the specific OLT share the same upstream channel. To avoid collision happens in Passive Splitter, Time Division Multiplexing Access (TDMA) scheme is used to slice upstream time and assign it frames as it is clarified in figure 7 [13].

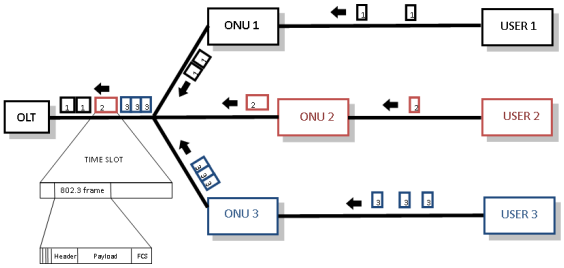


Figure 7: Upstream Traffic in PON [13]

7. FI-WI NETWORKS

Extensive research done in the field of RoF and R&F, Fi-Wi came into the limelight. It is the combination of wireless access technology (e.g. cellular, Wi-Fi & Wi-Max) with the optical infrastructure.

By integrating (EPON) and Wi-MAX access network, worldwide interoperability for Microwave Access (Wi-Max) is possible. Based on the IEEE 802.16 standard, Wi-Max is an access technology having a bit rate of 2.5/1.25 Gbps and wavelength 1490/1310 nm [18], using TDM-PON technology. It can provide maximum data rates up to 75 Mbps within the limited range of 5 Km [19]. In general two technologies can be used for this implementation: Passive Optical Networks (PONs) and Active Optical Networks (AONs). Both terminate to an Optical Network Terminator (ONT) residing on a single client's premises or an Optical Network Unit (ONU) in the case of a building or office where multiple clients exist. ONUs are more complicated devices and therefore more expensive than ONTs.

8. CONCLUSIONS

At present more and more proposals on Fi-Wi based communication system is coming out from both researchers and some private laboratories. This indicates the latest trends in the field of modern communication engineering. Various issues are still open for researchers in order to improve and get the optimum outcome by using this technology. A lot of benefit has already taken such as high bandwidth and comparatively less cost. Moreover the technology is useful and applicable were it is difficult to lay down the optical fiber cable between the two ends. Reducing the number of ONUs required in system by changing the placement of it can be another area of interest to explore. This can reduce overall cost of the system.

In the present scenario, it is obvious that the bandwidth demand will be increased exponentially as clients asking for high speed data rate seamlessly. Therefore both optical and wireless technologies are involved and used together in the form of Fi-Wi Network. This technology provides high broadband accessibility to both fixed and mobile client. Survivability is another area which is very important since failure at any point in the network will result in great data loss.

In addition, issues like peer to peer communication and multicasting which save network resources improve user mobility and therefore efficient

handover schemes and energy consumption are playing vital role nowadays. Before deployment of any new technology it is obvious that all the issue must be explored thoroughly. Therefore a scope is always there to investigate the issues and optimize the system again and again for further improvements.

9. Futuristic

After arising Fi-Wi access network technology the area of investigation has been broaden. Nowadays the researchers are exploring on Future Smart Grid Concept for Fi-Wi to improve Fi-Wi communication system. Issue of Green Survivability, energy saving and cost reduction techniques are the area of interest in which researchers can explore ample of possibilities. In future 5G mobile network which works on decentralization based on cloudlets, intelligent BS and Mobile Edge Computing (MEC), the R&F technology becomes the priority for Fi-Wi networks.

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