Integrated Optical Wireless Network For Next Generation Wireless Systems

Dr. Aditya Goel adityagoel2@rediffmail.com
Department of Electronics and Communication Engineering,
Maulana Azad National Institute of Technology, (Deemed University);
Bhopal. (MP) – INDIA, 462051

Er. R. K. Sethi sethirk@hotmail.com
Department of Electronics and Communication Engineering,
Maulana Azad National Institute of Technology, (Deemed University);
Bhopal (MP) – INDIA,462051

ABSTRACT

The demand of bandwidth in mobile communication is growing exponentially day-by-day, as the numbers of users have been increased drastically over the span of last five years. The next generation wireless communication systems therefore need to be of higher standards, so as to support various Broadband wireless services- such as, Video conferencing, mobile videophones, high-speed Internet access etc. The existing wireless systems can hardly provide transmission capacity of the order of few Mbps. However, millimeter (mm) waves and optical fiber technology has the potential of providing data capacity of the order of Mbps and Tbps respectively. Therefore the requirements of broadband wireless system can be met through the integration of optical fiber and millimeter wave wireless systems.

In this paper we suggest a modified millimeter wave wireless system using orthogonal frequency division multiplexing (OFDM) technique, integrated with optical fiber as a feeder network. Here we have investigated how well OFDM performs when transmitted over the wireless channel and multi mode optical fiber (MMOF) channel for various S/N values & fiber length respectively. Simulated performance shows that as the SNR is increased the signal gets less affected by noise; hence there will be fewer errors in decoding. For SNR greater than 12 dB, there is no significant difference observed in the received constellation. Therefore, it is not recommended to increase the SNR above 12 dB, as it results in unnecessary enhancement of the system complexity.

When simulated results of Fiber are compared with AWGN channel, it is observed that the performance of MMOF link even for distance of 100 KM is better than that of the AWGN channel with SNR of 50 dB & above, due to the better transmission capabilities of Optical fiber.

Keywords: Fiber radio networks, Additive White Gaussian Noise (AWGN), multimode optical fiber (MMOF), orthogonal frequency division multiplexing (OFDM).

1. INTRODUCTION

Present day's wireless systems are undergoing rapid technological changes. Development of a variety of handheld devices, like Mobiles, PDAs, IPODs etc have revolutionized the wireless communication system. Under the present scenario, the requirement in telecommunication is the development of high capacity wireless network. Though data broadcasting is already on the air for quite some time, the multimedia aspects was not explored until recently. Due to ever-increasing bandwidth demands in future wireless service, the radio frequency band becomes more and more invaluable. The present days wireless systems, based on cellular structure, have historically been designed with voice traffic in mind. Presently second generation (2G) of network is operating and third generation (3G) is almost implemented. The third generation 3G systems provides a significantly higher data rate (64 Kbps– 2 Mbps) as compared to 2G systems (9.6–14.4 Kbps), The spectral efficiency of 3G networks is too low to support high data rate services at low cost, limiting the usefulness of such services.

The next generation wireless communications systems need to be of a higher standard so as to support various Broadband wireless services, such as HDTV (4-20 Mbps), Video conferencing, mobile videophones, high-speed Internet access, computer network applications (1- 100 Mbps), and potentially many multimedia applications at a significantly reduced cost, in comparison with 3G networks. The existing wireless systems can hardly provide transmission capacity of the order of few Mbps. To deliver multimedia/ broadband signals at remotely distributed cells, wireless transmission channels are no more able to fulfill the demands of higher bandwidth. For exploiting the wideband capabilities of the mobile/wireless network, researchers have observed that millimeter (mm-wave) waves when transmitted can provide very high bandwidth. Although, due to high attenuation losses (16 dB/km) at 60 GHz , the overall transmission distance is limited to a relatively shorter span.

Optical fiber is well known as a transmission media with an enormous transmission capacity of about 4 Tbps for the 1.55-μm-wavelength region where erbium doped fiber amplifiers (EDFA) are most effective. Millimeter waves and optical fiber can therefore provide data capacity of the order of hundreds of Mbps and Tbps respectively. Hence the requirements of broadband wireless system can be achieved through the integration of optical fiber and millimeter wireless systems. We suggest modified wireless system with optical fiber as feeder network as an up gradation of existing wireless network in terms of transmission capability.

An integration of optical and wireless network suggests an excellent cost effective means for transmitting various wideband applications. For enhancing the capacity of the existing network we have to investigate various aspects of integrated fiber radio network so that data carrying capacity can be increased at an acceptable level. Millimeter-wave wireless systems employing fiber Feeds are seen as having the potential to provide bit Rates in excess of 500 mbps to both mobile and fixed Users by Noel et al in [3]. However he has not taken into consideration multi mode Optical Fiber, we explore the possibility for MMOF. Similarly A J Cooper et al have used radio over optical network to the radio access point as demonstrated in [5] however the overall capacity was limited due to the low frequency of the carrier signals. In most of the above approaches either the low frequency carrier was used or the high frequency milli-meter wave without the integration with MMOF has been demonstrated.

In this paper we explore the possibility of employing OFDM modulation techniques for 60 GHz integrated wireless MMOF optical system. When carried out the performance analysis it has been observed that an integrated fiber radio network is a cost effective media for higher data rates (>100 Mbps). This has been demonstrated and discuss in detail in section 5.

2. INTEGRATED OPTICAL WIRELESS SYSTEM

Millimeter wave radio access is a promising technology for the next generation wireless network services in fixed access and mobile applications. In such systems, the radio frequency (RF) signals can be generated at a central office (CO) and distributed to remote antenna sites using optical fibre links. This optical distribution system enables small and functionally simple radio base stations (BSs) to be implemented. We will therefore investigate modified wireless communication system with optical fiber as feeder network for up gradation of existing wireless network, which is capable of supporting data rates of the order of Gbps.

Because in the wireless environment fading usually impairs signals and multipath delay , traditional single carrier mobile communication systems do not perform well. In such channels extreme fading of the signal amplitude occurs and Inter Symbol Interference (ISI) multipath effects due to the frequency selectivity of the channel appears at the receiver side. This leads to a high probability of errors and the system's overall performance becomes very poor. Techniques like channel coding and adaptive equalization have been widely used as a solution to these problems. However, due to the inherent delay in the coding and equalization process and high cost of the hardware, it is quite difficult to use these techniques in systems operating at high bit rates, for example, up to several Mbps.

A promising solution is to use a multi carrier system like OFDM, a modulation scheme that allows broadband transmission in a frequency selective multipath environment efficiently and reliably. The resilience of OFDM to multipath fading in the RF channel suggests that it may also be tolerant to the effect of dispersion in MMOF, thus permitting the use of OFDM in optical fiber channels. In order to overcome the significant problems of multipath fading for high bit rate signals in a mm wave wireless environment they will have to be compatible with the fiber back bone.

2.1 Optical wireless system

Integrated fiber radio system based on mm wave radio systems have much lower cost of the infrastructure than the currently used systems [5], where radio signals at the carrier frequency are delivered over an optical network to the radio access point. At 60 GHz there is an absorption peak (16dB/km), which can be selectively exploited to limit signal propagation beyond the micro cell boundaries. Fiber optic transmission lines have almost negligible loss (0.15 dB/Km at 1550 nm) for lengths less than one kilometer. The system control function can be located within central base station, thus reducing the size, complexity, and power requirements of the remote hubs [10].

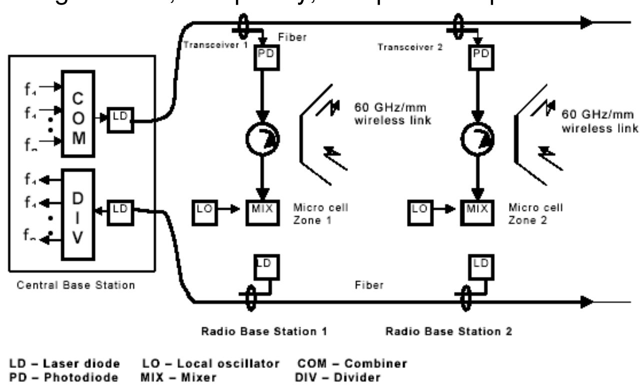

Fig.1 Conceptual diagram of fiber radio system

The system concept of the fiber optic mm wave sub carrier transmission link [3][4] is shown in Fig 1. A large numbers of modulated mm wave sub carriers are combined electrically by power combiners. The optical carrier is intensity modulated by this composite signal, transmitted by fiber, and is then optically divided at each radio base station. The tapped optical signal is directly detected by a high frequency photo detector and amplified by monolithic microwave integrated circuit (MMIC) amplifier. The amplified mm wave signals are subsequently radiated into the micro cell zone (down-link) and received by portable communication terminals. Each radio base station also receives mm wave signals from the portable terminals and down converts them to Radio frequency by using a frequency converter and local oscillator signal. The down converted signals are used to intensity modulated a relatively inexpensive and low frequency laser diode. The optical signal from each radio base station are combined and then transmitted back to the central base station over optical fiber. The received optical signals are detected amplified and de-multiplexed.

3 PERFORMANCE ANALYSIS OF AWGN & MMOF CHANNEL

To analyse the performance of OFDM over an Additive White Gaussian Noise (AWGN) channel, and multimode optical fiber (MMOF) channel, the channel models discussed here has been simulated using MATLAB codes.

3.1 AWGN WIRELESS CHANNEL

In AWGN channel model, depending on the level of the signal, noise is added to get desired signal to noise ratio (SNR). The output signal Y of the channel model is described as a function of the input signal X: Y = AWGN (X, SNR) (1)

FIGURE 2

Y = AWGN (X, SNR)

3.2 OPTICAL FIBER CHANNEL

For the modeling of α-profile multimode fiber channel we have used the results described in [1],[2]. In this analysis, we consider the class of α-profile multimode optical fibers with negligible mode mixing. Also propagation of cladding modes is assumed negligible. In addition we assumed that fiber is relatively loss less. Finally, we assumed that the dispersive effects due to the material and wave-guide phenomena are small compared to the modal dispersion. Additionally we assumed in our model that there is no modal dependent or bulk attenuations of the input field amplitude as it travels down the fiber i.e. β_m (the propagation constant for mth mode) is a real constant.

For MMOF channel, the output intensity spectrum I_o (f) of the channel in terms of the input intensity spectrum I_i (f) is:

I_o(f) = $[H(\Omega)]^2$ **Ii(f) (2)**

Where H (Ω) is field intensity transfer function. The $[H(\Omega)]^2$, magnitude squared of field intensity transfer function is required in order to relate the input field intensity spectrum to the output field intensity spectrum. From the proposed work [1] & [2], this has been found as:

$$
\begin{aligned}
&|H(\Omega)|^2 = \\
&\{(((2-\in)/2)\cos(\in-2)^2\Omega).\sin c((2-\in)\Omega) \\
&\quad + (2\pi \in^2 /64\Omega)[C(\xi_1)+C(\xi_2)]\}^2 \\
&\quad + \{((2-\in/2)\sin((\in-2)^2\Omega).\sin c((2-\in)\Omega) \\
&\quad + (2\pi \in^2 /64\Omega)[S(\xi_1)+S(\xi_2)]\}^2
\end{aligned}
\qquad (3)
$$

; Where $\xi_1 = (\in^2 \Omega / 2\pi)^{1/2}$ (4)

$\xi_2 = [(\in^2 \quad 4)^2 \Omega / 2\pi)^{1/2}]$ (5)

$C(x) = \int_0^x \cos(\pi\tau^2/2)d\tau$ (6)

$S(x) = \int_0^x \sin(\pi\tau^2/2)d\tau$ (7)

$\Omega = \Delta^2 T_0 \pi f / 4$, & $T_0 = zn_0/c$ (8)

This assumes a straight multimode fiber of length Z and index of retraction profile:

$$n(r) = \begin{cases} n_o \left[1 - 2\Delta(r/a)^{\alpha}\right]^{1/2} & r < a \\ n_o (1 - 2\Delta)^{1/2} & r > a. \end{cases} \quad (9)$$

Where $\Delta = \dfrac{n_o^2 - n_{cl}^2}{2n_{cl}^2}$ (10)

$\alpha = 2 - \in\Delta$, for $0 < \in < 4$; Where ε is the small variation around the optimum value. Where Δ is typically .01. Here, we are interested in the behavior of the channel when α is optimum. Also from (2) we know that α achieves its optimum value α_0 at $\varepsilon = 2$, i.e., $\alpha_0 = 2 - 2\Delta$.

4. IMPLEMENTATION

This research work is concerned with how well OFDM performs when transmitted over an AWGN channel integrated with MMOF channel. In order to evaluate this, a software simulation of OFDM modulated data; based on the 2K mode of DVB-T has been carried out using MATLAB codes. The 2K mode of DVB-T is intended for mobile reception of standard definition DTV [8], [9]. DVB-T is a flexible standard using OFDM, where the terrestrial network operator can choose any combination of, Number of carriers (8k/2k), Guard interval (T/4,T/8.T/16,T/32), Constellation (QPSK/16QAM/32QAM), Convolution code rate (1/2,2/3,3/4,5/6,7/8) [12]. The transmitted OFDM signals organized in frames, with each frame of TF, and consist of 68 OFDM symbols.

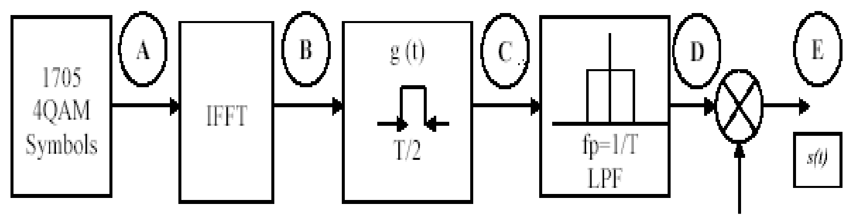

FIGURE 3: OFDM system generation simulation

Four frames constitute one super frame. Each symbol is constituted by a set of K=1705 carriers in the 2K mode & transmitted with a duration Ts. (Ts=Tu+Δ.).

A block diagram of the generation of one OFDM symbol is shown in Fig-3, where we have indicated the variables used in the MATLAB code. The generation of the OFDM signal consists of blocks labeled - QAM symbols(for generating 1705 symbols), IFFT (converts frequency domain to time domain), transmit filter g(t) (Produce continuous time signal), Butterworth LPF (Order 13 – to generate baseband signal), Quadraure amplitude multiplier (to generate transmitted signal s(t)) .The real part of the signal s (t) is centered on the RF transmit carrier frequency *f*c.

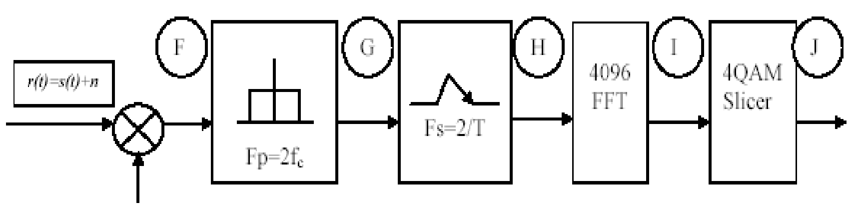

FIGURE 4: OFDM receiver

The OFDM signal transmitted over the AWGN channel for various signal-to-noise ratio (SNR) values and over the MMOF channel for various length of fiber. Simulations have been carried out for AWGN and optical fiber channels using MATLAB code, so as to compare their individual performance.

The reception process is straightforward the received OFDM signal is first low pass filtered to get the corresponding base band signal and sampled as shown in Fig 4.0.. The output of the FFT Modulation block is the received constellation. This is then passed through a 4QAM slicer, which assigns the received symbols into the four possible constellation points. The constellation plots of the received symbols and the original transmitted symbols were compared to show the simulated OFDM performance over the channels.

4.1 Multimode Fiber Optic Channel

The channel model for MMOF is used as mentioned in section 3.2. important parameters of multimode fiber are: Length of the fiber, and α= 2- 2Δ; for ε =2. We have taken the refractive index of core n_0=1.5 and Δ= .01.

4.2 Validation

Magnitude square frequency response, i.e. equation (3) is plotted in Fig. 5(a) as functions of normalized frequency [1]. The magnitude squared frequency response, i.e. equation (3), simulated using MATLAB code, is plotted in Fig. 5(b) as functions of normalized frequency. Here we performed analysis for the optimum value of alpha i.e. α=2-$\varepsilon\Delta$, for the value of ε equals to 2. The simulated result i.e. Fig. 5(b) is compared with the reported result i.e. Fig. 5(a), and found in agreement to the reported result

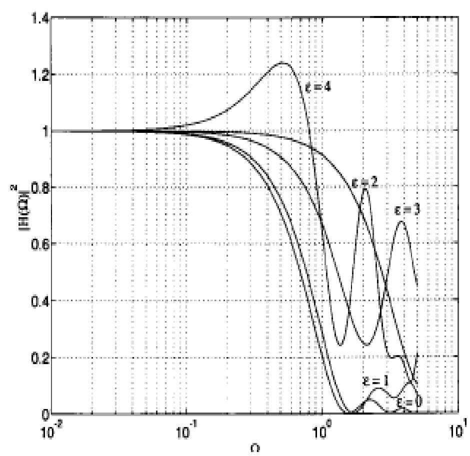

Fig.5 (a) Magnitude squared frequency response v/s normalized Frequency

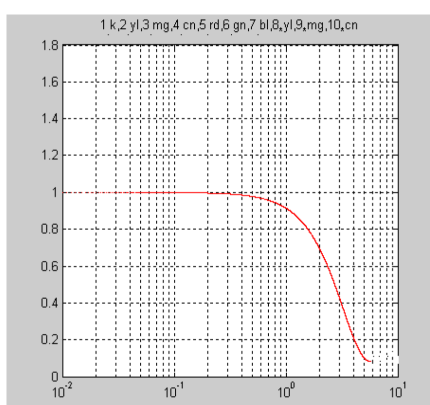

Fig.5 (b) Magnitude squared frequency response v/s normalized Frequency [MATLAB Simulated]

5 RESULTS & DISCUSSIONS

For the performance evaluation of OFDM over AWGN and MMOF channels a comprehensive simulation has been carried out using MATLAB. The OFDM signal was transmitted over the AWGN channel for different SNR values and over the MMOF channel for different lengths of fiber. To evaluate the performance, the constellations plots for the received data were compared to the constellations plots of the original transmitted data.

5.1 Wireless AWGN Channel

To evaluate the performance of wireless AWGN channel the OFDM modulated signal is transmitted over the AWGN channel for various SNR values. The received signal after demodulation is plotted as constellation plots. The AWGN channel introduces the noise in transmitted signal, resulting in a noisy QAM constellation. For each SNR values, the constellations plots for the received data were compared to the constellations plots of the original transmitted data, as shown in Fig 6.

The received constellation plots are shown in, Fig.7 (a), 7 (b), 7 (c), and 7 (d), for corresponding SNR values of 2 dB, 6 dB, 12 dB, and 50 dB respectively.

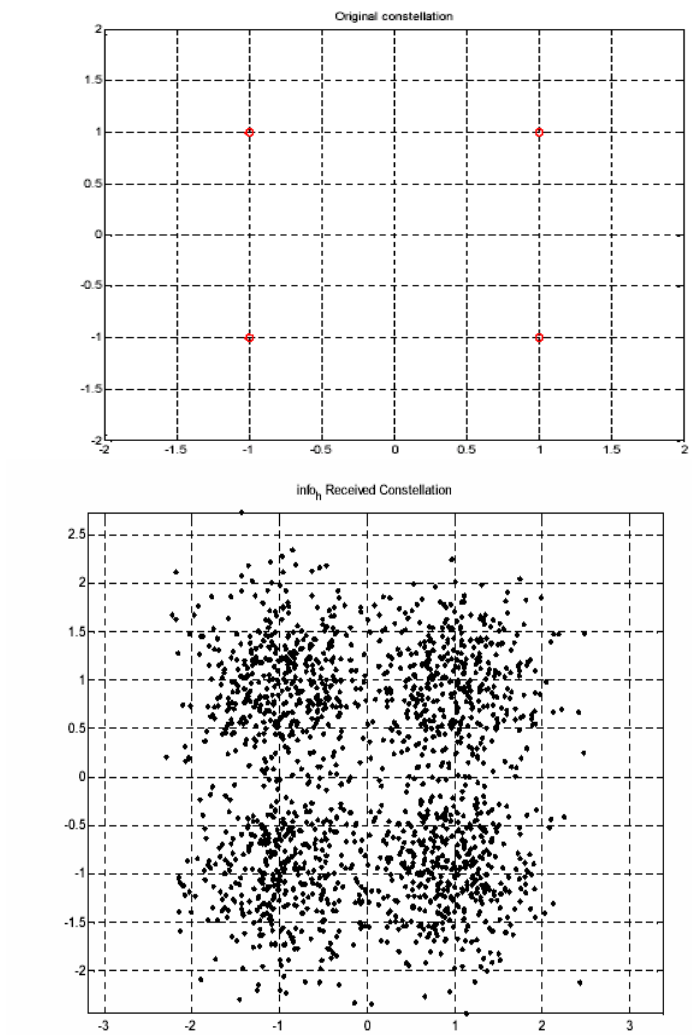

Fig-7(a) Received 4-QAM constellation for AWGN for SNR=2dB

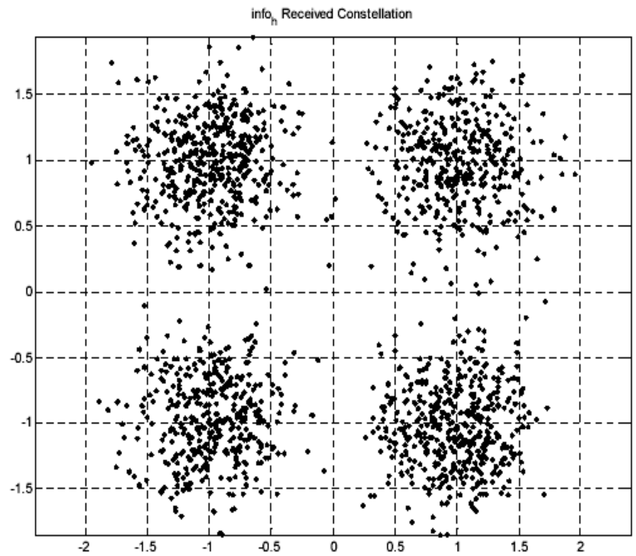

Fig-7(b) Received 4-QAM constellation for AWGN for SNR=6dB

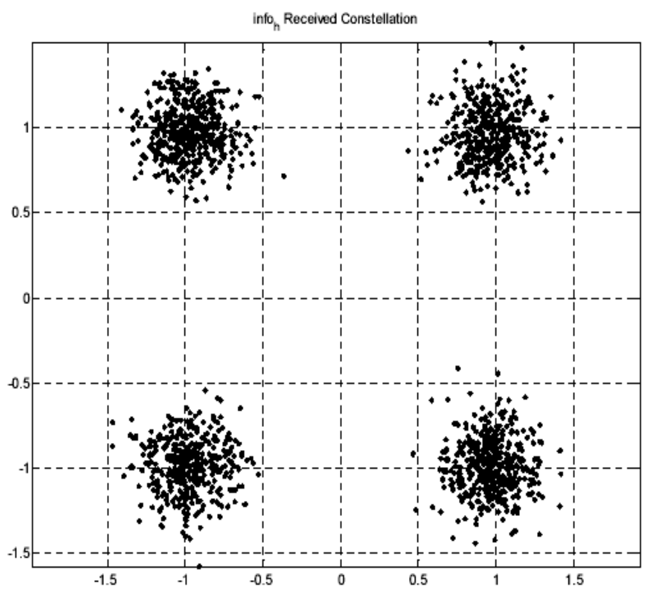

Fig-7(c): Received 4-QAM constellation for AWGN for SNR=12dB

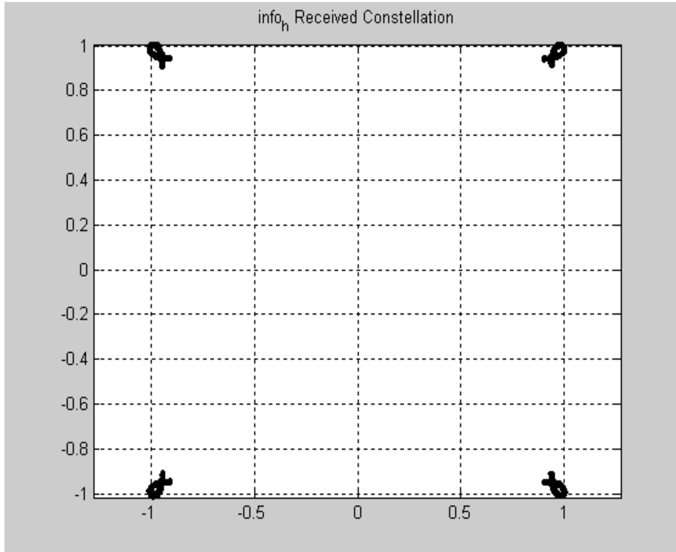

Fig.-7(d): Received 4-QAM constellation for AWGN for SNR=50 db

It is evident from the received constellation plot that for small values of the SNR (2 dB or less), due to the high relative noise power, the symbols are scattered and interfere with adjacent symbols. As the SNR is increased the signal gets less affected by noise; hence there will be fewer errors in decoding. For SNR greater than 12 dB, there is no significant difference observed in the received constellation. So, it is not advisable to increase the SNR above 12 dB which ultimately increases the system complexity

From the above analysis we conclude that for SNR>12dB the performance is relatively tolerable, which further depends upon the application requirements.

5.2 Multimode Optical Fiber Channel

Performance has been evaluated for the optimum value of alpha profiles (i.e. α =2-2Δ), for different lengths of fibers. The received constellation plots for different length of the optical fiber are shown in Fig's 8(a), 8(b), 8(c), and 8(d) for corresponding fiber lengths 1, 1 to10, 20, and 10 to 100 km respectively. The plots show that the received constellation patterns are nearly the same. Also it shows that, as the length of the fiber is increased, there is no noticeable change

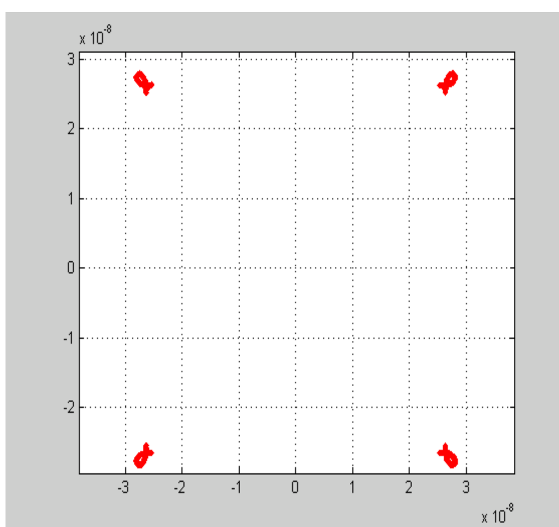

Fig.8 (a): Received constellation for the Fiber length1Km

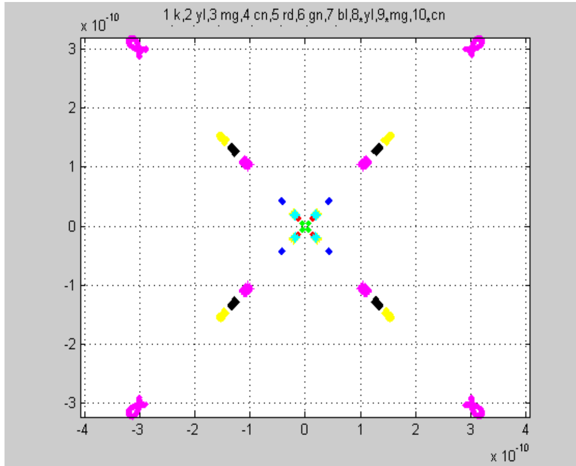

Fig.8 (b) Received constellation for the fiber length, from 1 Km to 10 Km.

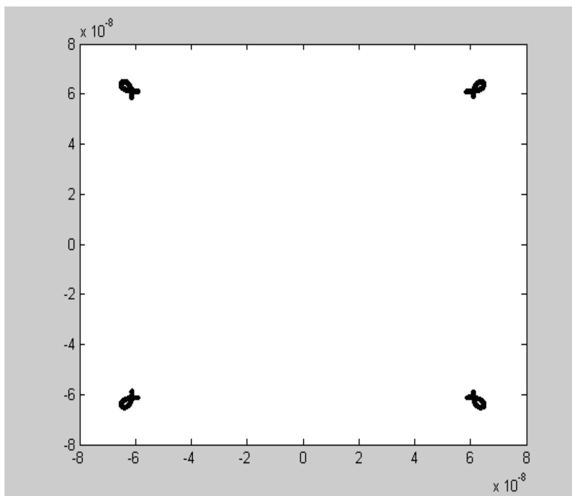

Fig.8 (c) Received constellation for the fiber length 20 km

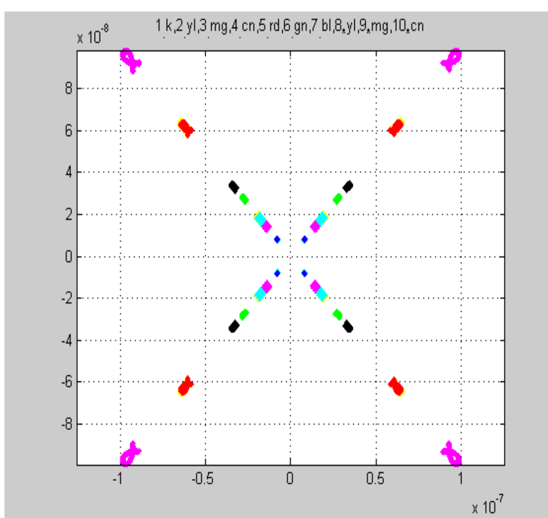

Fig.8 (d) Received constellation for the fiber length from 10-100 km in the received constellations pattern only the distance from the origin varies. These received constellation patterns are as good as the pattern received for the AWGN channel for the values of SNR greater than 50 dB. Since the optical fiber have very high transmission capacity, so for long distances (up to 100 Km) , it is suggested that MMOF link, with the optimum profile (i.e. α = 2-2Δ,) with OFDM modulation can be used. For short distance wireless link with OFDM modulation can be used. The comparisons of the results also show that the performance of the optical fiber links even for distance of 100 KM is better than that of the AWGN channel.

Also the received constellation patterns obtained with MMOF channel, shown in Fig.9 (a), are of similar pattern, when compared with those obtained with AWGN channel with SNR of 50 dB as shown in fig.9 (b). These suggest that the optical fiber is definitely an excellent transmitting media especially for high data rate long distance communication. Hence, an integrated fiber radio network is an excellent cost effective means for transmitting various wideband applications such as multimedia, video conferencing etc.

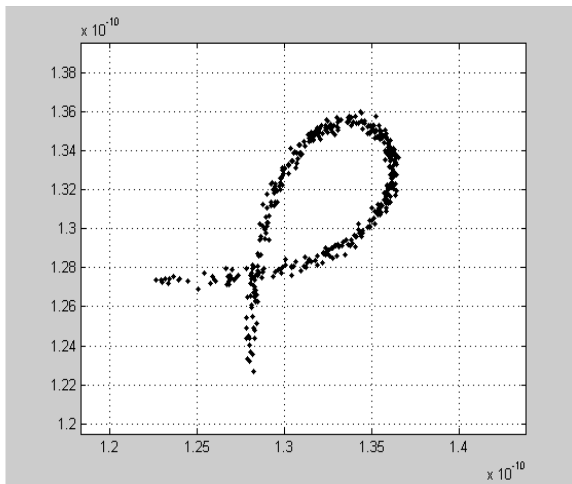

Fig.9 (a) Received 4-QAM constellation patterns for the fiber

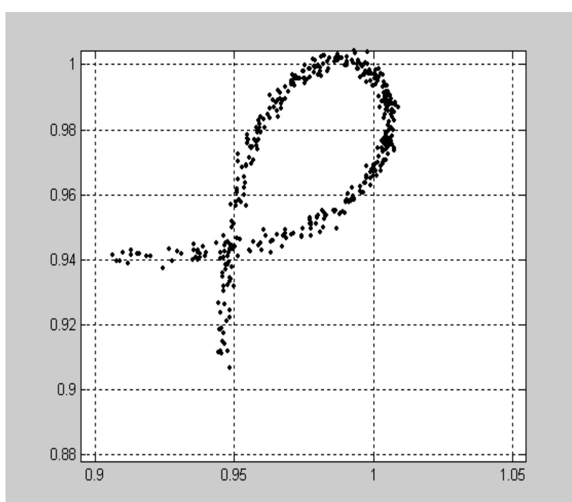

Fig.9 (b) Received 4-QAM constellation pattern for AWGN for SNR 60 dB

6. CONSLUSION

In this paper, we have investigated the modified wireless communication system with OFDM integrated with the alpha-profile multimode optical fiber (MMOF) for up gradation of existing wireless system. Simultaneous use of fiber optic distribution links and millimeter wave frequencies provide various advantages with in micro cellular systems. At 60 GHz there is an absorption peak (16dB/km), which can limit the signal propagation beyond the micro cell boundaries. Millimeter waves are essentially broadband frequencies, which can transmit a large number of video / voice sub carrier. Fiber optic transmission lines have almost negligible loss (0.15 dB/Km at 1550 nm) for lengths less than one kilometer. The high tolerance to multipath / frequency-selective effects makes OFDM more suited to high-speed data transmissions, in inexpensive multimode fiber.

Simulations have been carried out for AWGN and optical fiber channels using MATLAB code, so as to compare their individual performance. The OFDM signal was transmitted over the AWGN channel integrated with optical fiber channel for various S/N values. To evaluate the performance for each SNR level, the received signal was demodulated and the received data was compared to the original information. For small values of SNR the received constellation are noisy, however as the SNR increases, the received constellation patterns become better. It has been observed that with AWGN channel for a SNR value greater than 12 dB, there is no significant improvement.

Performance has been evaluated for alpha profile graded index MMOF, for different lengths of fiber. When compared it is observed that the performance of MMOF link even for distance of 100 KM is better than that of the AWGN channel with SNR of 50 dB and above.

For long distance it is capable of supporting the data rates in excess of 100 Mbps it is suggested that multimode graded index optical fiber link , with the optimum profile of (alpha=2-2*delta) with OFDM modulation can be used . However for short distance, wireless link with OFDM modulation can be used.The modified wireless communication system with multimode optical fiber as feeder network therefore suggests an excellent cost effective means for transmitting various wide band applications

REFERENCES

1. Ernest I. Walker. Senior member, IEEE "a model for the a-profile multimode optical fiber channels: a linear systems approach" journal of light wave tech., vol. 12, no. 11, November 1994.
2. D. Gloge and E. A. I. Marcatili, "multimode theory of graded-core fibers," bell system tech. j., vol. 52, pp. 1563-1578, Nov. 1973.
3. L. Noel, D. Wake, D. G. Moodie, member, , IEEE, D. D. Marcenac, L. D. Westbrook, and D. Nesset "Novel techniques for high-capacity 60-ghz fiber-radio transmission systems "IEEE trans. on microwave theory & tech., vol. 45, no. 8, Aug. 1997.
4. Hiroyo Ogawa, member, IEEE, David Polifko, member, ieee, and Seiichi Banba millimeter-wave fiber optics systems for personal radio communication IEEE trans. on microwave theory and tech. vol, 40, no. 12, December 1992
5. A.J. Cooper. "Fiber /radio for the provision of cordless/mobile telephony services in the access network" electron.lett. Vol.26, pp.2054-2056, 1990
6. Wlliam y. zou, yiyan wu, "COFDM: an overview", IEEE *trans. on broadcasting*, pp. 1-8 vol. 41, no. 1, march 1995
7. S. Lezekiel and N. Bourhill, "optical control of millimeter-wave p-hemt's with applications to fiber radio," in *int. topical microwave photon, meeting*, vol. 45, oxford, u.k, 2000.
8. U. Reimers digital "video broadcasting – current status, future developments" IEEE multimedia newsletter vol3 no-1 1995
9. Ulrich Reimers, digital video broadcasting, *ieee communications magazine*, June 1998, pp. 104 – 110
10. P. M. Lane, R. A. Griffin, H. M. Salgado, and J. J. O'reilly, "system capacity for millimeter-wave radio-over-fiber distribution employing an optically supported PLL," j. light wave techno. Vol. 17, pp. 2480–2487, Dec. 1999.

11. R. D. J. Van Vee et al., “new high-rate wireless LAN standards,” IEEE Commun. mag., vol. 37, pp. 82–88, Dec. 1999.
12. ETS 300 744, "digital broadcasting systems for television, sound and data services; framing structure, channel coding, and modulation for digital terrestrial television. European telecommunication standard, doc. 300 744 1997.
13. European radio communications office, detailed spectrum investigation.
14. Zhou, Wang and Liu analysis and modeling of a nonlinear radio-over-fibere system optical engineering 46_8_085001_august 2007.
15. Jianping Wang Xianwel Zhou Wenzhe Guo Xiao Liu university “modeling and linearization of nonlinear radio over fiber system “ optical engineering 47_2_025004_ Feb-2008
16. s. suchat, a,b w. khunnam,a and p. p. yupapin,b “quantum key distribution via an optical wireless communication link for telephone networks” optical engineering 100502-1 /vol 46_10 October 2007
17. Luong Hong Hai Takeshi Higashino Katsutoshi Tsukamoto Shozo Omaki “grouping methods for orthogonal frequency and space division multiple access in a radio on fiber radio space transmission system “ Osaka university optical engineering 46_9_95006 september 2007
18. Chang-Soon Choi, Member IEEE Vozo Shoji Member IEEE and Hiroyo Ogawa Fello “millimeter wave fiber fed wireless access systems based on dense wavelength division multiplexing networks” IEEE transactions on microwave theory and techniques vol 56 no1 January 2008