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Downlink System in Millimeter Wave with Fiber Optic Communication Using External Modulation of 60 GHz Band

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Abstract: *This paper emphasizes on the fiber-optic millimeter-wave downlink system using 60 GHz-band external modulation. It consists of an optical modulation section with a mm-wave signal generator, an optical single sideband (SSB) filter, a standard single-mode fiber (SMF), an optical detection section with a 60 GHz-band radio transmitter and a 60 GHz-band radio receiver. To modulate the laser output with 60 GHz-band mm-wave signals, a specially designed electro absorption modulator with 60 GHz is used. Radio-over-fiber (ROF) technology has larger bandwidth, reduced power consumption etc, for several communication systems. The generation of mm-wave wireless signal in base station (BS) using optical techniques is the key technical issue of mm-wave ROF systems. The three optical technologies to yield mm-wave signal, such as direct intensity modulation, optical self-heterodyning and orthogonal frequency division multiplexing (OFDM) will be introduced. This paper is to investigate the feasibility of the orthogonal OFDM used as modulation technique to transmit and receive the baseband signal over optical fiber. Laser diode and photodiode are modeled which are used as optical modulator and optical demodulator respectively. The result of the system is implemented with MATLAB/SIMULINK software.*

Keywords: *Electroabsorption modulator, fiber-optic mm wave Downlink system, External Modulator, Orthogonal Frequency Division Multiplexing (OFDM), MATLAB/SIMULINK*

1. INTRODUCTION

A millimeter-wave (mm-wave) is expected to be the promising and important frequency for future radio com- munication systems. In this paper, a fiber-optic mm-wave downlink system using 60 GHz-band external modulation is investigated by preparing the fiber-optic 60 GHz-band mm-wave downlink test bed. The specially designed with electro absorption (EA) modulator with high efficiency at around 60 GHz is the key to the external modulation. To support mm wave radio communication system such as a cellular system, a fiber-optic the transport of mm-wave signals between the central station (CS) and remote base stations (BS's) is very attractive and because it have to low transmission loss, extremely wide bandwidth, availability of optical amplifiers, low cost of whole system, and it consists of a CS, a fiber-optic access network, BS's and mm-wave wireless terminals (WT's) in picocells and indoor wireless local area networks (LAN's).

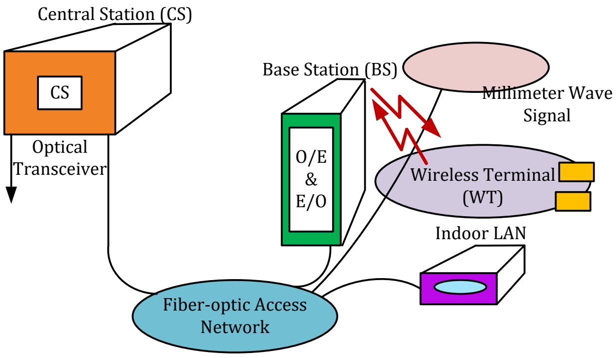

Fig -1: Fiber-Optic MM-Wave Radio Access Network

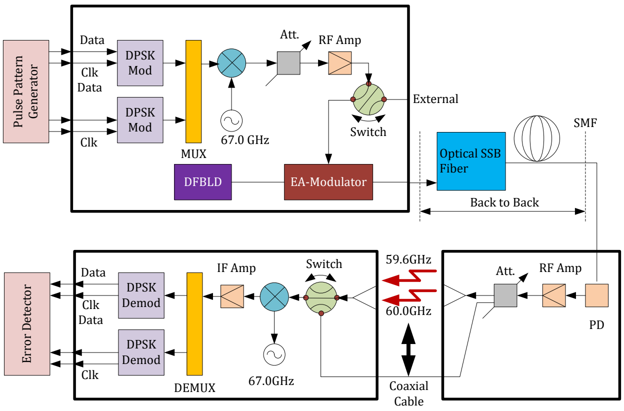

Fig -2: Configuration of Fiber-Optic 60 GHz-Band MM-Wave Downlink Testbed

The CS has the optical transceivers that controls and converts the signals between the fiber-optic networks. The base station (BS) which is an access point for the WT's, has the optic-to-electric (O/E) and electric-to-optic (E/O) converters with a mm-wave antenna, for the downlink and the uplink, respectively. The WT is mm-wave radio transceiver station which may be stationary or mobile. By concentrate on the fiber-optic downlink system for distributing 60 GHz-band mm-wave signals from CS to a number of BS's. In the downlink system, the BS requires a function of the O/E converter and the WT becomes a millimeter-wave radio receiver. The cost effectiveness and reliability of the BS are keys to accelerate the initial deployment. The external modulation techniques will fit best to these requirements, according to the assessments from the technical and economical points.

2. SYSTEM CONFIGURATION

The system configuration of fiber-optic 60GHz-band mm-wave downlink testbed is implemented. The testbed consists of the CS, an erbium-doped fiber amplifier (EDFA), an optical SSB filter, the 1.3 m standard SMF, the BS and the stationary WT. The CS is made up of two intermediate frequency (IF) DPSK modulators, an IF signal power combiner, a 57.0 GHz local oscillator (LO), a mixer for up-conversion, a mm-wave amplifier, a continuous wave (CW) distributed feedback laser diode (DFB LD) and the EA modulator module. The inputs of DPSK modulators are connected with a pulse pattern generator. The optical SSB filter consists of a Fabry–Perot etalon filter and an optical bandpass filter with 3 dB-bandwidth of 0.5 nm. The EDFA is used to compensate the optical insertion loss of this optical SSB filter. The 1.3 m standard SMF with a fiber propagation loss of 0.2 dB/km and a dispersion coefficient of 16.8 ps/nm/km at 1.55 misused in all fiber-optic transmission experiments. The BS includes only three components which are a high-speed p- i-n photodiode (PD), another mm-wave amplifier and a V-band pyramidal horn antenna. The WT has another antenna, another mixer for down-conversion, another 57.0 GHz LO, an intermediate frequency (IF) signal power divider and two IF DPSK demodulators. The outputs of DPSK demodulators are connected with an error detector. In the CS, two 155.52 Mb/s-DPSK IF-band signals (2.6GHz, 3.0 GHz) are combined and up converted to mm-wave signals (59.6 GHz, 60.0 GHz). The optical carrier of the DFBLD at 1.55 m is intensity-modulated with the subcarrier multiplexed mm-wave signals by the EA modulator. The modulated optical signal is launched to the SMF after the optical SSB filter. The received optical signal is detected by the PD. The recovered mm-wave signals are amplified and propagated from the antenna of the BS to another remote antenna of the WT. The received mm-wave signals are down converted, amplified and demultiplexed to two IF channels (2.6 GHz, 3.0GHz). Each IF signal is individually demodulated to regenerate the 155.52 Mb/s data and extract the clock.

2.1 External Modulation Using Electroabsorption (EA) Modulator

The EA modulator adopted in the testbed was specially designed to enhance the modulation efficiency at around 60 GHz. The EA modulator chip consists of an electroabsorption region and two passive waveguide regions monolithically integrated into both ends. The total length of the EA modulator was 370 m. The absorption region was a low-mesa ridge structure with an absorption layer using an InGaAsP/InGaAsP tensile strained multiple quantum well, and the length of the absorption region was 100 m. A core layer of both the passive waveguide regions was made with an In-GaAsP bulk. EA modulator module is packaged, including an impedance-matching circuit for a mm-wave input, lenses, fibers, a thermoelectric cooler (TEC) and a thermistor. The impedance-matching circuits of double open stub type were formed to enhance the frequency response for the mm-wave input. The size of module is 13(D) 21(W) 11(H) mm3 and it is connected with a polarization maintaining fiber (PMF) for the input and an SMF for the output. The device is controlled to keep the temperature at 25˚C. The frequency response does not have to be broadband from dc, but it has to be tailored to have a peak response in the mm-wave region of interest, the frequency response of the EA modulator module is tailored by laser trimming of the modulator's electrode so that the return loss is minimized at around 60 GHz. The 15 dB reflection loss bandwidth of about 3 GHz (58.5–61.5 GHz) is wide enough to modulate the optical carrier with the two 155.52 Mb/s-DPSK mm-wave signals. By modifying the bandwidth of the frequency response, the EA modulator can be adopted to the different carrier frequency, data rate, and number of mm-wave signals.

2.2Fiber-Optic Transmissions

The transmission of optical double side band (DSB) signal over the standard SMF causes the destructive interference, fading, along the fiber length due to the fiber chromatic dispersion and result the power penalty. To overcome this problem, the optical SSB modulation format is adopted.

2.3Radio-Over-Fiber (ROF) Technology

ROF technology is a technology by which microwave (electrical) signals are distributed by means of optical components and techniques. A ROF system consists of a central site (CS) and a remote site (RS) connected by an optical fiber link or network. If the application area is in a GSM network, then the CS could be the mobile switching centre (MSC) and the RS the base station (BS). For wireless Local Area Networks (WLANs), the CS would be the head end while the Radio Access Point (RAP) would act as the RS. The frequencies of the radio signals distributed by ROF systems span a wide range (usually in the GHz region) and depend on the nature of the applications. In this condition, the terms microwave and Radio Frequency (RF) are used interchangeably when referring to all the electrical signals generated at the RS of the ROF system. Thus high frequency millimeter waves (mm-waves), microwaves, and lower frequency signals are all loosely referred to as microwave or RF signals in the report. Pioneer ROF systems such as the one depicted in were primarily used to transport microwave signals, and to achieve mobility functions in the CS. That is, modulated microwave signals had to be available at the input end of the ROF system, which subsequently transported them over a distance to the RS in the form of optical signals. Unlike the conventional discussions about mm-wave ROF systems focusing on the downlink system only, the design of bidirectional mm-wave ROF systems are considered. Two multiplexing techniques, wavelength division multiplexing (WDM) and orthogonal frequency division multiplexing (OFDM) like subcarrier multiplexing are introduced to realize the distributed BSs. Fiber chromatic dispersion, the main cause of performance degradation in optical communications also affects mm-wave ROF systems, making the mm-wave fade with distance in the fiber links. The electrical signal is used to modulate the optical source. The resulting optical signal is then carried over the optical fibre link to the remote station. The data is converted back into electrical form by the photo detector. The generated electrical signal must meet the specifications required by the wireless application be it GSM, UMTS, wireless LAN or other. In any RF communication system, the baseband information is modulated to a suitable carrier frequency. The purpose of the ROF link is to provide a transparent, low distortion communication channel for the radio signal for antenna remoting. Laser diodes can be directly modulated up to several GHz of radio frequency depending on their resonance frequency. Up to several GHz directly modulated ROF transceivers are commercially available. At higher frequencies, external modulators such as the Mach-Zehnder interferometer should be used.

3. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM) is the modulation technique for future broadband wireless communications because it provides increased robustness against frequency selective fading and narrowband interference, and is efficient in dealing with multi-path delay spread. To achieve this, OFDM splits high-rate data streams into lower rate streams, which are then transmitted simultaneously over several sub-carriers. OFDM uses multiple subcarriers to transmit low rate data streams in parallel. The subcarriers are themselves modulated by using differential phase shift keying (DPSK) or quadrature amplitude modulation (QAM) and are then carried on a high frequency microwave carrier (e.g. 5 - 60 GHz). This is similar to conventional frequency division multiplexing (FDM) or sub-carrier multiplexing, except for the stringent requirement of orthogonality between the sub-carriers. Sub-carrier orthogonality can be viewed in two ways, namely the time, and the frequency domains. In the time domain, each sub-carrier must have an integer number of cycles during each OFDM symbol interval (duration). In the frequency domain, the amplitude spectra of individual sub-carriers (which are PSK or QAM modulated) overlap. However, at the maximum of each subcarrier spectrum, all other sub-carrier spectra are zero. Since the OFDM receiver calculates the spectrum values at the maximum points of individual sub carriers, it can recover each sub-carrier without inter-carrier-interference (ICI) from other sub carriers. OFDM is processor intensive because the basic OFDM signal is formed using the inverse fast fourier transform (IFFT), adding a cyclic extension and performing windowing to get steeper spectral roll off. In the receiver, the sub-carriers are demodulated by using fast fourier transformation (FFT). The requirement for the intensive computations accounts for the complexity of OFDM transmitters and receivers. In comparison to single-carrier modulation systems, OFDM is more sensitive to frequency offset and phase noise. Furthermore, OFDM has a relatively large peak-to-average power ratio, which reduces the power efficiency of the RF amplifier. OFDM is already used in many access network technologies including high-bit-rate, digital Subscriber Lines (HDSL), asymmetric digital subscriber Lines (ADSL), very high-speed digital Subscriber Lines (VDSL), digital audio broadcasting (DAB), and high definition television (HDTV) broadcasting. A laser-diode exhibits a non-linear behavior with memory which is called weak non-linearity. The volterra series may be used to model the diode input/output characteristic. When the laser-diode is driven well above its threshold current, its input/output relationship can be modelled by a volterra series of order 3. When the kernels of the volterra series are taken as dirac delta functions, then the system is modelled without memory. To simplify the analysis, a power series of order 3 can be used to adequately model the non-linear behaviour, because simple models can be used more readily for the analysis of wideband systems such as OFDM as well as narrow-band systems.

4. SIMULATION MODEL OF THE SYSTEM

The simulation model of the system is presented in Fig.3. The blocks stated in which have been collected to present the whole simulation model and the parameters of each block are also designed. OFDM uses multiple sub-carriers to transmit low rate data streams in parallel. The sub-carriers are modulated by using quadrature amplitude modulation (QAM) and are then carried on a high frequency microwave carrier. The transmitter converts the input data from a serial stream to parallel sets. Each set of data contains one symbol for each subcarrier. An inverse Fourier transform (IFT) converts the frequency domain data set into samples of the corresponding time domain representation of this data. The parallel to serial block converts this parallel data into a serial stream. The base band signal has been generated by Bernoulli binary generator block Reed Solomon (RS) double error correcting (15, 11) code has been used as FEC code for base band signal to be sent to next stage. Coherent QPSK modulation and training (pseudo noise sequence generation) blocks are used to provide input to OFDM symbol generation (IFFT add cyclic prefix block). In

OFDM symbol generation the transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one symbol for each subcarrier. An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data. Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with frequency components satisfying orthogonality conditions. Then add cyclic prefix means insert guard time between consecutive OFDM symbols which helps to combat against ISI. Training insertion block identifies training pattern in OFDM symbol and place them at predefined position in OFDM symbol to facilitate training process. Then, the parallel to serial block converts this parallel data into a serial stream and creates the OFDM signal by sequentially outputting the time domain samples. The OFDM signal is used to modulate the Laser Diode which will convert the signal from electrical to optical signal. The optical signal will be carried over single mode optical fiber link .The receiver performs the inverse of the transmitter to recover the baseband signal and transmit to the corresponding wireless user. At the receiver the photodiode will convert the signal from optical to electrical signal. The channel estimator and channel compensation blocks are used to characterize the fluctuating noisy channel of power line and hence to improve SER. The symbol error rates (SERs) with and without RS FEC code can be observed in scope1 and scope2 respectively. It can be seen that SER is less with RS FEC code.

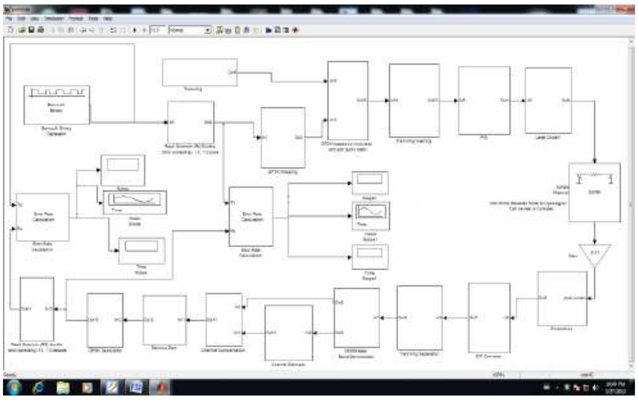

Fig -3: Simulation Model of OFDM System

5. SIMULATION RESULTS

Fig.4 and Fig.5 that shows OFDM over fiber transmitted and received power spectrum. For transmitted power spectrum in Fig.4, it the same like transmitted power spectrum before sending the signal over fiber. For received power spectrum in Fig.5, it became different with received signal before sending over fiber. The photodiode are used as optical demodulator with laser diode as optical modulator but the photodiode is working better with Mach-Zehnder optical modulator.

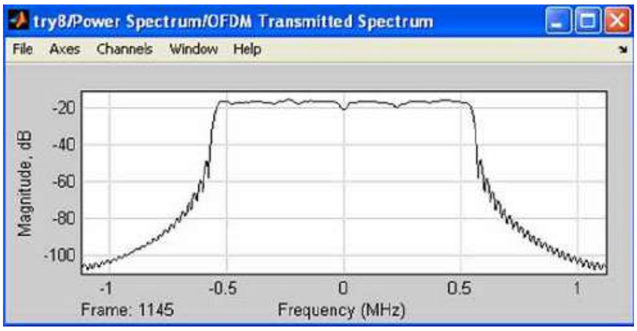

Fig -4: OFDM Transmitted Spectrum over Fiber

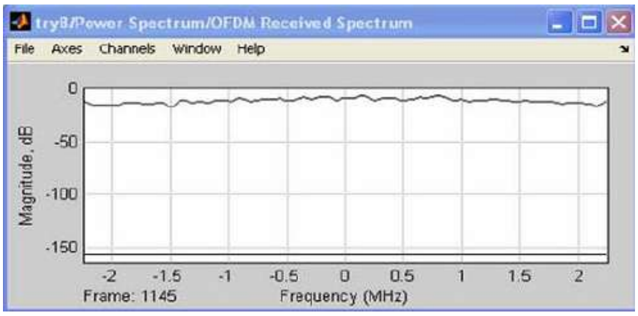

Fig -5: OFDM Received Spectrum over Fiber

5.1 The Constellation Before and After Channel Estimation

A constellation diagram is a graphical representation of the complex envelope of each possible symbol state. The constellation before channel estimation is shown in Fig.6. The channel estimator and channel compensation blocks are used to characterize the fluctuating noisy channel of power line and hence to improve SER. The symbol error rates (SERs) with and without RS FEC code can be observed in scope1 and scope2 respectively. It can be seen that SER is less with RS FEC code.

QPSK uses binary-level modulation of the single frequency carrier wave components, generating an output signal space, or constellation, with four message points. Each of these message points, or symbols, carries two bits of information. By using two components of the carrier wave, QPSK is able to carry twice information in the same amount of bandwidth.

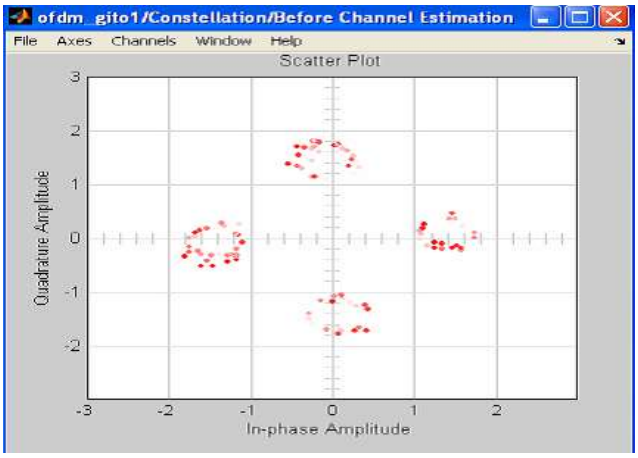

Fig -6: The Constellation before Channel Estimation

This QPSK constellation diagram shows symbols, each represented by two data bits that were first gray encoded. One can see that each adjacent symbol is represented by two data bits that vary by one bit. The power efficiency is related to the minimum distance between the points in the constellation. The constellation after channel estimation is shown in Fig.7.

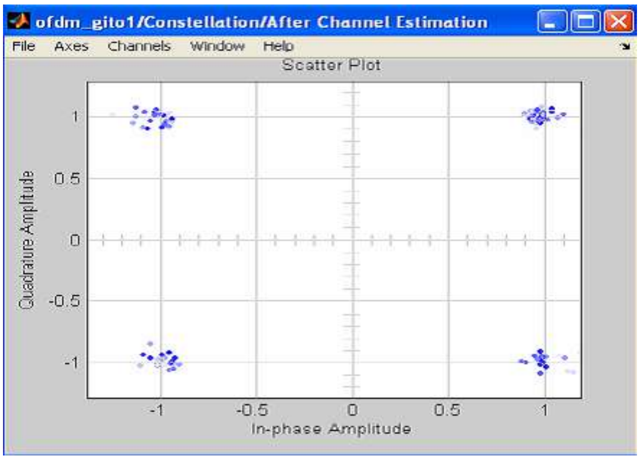

Fig -7: The Constellation after Channel Estimation

5.2The Constellation Before and After Channel Estimation

The following figures show OFDM over fiber transmitted and received signal. For transmitted signal in Fig. 8, it is the same like transmitted signal before sending the signal over fiber. For received signal in Fig. 9, it became different with received signal before sending over fiber. The result in Fig.9 indicates to the photodiode can used as optical demodulator with laser diode as optical modulator but the photodiode is working better with Mach-Zehnder optical modulator.

Fig -8: OFDM over fiber transmitted signal

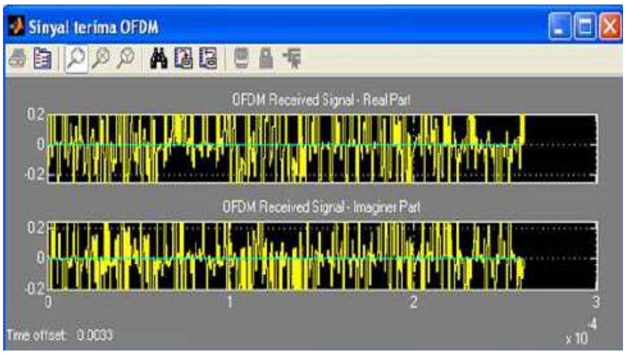

Fig -9: OFDM over fiber received signal

5.3Comparison Between Theoretical and Simulation BER

Comparison between theoretical and simulation BER is shown in Fig.10. Both of theoretical and simulation BER are close to each other.

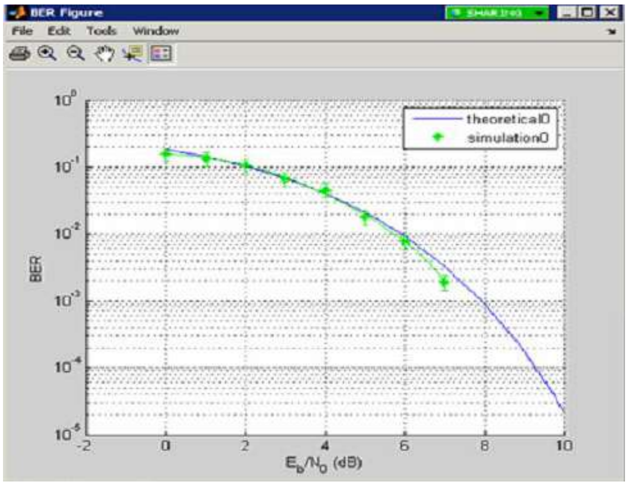

Fig -10: Comparison between theoretical and simulation BER

At the receiver the signal is filtered by the FFT stage, thus making the receiver only see noise within the signal bandwidth. Increasing the cyclic prefix duration improves the BER performance for the OFDM system. The BER performance is in all cases improved by increasing the OFDM symbol length.

3. CONCLUSIONS

As a conclusion that covers the determination made by studies the system impact of implementing ROF schemes is substantial. The fiber dispersion has been completely over-come by using the special optical SSB filtering technique, and fiber dispersion. The deployment of optical fiber technology in wireless networks provides grate results obtained from the first part OFDM over AWGN channel which were close for expected results. The results of transmit QPSK-OFDM signal over fiber were good specially in the transmitter part but it still need to improve and as a result, the photodiode can used as optical demodulator with laser diode as optical modulator but it is working better with Mach-Zehnder optical modulator. Overall, the paper offered vast learning opportunity in the OFDM and Radio over Fiber technology and how to simulate using MATLAB/SIMULINK software. The studying of OFDM modulation and radio over fiber technology became very important because both of them have been developed to support some important future wireless systems. Finally this paper was transmitting of QPSK - OFDM baseband signal over fiber and it is able to improve to transmit radio signal over fiber, constellation before and after channel estimation. The model of this system can be used with different wireless communication systems such as wireless LANs and digital video broadcasting (DVB) and it is supporting to the 4th generation cellular systems.

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