Analysis of Fiber-optic Link Budget for Optically fed Wireless Communication

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Abstract—Analyses of performance of wireless broadband communication systems employing fiber-optic link have presented. We have analyzed CNR penalty to evaluate system performance by taking into account, radio link considering rainfall attenuation, and optical link considering several carrier-to-noise ratio versus the optical modulation index.

Index Terms—Wireless Broadband, Fiber Optic Link, Carrier-To- Noise Ratio.

I. INTRODUCTION

Video-on-demand, interactive multimedia, high-speed internet, and high-density television to homes and industrial and educational institutions has been a subject of intense interest in recent years. Both wireline, hybrid fiber-coax and wireless access techniques show considerable potential in this regard. These access schemes mainly utilize the lower microwave frequency spectrum (<5 GHz) for distribution of broadband signals. Recently, however, the millimeter-wave frequency band (26 ~ 60GHz) has been considered for wireless access, primarily to avoid spectral congestion at lower microwave frequencies and to offer large transmission bandwidth. Future millimeter-wave broadband access systems may employ an architecture in which signals generated at a central location will be transported to remote base stations for wireless distribution [1,2]. Optical feeding of base stations in these systems is an attractive approach because it enables a large number of base stations is an attractive approach because it enables a large number of base stations to share the transmitting and processing equipments remotely located from the customer serving area. In such systems, millimeter-wave signals can be generated and modulated using optical techniques and transported to base stations very efficiently via low cost, low loss, and EMI-free optical fibers. Together with high-speed photodetector integrated with mixer, amplifiers, diplexers and printed antennas, simple and investigated and lightweight base stations can be designed to allow easy installation on building walls and corners, street lights, and telephone poles. Figure 1 shows a basic configuration of a pico-cellular mobile communication system using optical techniques for the generation and transmission system using optical techniques for the generation and transmission of millimeter-wave signals. A number of techniques for the generation, modulation, and distribution of millimeter-wave modulated optical carriers for fiber-wireless systems have been developed [3,4].

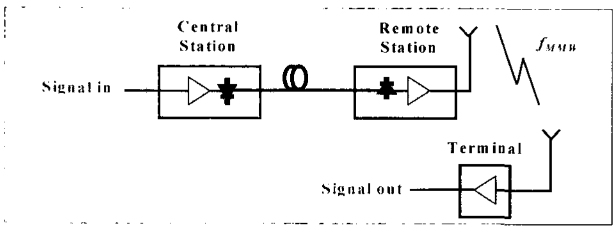

Fig. 1 Application of wireless fiber-optic communication using millimeter-wave signal

II. ANALYSIS OF MILLIMETER-WAVE SIGNAL IN FIBER OPTIC LINK

Fiber-optic microwave and millimeter-wave links which are subject to a still increasing interest can be implemented either by the use of direct detection techniques or heterodyne detection techniques. Many such links have been proposed, analyzed, and experimented. In the direct detection, the millimeter-wave signal is intensity modulated onto the optical carrier from a laser. The optical signal is then transmitted through the optical fiber, and the millimeter-wave signal is recovered by direct detection in a photodiode. In the remote heterodyne detection links, two phase correlated optical carriers are generated heterodyne detection links, two phase correlated optical carriers are generated in a dual-frequency laser transmitter with a frequency offset the same as to the desired millimeter-wave frequency. Further, one of the optical carriers is modulated by the information to be contained in the millimeter-wave signal. Both optical signals are then transmitted through the optical fiber, and the millimeter-wave signal is generated using heterodyning the two optical signals in a photodiode. In both approaches the chromatic fiber dispersion becomes a limiting factor for the transmission distance when the microwave signals are in the above 20 GHz regime. In an Intensity Modulation Direct Detection link, the millimeter-wave signal is carried as a lower and upper sideband on the optical carrier. Due to the dispersion and the large frequency offset between the side bands and the optical carrier, the phase of each of the spectral components of the transmitted optical signal has experienced a differential change. After detection, this results in a power reduction of the recovered millimeter-signal and thereby decreasing its carrier to

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noise ratio (CNR). The dispersion induced CNR penalty on the recovered millimeter-wave signal with the carrier frequency is found by comparing the signal power of millimeter-wave signal which is recovered by square law detection of the optical signal. Power shift of millimeter-wave is characterized by function of fiber distance effect the chromatic dispersion effect in fiber. IMDD link and shift of optical spectrum by external modulation technique is shown in Fig.2.

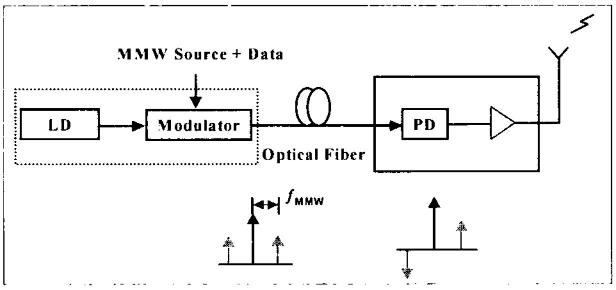

Fig. 2 External Modulation Method

Power shift is induced by a dispersion limited fiber length and is represented[5].

$$P_c \propto \cos\left[\left(\frac{\pi L D}{c}\right)\lambda^2 f_{MMW}^2\right] \tag{1}$$

where, f_{MMW} demotes the RF offset frequency from the optical carrier, λ is the length of fiber, D is the chromatic dispersion parameter and c is the speed of light in vacuum. As shown in Figure 3, for a millimeter-wave of 30GHz and 60 GHz, the dispersion results in a significant decrease of the CNR as the transmission distance is increase. CNR penalty is defined as follows.

$$CNR\ penalty = 10\log\left[\frac{P_{c\ without\ dispersion}}{P_{c\ with\ dispersion}}\right] \tag{2}$$

This penalty limits the obtainable transmission in IM-DD fiber-optic millimeter-wave links. A complete extinction of the recovered millimeter-wave carrier occurs when the lower and upper sidebands are out of phase. The millimeter-wave carrier at 30GHz is transmitted on an optical carrier at a wavelength of 1550 nm over a standard single-mode fiber with a chromatic dispersion of 17 ps/km nm, large CNR penalty occurs for a transmission distance of 4km. The dispersion effect exhibits a cyclic behavior is shown in Figure 3. The period length is found the following equation [7].

$$\Delta L = \frac{c}{D\lambda^2 f_{mmw}^2} \tag{3}$$

The dependence of transmission of distance on chromatic fiber dispersion and millimeter-wave frequency can be estimated above equation. An increase in either dispersion or carrier frequency, therefore, significantly limits the obtainable transmission distance.

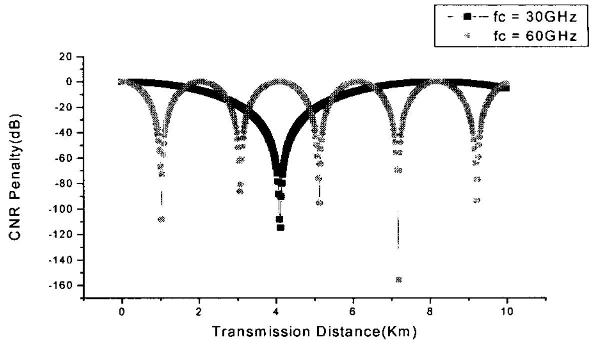

Fig. 3 CNR Penalty according to transmission distance in Fiber-optic link

III. PERFORMANCE ANALYSIS OF PARAMETERS IN FIBER-OPTIC LINK SURROUNDING

In the case of wireless communication using millimeter-wave band, we can communicate within a line of sight. Also, the cell radius is small, but it is efficiently used as the frequency reuse because the operation of frequency interference is small. In wireless environment, the subscriber in operating mode is not fixed. the increase of bandwidth gives a lot of capacity of subscriber. Contrary to this effect, we have to consider the effect of radio frequency by rainfall to use millimeter-wave band. In wireless link design, we have to evaluate the intensity of signal required in receiver. Especially, the parameters stressed in millimeter-wave band are effected by such as free space loss, rain attenuation, antenna height, gain, the absorption of radio frequency by obstacle in transmission line, and multipath. The relationship between cell radius and the reduction of signal intensity by path loss of radio frequency is as follows [7].

$$Z_a = P_T + G_R + G_T - L_f - KTBF - rQAM \tag{4}$$

where, Z_a is cell radius by attenuation of signal, P_T is transmission power of subscriber, G_R is antenna gain of subscriber, G_T is antenna gain in base station, L_f is free space loss, KTBF is noise in receiver, rQAM denotes CNR value to be required 10^{-6} BER. From the Figure 4, we can estimate that the variation of signal to cell radius by modulation method is superior to QPSK method compared to 256QAM modulation method in millimeter-wave band.

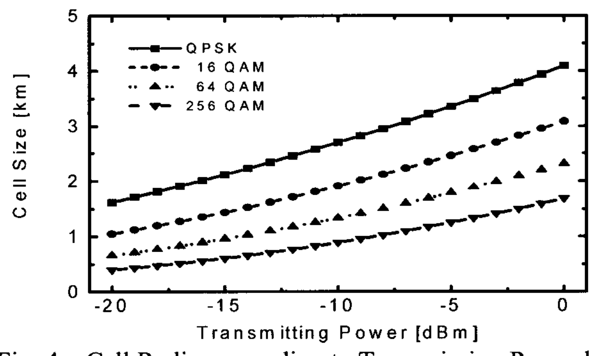

Fig. 4 Cell Radius according to Transmission Power by Modulation Method

The loss of free space represents that it absorbs radio frequency energy in free space or radio emission loss in scattering ideal space. Signal power density of receiver in distance d is represented as follows [8,9,10].

$$P_r = P_t/4\pi d^2 \quad (5)$$

where, we can obtain loss by calculating the ratio of receiver power P_r to transmitter power P_t. We call it as free space loss and it is denoted as follows.

$$L_s = P_t/P_r = (4\pi d/\lambda)^2 \quad (6)$$

The equation can be represented as decibel form.

$$L_s(dB) = 10\log(4\pi d/\lambda)^2 = 20\log(4\pi d/\lambda) \quad (7)$$

In the case of loss of air, the millimeter-wave signals induce losses employing absorptions of energy which are generated synchronizing specific molecule and oscillation frequency. It is well known that the loss is very high per km. Generally, when we consider attenuation by rainfall in local multi-point distribution service, system. The main loss would be a rainfall in short time rather than total of rainfall. That is to say, the attenuation is represented as rainfall per time. Korea rainfall model is K rainfall region by means of recommend of ITU-R. If we assume 0.01% of the non-availability in proposed link, the average rainfall to confirm 99.99% of availability is 42mm/hr [10,11]. If we assume that extra attenuation by rainfall is A(dB/km). R is average rainfall intensity per tome is R, the equation between A and R is described as follows [11].

$$A = kR^{\alpha} \quad (8)$$

where, k and a is frequency and function of temperature, respectively.

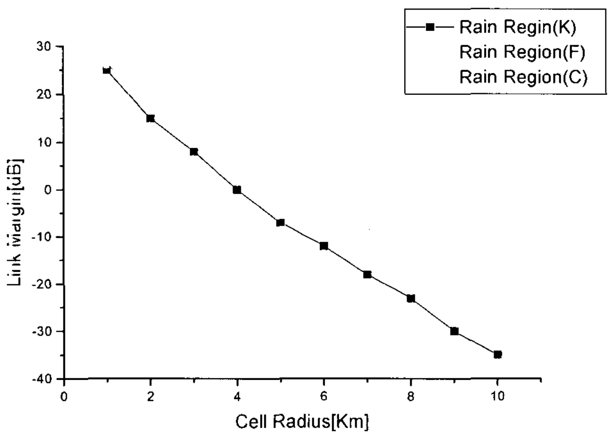

Fig. 5 Relations between Cell Radius and Link Margin

when the signal propagated from transmitter of long distance is injected, antenna collects signal power involved in effective area A_e. The effective area of antenna A_p with a lossless antenna is described as follows.

$$A_p = \pi \times D^2/4 \quad (9)$$

But, real antenna aperture does not have homogeneous characteristics because of its material and shape, the effective area A_e is as follows.

$$A_e = \alpha \times A_p \quad (10)$$

where, α is antenna efficiency. The relation between antenna gain G_{max} and effective area A_e is represented as follows.

$$G_{max} = 4\pi \times A_e/\lambda^2 \quad (11)$$

where, λ is wavelength. We can describe the circular aperture with D diameter as the dBi representation [10].

$$G_{max}(dB_i) = 10\log G_{max} = 9.94 + 10\log + 20\log(D/\lambda) \quad (12)$$

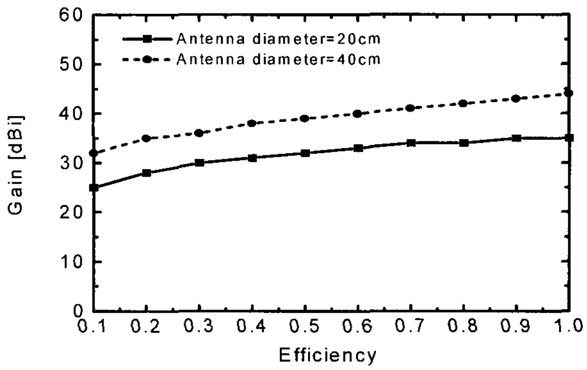

Fig. 6 CNR Penalty in OMI(Carrier variation)

Also, from the simulation results, as signal power increases, the CNR increases until nonlinear distortion element is major factor. This means that as the D value increase it operates as a noise factor. Also, we can estimate that the CNR value diminishes as the number of carrier increase. The main reason is that the total bandwidth of SCM (Sub-Carrier Multiplexed) is increased. major carrier is transmitted when the probability which the clipping can be generated increase. Figure 7 shows CNR value to OMI (Optical Modulation Index) according to the change of bandwidth. From the result, we can estimate that the noise factor increases when the bandwidth of channel increases. The main result is caused by signal distortion by clipping and effect of resonance frequency of laser diode.

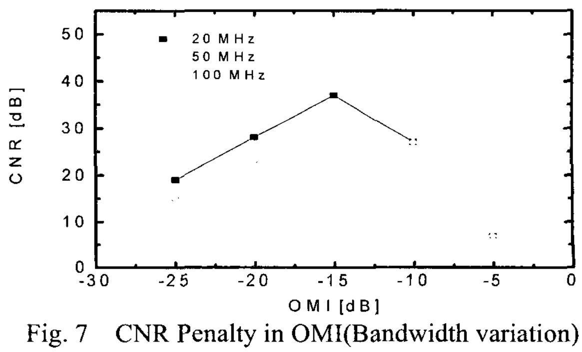

Fig. 7 CNR Penalty in OMI(Bandwidth variation)

IV. CONCLUSIONS

We have analysed the performance of broadband system using millimeter-wave employing wireless and fiber-optic link applicable to broadband communication. In IM-DD millimeter-wave link, the distance is characterized as a limited factor as the frequency of transmitted signal and chromatic dispersion are increased. In wireless link, the shift of cell radius by modulation method is superior to QPSK method compared to QAM method. The CNR value to evaluate the performance is increased until nonlinear distortion factor is important factor as signal power increases. Also, the CNR value diminishes as the number of carrier increase. We have concluded that the signal attenuation effects by rainfall in wireless environment and chromatic dispersions in fiber-optic link are major effects in broadband system design.

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