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A survivable Point-to-Point (PTP) Wireless Transmission Based On Adaptive Coding and Modulation (ACM) Technique

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Abstract

Wireless transmission can be affected by severe weather conditions such as heavy rain. Such a temporary weather condition leads to decrease the received power and thus reduce the signal-to-noise ratio, which degrades the overall performance. In some cases in which a high bit rate is being transmitted where a specific amount of signal-to-noise ratio is required, the wireless transmission drops down completely. Adaptive Coding and Modulation technique could provide the feature of adaptation during transmission. In Adaptive Coding and Modulation, transmission parameters such as modulation scheme and/ or code rate can be altered based on signal-to-noise ratio measurements. In this paper, a survivable point-to-point wireless transmission was established using Adaptive Coding and Modulation technology. A concentration on the Adaptive Modulation was made in this work by using the AF-11FX equipment which is capable of modulate carriers using different modulation schemes (QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM). In this context, the wireless point-to-point link was examined with and without the use of Adaptive Modulation. A survivable transmission was achieved in which an automatic switching mechanism is performed among the aforementioned modulation schemes based on signal-to-noise ratio measurements, which led to increase the average transmission rate.

Keywords: Wireless Transmission, Modulation Schemes, Coding Rate, Adaptive Coding, Adaptive Modulation

INTRODUCTION

The introduction should articulate the problem being addressed. It should provide sufficient background information on the subject allowing the reader to have more insight into what will be It has been known until a recent time that optical fibers are the most successful means of transmitting data at high rates due to their huge bandwidth. However, they will not remain the best in the near future due to the expected challenges in the next generations of communication networks [1]. One of the most important of these challenges is the large tendency of users to use smart phones along with the demand for broadband transmission. This challenge can be overcome if transmission and reception are activated wirelessly in the millimeter waves band. Another challenge arises here, which is the sensitivity of the millimeter waves band to severe weather conditions such as heavy rains. This might lead to cut-off transmissions when high data rates are sent where a certain amount of SNR is required. This problem can be settled if some type of adaptive transmission becomes available. In other words, transmission under severe weather conditions can be maintained by automatically altering transmission parameters such as modulation and/ or code rate that require lower SNR value [2]. In this article a survivable wireless PTP transmission was realized over 11 km in a mountainous area. The implementation method was divided into two parts. The first part of the implementation method was based on simulation approach in which the web application tool was exploited to validate the feasibility of the 11 GHz band. Whereas the second part was based on experimental approach in which the technology of Adaptive Coding and Modulation (ACM) was involved. Followings are some related works found in the literature:

Satoshi et, al in [3] evaluated the performance of super high bit rate mobile communications using computer simulation at 11 GHz band 24×24 Multi-input, Multi-output MIMO outdoor propagation environment where an increase in the throughput exceeding 30 Gbps was achieved. The work in the above mentioned article also clarified the requirements for the average SNR, channel conditions, and accuracy of channel state information (CSI) for achieving 30 Gbps throughput over a real 11 GHz band 24×24 MIMO channel. However, an experimental solution have not been conducted due to hardware limitations. Kentaro et, al in [4] discussed the characteristics of 11 GHz band MIMO channel in a street micro-cell environment. The results showed that the scattered signal component was weak compared with measurement results of indoor environments. In addition, a further utilization for the MIMO channel modeling in the higher frequency band was expected. Y. Oda et, al in [5] presented outdoor wideband 8×8 MIMO channel measurements using dual-polarized antennas at 11 GHz. The measurements were conducted in the urban and residential areas of Ishigaki City, Okinawa, Japan. The effect of different polarizations on MIMO capacity and efficiency were estimated with respect to the dependency on local propagation environments. The results showed that there is a proportional increase in the capacity as the number of the antenna increases in non-line-of-sight environment.

Fresnel Zones Concept and Analysis

In wireless channels, a transmitted signal might take several paths before it reaches the receiver even in a line-of-sight environment. The parts of the signal that take paths other than the line-of-sight path, might subject to reflection before reaching their destination [6]. This would lead to destructive interference between the part of the signal that passes through the direct path and the other part that passes through the reflected path if the phase difference between the two parts is half an odd integer multiple of the period. The n-th Fresnel zone can be represented as a group of reflecting points that are located on three dimensional space such that a two segments path from the transmitter to the receiver that reflected off at any arbitrary point on that surface will be between n-1 and n half-wavelengths out of phase with the straight-line path. The shape of these zones are elliptical with foci at the transmitter and receiver. Fresnel zone analysis can help in designing a clear path between the transmitter and receiver. Obstructions within the first Fresnel zone can cause significant destructive interference and thus leads to weaken the received signal, even if those obstructions are not blocking the apparent line-of-sight path. Thus, it is required to determine the size of the 1st Fresnel zone to decide whether or not a noticeable signal weakness will take place. To realize an ideal 1st Fresnel zone, 80% of clearance is required. However, practically, not less than 60% of clearance is considered adequate [7] [8]. Consider an arbitrary point P at distances d_1 and d_2 with respect to each of the two antennas as shown in Figure 1.

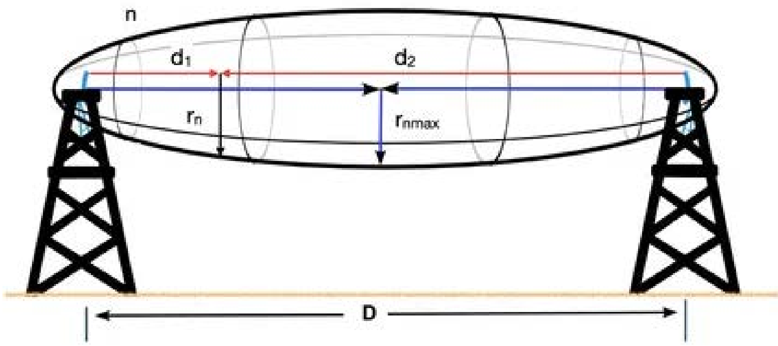

Fig.1 Schematic Representation of nth Fresnel Zone

To obtain the radius r_n of zone n, note that the volume of the zone is delimited by all points for which the difference in distances, between the direct wave ($D = d_1 + d_2$) and the reflected wave ($\overline{AP} + \overline{PB}$) is the constant n times half of the wavelength $\frac{\lambda}{2}$.

This can be represented mathematically as:

$$\overline{AP} + \overline{PB} - D = n\frac{\lambda}{2} \qquad (1)$$

Re-writing (1) with the coordinates of point $P$and the distance between antennas gives:

$$\sqrt{d_1^2 + r_n^2} + \sqrt{d_2^2 + r_n^2} - (d_1 + d_2) = n\frac{\lambda}{2} \qquad (2)$$

Doing more simplification in (2) gives

$$d_1\left[\sqrt{1 + \frac{r_n^2}{d_1^2}} - 1\right] + d_2\left[\sqrt{1 + \frac{r_n^2}{d_2^2}} - 1\right] = n\frac{\lambda}{2} \qquad (3)$$

Assuming the distances between the antennas and the point P are much larger than the radius and applying the binomial approximation $(1 + x)^\alpha \approx 1 + \alpha x$ for $x \ll 1$.

Doing the binomial approximation for the square root would simplify the expression to:

$$\frac{r_n^2}{2}\left[\frac{1}{d_1} + \frac{1}{d_2}\right] \approx n\frac{\lambda}{2} \qquad (4)$$

solving (4) for r_n gives

$$r_n \approx \sqrt{n\frac{d_1 d_2}{D}\lambda}, \text{ where } d_1, d_2 \gg n\lambda \qquad (5)$$

Adaptive Coding and Modulation (ACM)

Rely on worst case scenario in designing any communication systems leads to inadequate utilization of available resources, whereas tolerance in the design would reduce the reliability [9]. For example, it is often intended to increase the capacity of wireless transmission while maintaining it available all the time, which is a very challenging issue. To solve this dilemma, ACM was introduced as a compromise which makes wireless transmission even more attractive. ACM technology seeks to realize adaptations during transmission by automatically altering some transmission parameters, such as modulation, code rate, or power based on feedback CSI [10]. More specifically, ACM refers to the automatic adjustment that a wireless system can make to resist weather-caused impairments that leads to fading and thus enhance the average rate of transmission. The idea is simply to make a frequent CSI at the receiver side and feed it back to the transmitter. As the transmitter receives the CSI, it alters its transmission parameters accordingly. In ACM-based transmission, the receiver sends back CSI to the transmitter via a feedback channel. The transmitter then adjusts its transmission parameters based on that CSI to maintain a survivable transmission. This scheme has the capability to significantly increase the spectral efficiency of wireless transmission. Figure 2 shows a basic ACM-based wireless communication system.

Work Implementation

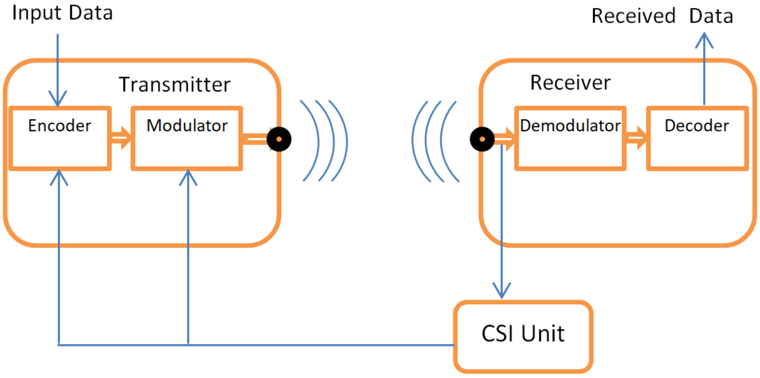

Fig. 2 A basic ACM-based wireless communication system

This section is divided into three parts. In the first part, an almost free of obstacles point-to-point link is established based on Fresnel Zone concept. In the second part, the channel capacity is estimated in case of using different types of modulation techniques. In the third part, the ACM is incorporated in the transmission process. As a part of preparing a clear Fresnel Zone, we entered the coordinates and height of the transmitter and receiver antennas using the web application. In this context, the positions of the transmitter and receiver antennas were 32.763989, 21.761985 and 32.806079, 21.870386, respectively, whereas, the height of the transmitter and receiver antennas were 42 m and 36 m, respectively. The antennas heights were entered with regardless of sea level altitude because it is included in the web application. The separation distance was calculated automatically by the web application which was 11.17 Km. The web application also suggested the use of 5 GHz band for transmission. Figure 3 shows the Fresnel Zone based on the recommended band. It is obvious from Figure 3 that the point-to-point link is not 100% clear. Based on the Fresnel Zone analysis, a reduction in radius can be achieved by increasing the frequency. Thus, we choose to increase the frequency to 11GHz and observe the situation via the web application.

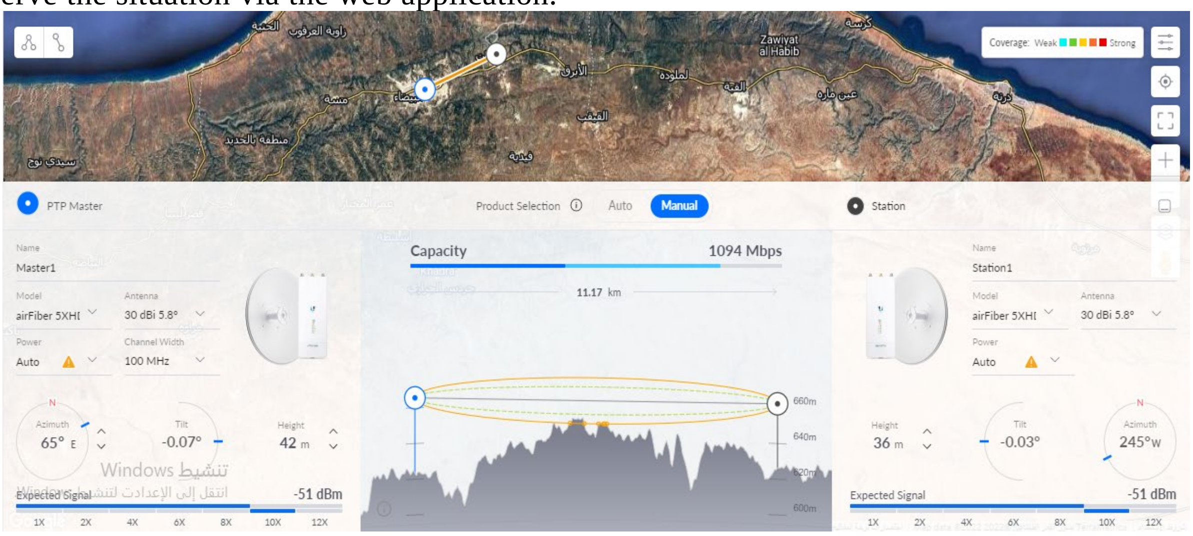

Fig.3 Fresnel Zone based on the 5 GHz recommended band by the web application

Figure 4 shows the Fresnel Zone when 11GHz is used where an almost free obstructions point-to-point link was achieved. The 11GHz band was chosen for the following reasons: (a) It is a part of the microwave bands that is devoted to the education sector, (b) It leads to a higher channel capacity, (c) Moving to 11GHz band helps to avoid interfering with the license free and commonly used 5GHz band. The equipment (AF-11FX) has been installed on both sides of the point-to-point link to work as transceivers. This equipment has the capability to modulate carriers using QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM.

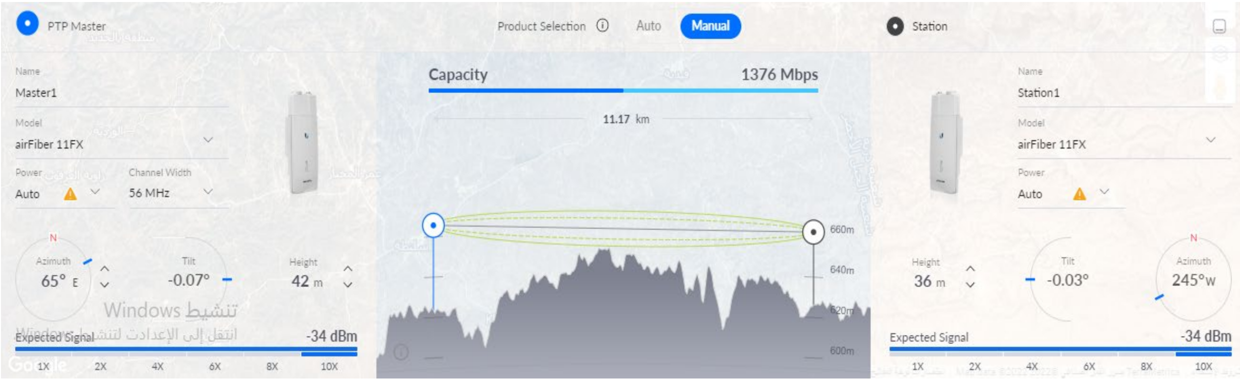

Fig.4 An almost free obstructions Fresnel Zone using 11 GHz

In addition, it is featured with ACM technology. To estimate the maximum channel capacity using the aforementioned modulation techniques, transmission was set using the following parameters:

- Tx frequency: 11060 MHz
- Rx frequency: 11550 MHz
- Channel Width: Max 56 MHz
- Modulation: QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM
- Mode: MIMO
- Tx Power: 20 dBm
- Tx Antenna Gain: 35 dBi

The obtained measurements were listed in Table 1.

Table 1: Maximum channel capacity obtained using AF-11FX Equipment

Channel Bandwidth	Mode	Modulation Scheme	Capacity (Mbps)
56 MHz	MIMO	QPSK	137.6
		16 QAM	275.2
		64 QAM	412.8
		256 QAM	550.4
		1024 QAM	687.9

Based on the capacity measurements, one can choose to establish the link using the lowest capacity all the time to ensure high reliable transmission, however, this will come at the cost of the spectrum efficiency. On the other hand, if the link is establish using the highest capacity, it might be dropped down due to un expected weather conditions, such as rain, snow, or even fog. Here, the role of incorporating the ACM comes clearly. To do so, transmission was made while altering the modulation to the automatic rate adaptation mode. The power and gain values are altered several times to monitor the automatic adaptation of modulation rate. The flowchart in Figure 5 describes the ACM mechanism performed by the AF-11FX equipment.

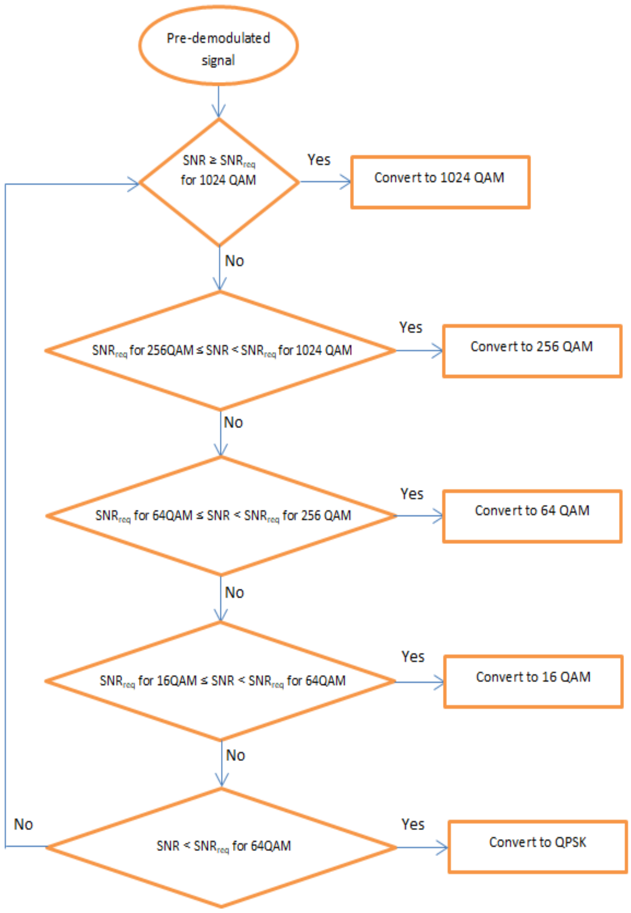

Fig.5 ACM mechanism using AF-11FX equipment

By observing Figures 6 and 7, one can easily extract the difference between the ACM-Free and ACM-Based transmissions. In the case of ACM-Free transmission, the link is going down if SNR lower than the required SNR is measured. ACM-Based transmission survive the link. In other word, the rate of modulation will be automatically changed depending on the link status, which led to increase the average capacity of the link.

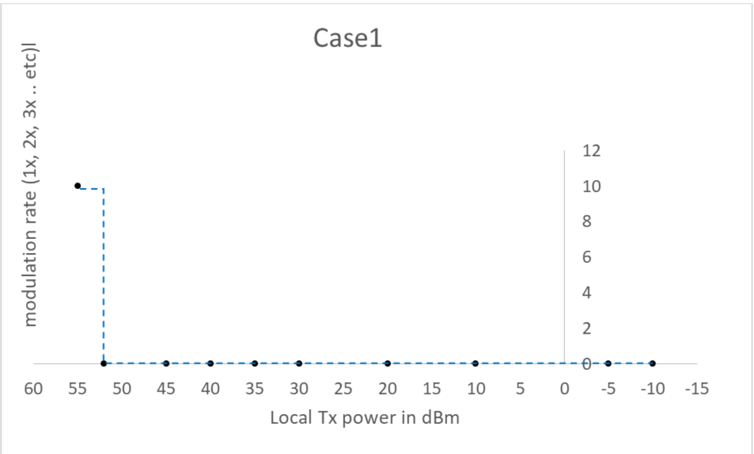

Fig.6 ACM-Free transmission

CONCLUSIONS

In this article a survivable wireless PTP transmission was implemented. The implementation was divided into two parts. In the first part, the web application simulation tool was exploited to validate the feasibility of the suggested 11 GHz band, whereas in the second part, the technology of ACM was experimentally involved. An improvement in the average capacity was achieved due the automatic switch among the employed modulation schemes rather than dropping the link down and getting zero capacity at severe weather conditions.

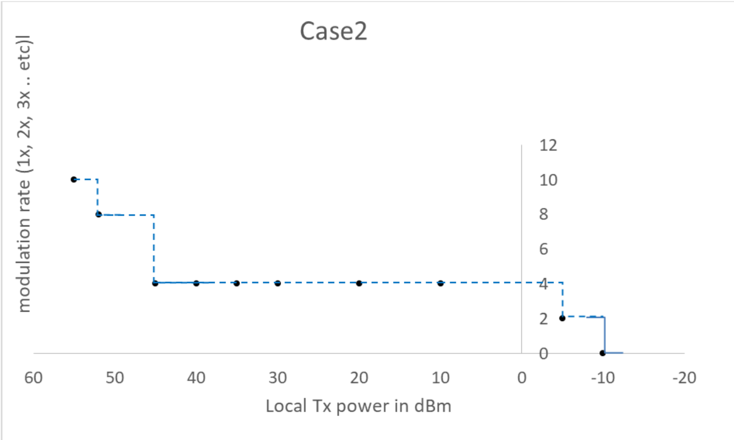

Fig.7 ACM-Based transmission

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