# *Survey on Techniques and Applications of Cooperative Diversity with Adaptive Modulation in Wireless Networks*

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***Abstract*—Cooperative diversity and adaptive modulation are considered the two most widespread techniques used to achieve improvement in several performance criteria at the wireless physical layer (PHY), such as; Signal to Noise Ratio, Bit Error Rate and Spectral Efficiency. Throughout this paper, a survey of adaptive modulation and cooperative diversity with an evaluation for combining diversity schemes is introduced. Throughput loss of using cooperative diversity can be compensated by using adaptive modulation. Cooperative diversity and adaptive modulation are used to meet the main requirements of the Fourth Generation (4G) systems and potential Fifth Generation (5G)networks. Recent works related to cooperative diversity and adaptive modulation in wireless communication are presented, discussed and reviewed by means of the main methods, concepts, goals and the obtained outcomes from each one of these studies. The paper also evaluated and compared these studies based on different criteria, such as; modulation scheme, diversity scheme and more ones. The paper finally introduces a set of suggestions for potential research topics.**

***Keywords*— Cooperative Diversity, Adaptive modulation, Spectral Efficiency, Bit Error Rate, Amplify and Forward, Decode and Forward.**

## I. INTRODUCTION

Most of the wireless communication systems can be affected with multipath fading [1-3]. Diversity technique can be used to overcome of multipath fading, such as frequency diversity and spatial diversity. Multiple Input Multiple Output (MIMO)systems can be used of spatial diversity using multiple antennas at the transmitter and/or the receiver. The main problem of MIMO systems especially at the mobile user, is the high power consumption. The benefits of MIMO systems can be achieved without multiple antennas at mobile user. The main idea, that the mobile user uses antennas in other terminals, by using virtual antenna [4,5]. In this case virtual antenna can provide spatial diversity and antenna array gain. This type of diversity called cooperative diversity. The simplest type of cooperative diversity is by adding one more terminal, which is called a relay. When the source transmits to the replay, same data will be received at the destination due to the nature of wireless media and electromagnetic wave. After that, the replay is retransmitted the data to the destination node, so the destination receives two independent copies of the original data.

Most of the challenges in cooperative diversity are the total throughput loss, because of extra resources for relaying which can be reduced to 50% for single relay compared with a direct link. To reduce throughput loss, different techniques are proposed in the literature, like full-rate cooperative diversity and superposition modulation. On the other hands, these techniques increase the complexity of the overall system. Adaptive modulation is one of the best techniques to reduce throughput loss in cooperative diversity, by changing constellation size bases on SNR at receiver.

This paper introduces a comprehensive survey of cooperative communication and adaptive modulation techniques. Contribution of this review paper can be summarized as follow:

1. Providing deep analysis of recent papers related to cooperative diversity with adaptive modulation with comparisons for main parameters that are common to these papers. There are several recent papers that provide a comprehensive survey for cooperative communication and adaptive modulation [6,7 and 8].Most of these papers focus on cooperative diversity in routing protocol perspective or in network layer in general. Authors in [6], presented a survey of distributed relay selection in cooperative ad-hoc network by focusing on sharing channel information with choosing an optimal selection of relay at the same time. Authors in [7], presented a survey of cooperative diversity for wireless networks by focusing on medium sharing with and without cooperation. Authors in [8] presented a survey of the capacity performance with cooperative communications and provides different applications of cooperative diversity especially in Long Term Evolution – Advanced (LTE-A) system. This paper provides a theoretical framework of the connection between adaptive modulation and cooperative diversity, by focusing on capacity on different

parameters that modelling overall system like modulation type, fading type and type of cooperation. This paper focuses on the physical model of these systems. The paper provides different practical scenarios of cooperative diversity and adaptive modulation especially in 5G systems.

2. Studying the main concept of adaptive modulation with the analytical solution of discrete adaptive modulation and its relation with spectral efficiency compared with Shannon capacity and non-adaptive schemes.
3. Providing adaptive modulation with cooperative diversity as a classification for different practical cases with different categories and some potential challenges related to the topic of adaptive modulation with cooperative diversity combining techniques.

Section II defines the adaptive modulation and its main parameters including thresholds of SNR. Cooperative Diversity is then presented with two main types of relaying protocols, which are; Decode and Forward (DF) and Amplify and Forward (AF) in section III. Section IV introduced a classification of models of adaptive modulation with Cooperative Diversity with different models in DF or AF. Section V introduced and investigated some of the previous works and researches introduced in the literature. Finally, Section VI concludes the whole works presented in this survey.

## II. ADAPTIVE MODULATION CONCEPT

Adaptive Modulation gets its benefit by adjusting the modulation order, the adaptation depends on the channel condition, by increasing modulation order in good channel and decrease modulation order in the poor channel, this change in the level have different schemes, by making the change of level continues or discrete. Adaptive continues rate (ACR) where the number of bits per symbol is not restricted to integer values, while in adaptive discrete rate (ADR) the constellation size $M_n$ is restricted to $2^n$ for $n$ positive integer ($n = 0,1,2, \ldots N$), where the average SNR is divided into $N + 1$ regions, and constellation size is assigned to $n^{th}$ region. In which the transmitted $M_n$ depends on feedback from the receiver to the transmitter. Adaptive discrete rate (ADR) is related to change the mode by integer number which the practical scenario shows, where the average SE is a summation of discrete modes weighted by the probability of SNR falls in the $n^{th}$ region[9].

For $N$ thresholds, the constellation size $M_n$ is assigned to the $n^{th}$ region, so when received SNR is estimated to be in the $n^{th}$ region, the constellation $M_n$ is transmitted. There are $N + 1$ regions with $N$ thresholds of SNR. Below first threshold it is assumed there is no transmission, so first region is assigned to be in outage, which information must be buffered at the transmitter end. Second region is between first threshold and second threshold, and so on, in other word the constellation size $M_n$ is to be used when SNR falls in the interval $[\gamma_n, \gamma_{n+1}]$, to operate under specific target BER (*BERT*).

The common measurement for the performance of wireless communication systems is related to bit error rate. BER of M-QAM in additive white Gaussian noise (AWGN) can be approximated by[9]

$$\mathrm{BER}_{\mathrm{M-QAM}} \approx 0.2\mathrm{e}^{\left(\frac{-1.5\gamma}{\mathrm{M}-1}\right)} \qquad (1)$$

The region's boundaries are set to SNR's requirement to achieve the BERT using $M$-QAM over AWGN channel, which use the following equations[9]

$$\gamma_1 = [\mathrm{erfc}^{-1}(2\mathrm{BER}_0)]^2 \qquad (2)$$

where $\mathrm{BER}_0$ is the target BER, the thresholds can be found by invert (1) to be as

$$\gamma_n = \frac{2}{3}\mathrm{K}_0(2^n - 1) \quad n = 0,2,3, \ldots\ldots \mathrm{N} \qquad (3)$$

$$\mathrm{K}_0 = -\ln(5\mathrm{BER}_0) \qquad (4)$$

$$\gamma_{N+1} = \infty \qquad (5)$$

Since (1) is only valid for values of $M \geq 4$ , that for $M = 2\ (i.e. n = 1)$ , BER for BPSK should be calculated. $erfc^{-1}(.)$ represents the inverse complementary error function. Average SE is related to the data rate divided by the bandwidth, which in the case of ACR the average SE is given by

$$\frac{R}{B} = \int_0^\infty k(\gamma)p(\gamma)d\gamma \qquad (6)$$

$k$ represents the number of bit per symbol and $\mathrm{p}(\gamma)$ represents the PDF of the channel model.The average SE in the case of ADR is given by[9]

$$\frac{R}{B} = \sum_{i=0}^{N-1} k_i \int_0^\infty p(\gamma)d\gamma \qquad (7)$$

In the case of fixed transmission (non-adaptive), the spectral efficiency is $log_2(M)$, where $M$ is constant (i.e. not a function of $\gamma$). For a Rayleigh fading channel, the PDF of a received SNR is given by

$$p_\gamma(\gamma) = \left(\frac{1}{\bar{\gamma}}\right)e^{\left(-\frac{\gamma}{\bar{\gamma}}\right)} \qquad (8)$$

where $\bar{\gamma}$ is the average received SNR. Average SE in the case of discrete adaptive transmission is a summation of data rates multiplied each term with the probability that the SNR falls in the $n^{th}$ region.

$$\frac{R}{W} = \sum_{n=1}^{N} n a_n \qquad (9)$$

$$a_n = \int_{\gamma_n}^{\gamma_{n+1}} p(\gamma)d\gamma \qquad (10)$$

The Shannon capacity in for variable rate is given by [9]

$$\frac{R}{W} = log_2(e)e^{\frac{m}{\bar{\gamma}}} \sum_{k=0}^{m-1} \left(\frac{m}{\bar{\gamma}}\right)^k \Gamma\left(-\mathrm{k}, \frac{m}{\bar{\gamma}}\right) \quad (11)$$

Assuming Rayleigh channel ($m$=1) that dominated by small scale fading, such as multipath, which is critical for the case of LTE-A transmissions. The spectral efficiency evaluated for Shannon Capacity, ACR and ADR with different regions are shown in Fig.1. For fixed transmission (non-adaptive), where the spectral efficiency is equal to bits per symbol is also illustrated, wherein for BPSK, in the case of Rayleigh channel the BER is given by [9]

$$p_b \approx \frac{1}{4\bar{\gamma}} \qquad (12)$$

As shown from the last equation, it is easy to find $\bar{\gamma}$ at certain BERT, for example, $BERT=10^{-3}$, $\bar{\gamma} = 250 = 24dB$ with spectral efficiency is $log_2(2) = 1$ bits/sec/Hz.

From Fig. 1, several observations are worth noting. First it can be seen that for non-adaptive modulation with same spectral efficiency, it is required *SNR = 24 dB.*

The second observation is that, while ADR regions increase from 3-regions up to 9-regions, in other words from $N = 2$, to 8, the spectral efficiency curve will be close to ACR curve. This is expected since the available regions are increasing, the number of bits per symbol also increase, so it follows the ACR definition by increased number of bits as a function of SNR.

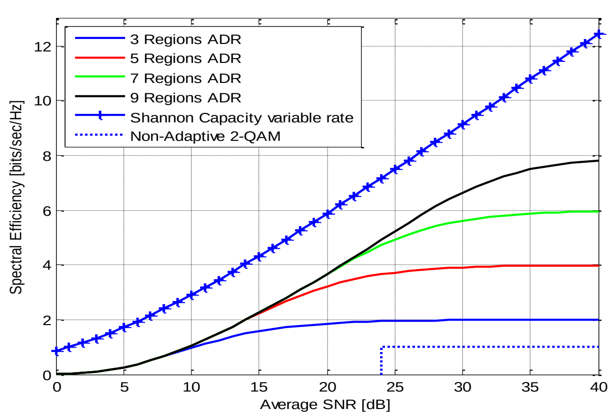


Fig. 1. Spectral efficiency for BERT = $10^{-3}$

ACR M-QAM always operates at BERT [9]. Since ACR is an instantaneous and continuous adaptation, it always meets BERT. While in the case of ADR, the average BER is always below BERT, because the switching thresholds are chosen such that instantaneous BER is always guaranteed to be below BERT. It can be evaluated by finding the BER over a single fading region $BER_n$ and multiplying it with its data rate $n$. Then we can make a summation of all single BER fading regions and divide them over spectral efficiency as shown in the following equation

$$\overline{B\ E\ R} = \frac{\sum_{n=1}^{N} n \int_{\gamma n}^{\gamma n+1} BER_n\left(M_{n,}\gamma\right) p_\gamma(\gamma)\, d\,\gamma}{\sum_{n=1}^{N} n \int_{\gamma n}^{\gamma n+1} p_\gamma(\gamma)\, d\,\gamma} \qquad (13)$$

Fig. 2 represents the average BER for ACR and ADR as shown, ACR always meet BERT, while ADR depends on region size, by increasing region size, BER becomes worst, on the other hand, increasing region size provides constant BER.

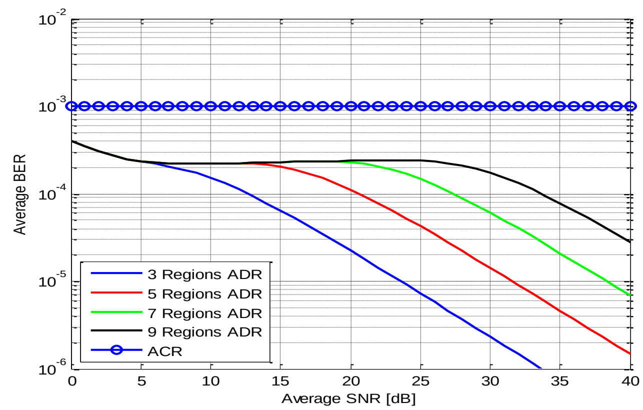


Fig.2. BER for ACR and ADR

## III. Cooperative Relaying Concept

The process of cooperative relaying is achieved through employing two main types of relaying protocols, which are; Decode and Forward (DF) and Amplify and Forward (AF) [10].

In AF relaying, the relay node receives the transmitter signal, amplifies it and forwards it again toward the receiver node. Differently, DF relaying the received signal is firstly decoded at the relay node before being transmitted again toward the receiver node. Single or multiple antennas may be employed at the relay node; the single antenna is usually adopted by the researchers during their investigations. Fig. 3 below illustrates the process of two relaying protocols.

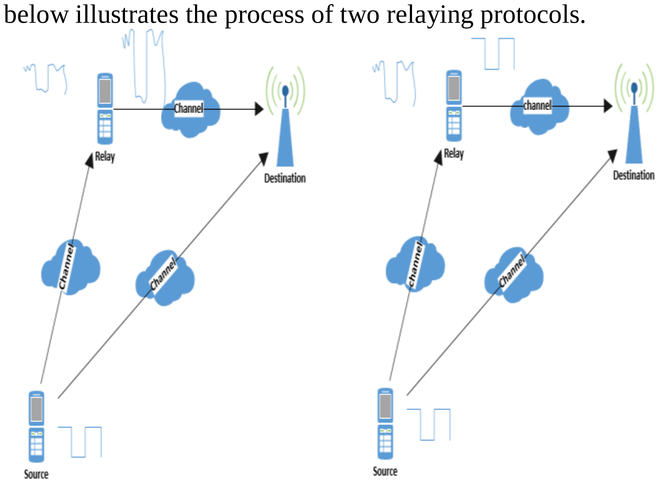


Fig. 3. (a) AF (b) DF cooperative protocol [11]

The source message is able to be transmitted using relay node during the second phase when CSI are obtainable. The destination node may later on utilizes this signal to improve the performance in terms of Bit Error Probability (BEP). A throughput loss is usually occurred when cooperative techniques are employed because of the additional required resources used by the relay node. Adaptive Modulation (AM) is a commonly used approach to compensate this loss and hence achieve throughput performance improvement.

It has been noticed that employing the two mentioned relaying protocols results in a clear degradation with the performance level in terms of the spectral Efficiency (SE). So; the relay node performs the relaying process is usually through using the supplementary orthogonal channel to transfer the signals. Several solutions were proposed in the literature to deal with this problem, such as; link adaption and opportunistic relaying methods. In opportunistic relaying, a certain policy is employed in order to select the superlative relay node from all obtainable relays. Similar trade-off as this obtained by transmission of relay-by-relay type can be achieved when opportunistic relaying is used.

Another common technique may be also effectively employed to enhance the wireless system SE is link adaption algorithm, in which Channel State Information (CSI) is exploited to change different parameters including; symbol rate, code rate, transmitted power, modulation size. Adaptive modulation is permitted to be performed only at the source node in case of using AF type of relaying and it can be performed at both the relay and the source nodes when DF type of relaying is employed. So, more Degree of Freedom (DoF) can be achieved with multi-link adaption type.

## IV. Models of Adaptive Modulation with Cooperative Diversity

This section illustrates the main models of adaptive modulation and cooperative diversity, many models can be viewed from previous literature. In order to classify these models, the first classification can be used to explain the method of using reply either amplifying the signal and forwarding (AF) it to the receiver or decoding the signal and forwarding (DF) it to the receiver. The second classification can be related to the model of cooperative diversity, there are many models for cooperative diversity like using a single relay, dual hop relay formulate relaying. Fig. 4 illustrates different models and the main references that related to that model.

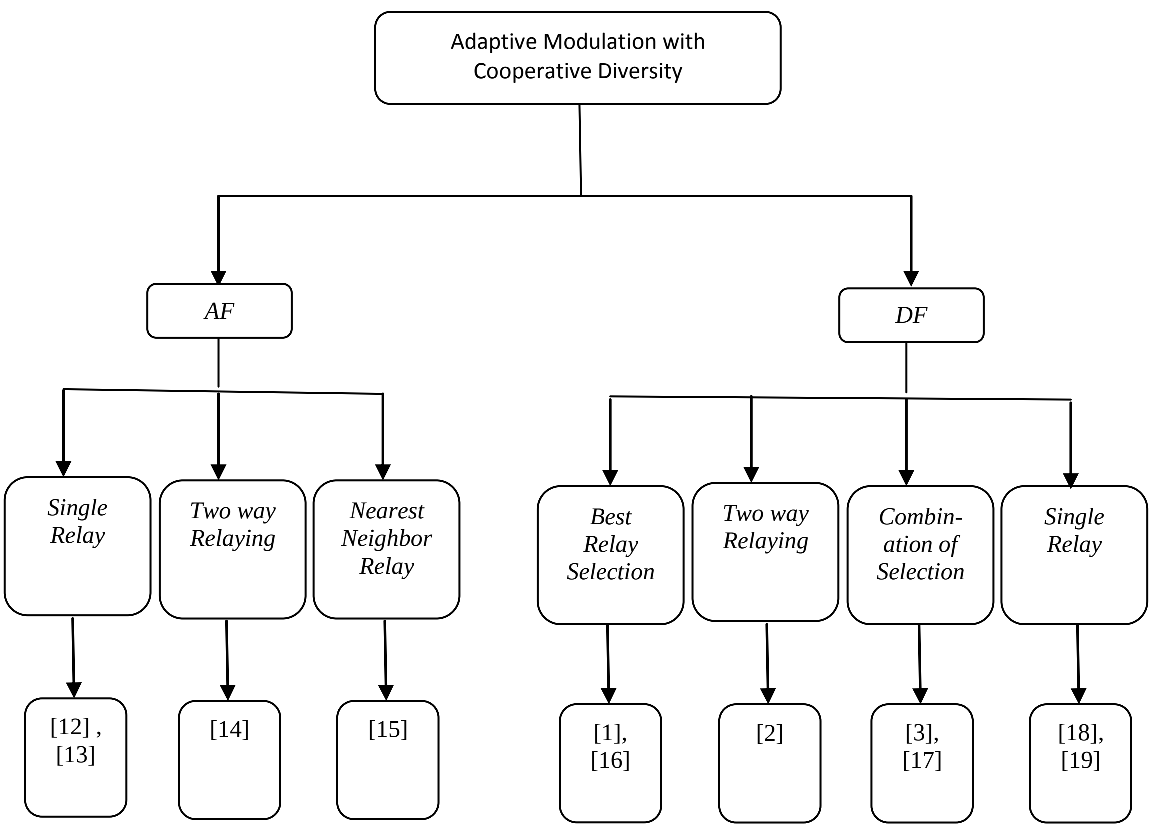


Fig. 4. Models of Adaptive Modulation and Cooperative Diversity

## V. REVIEW OF SYSTEMS AND SOLUTIONS

In practice, cooperative relaying is an efficient technique that utilized to enhance both the coverage and spatial diversity. Therefore, authors in [16] developed an advanced relay scheme called $N^{th}$ best path relay selection in order to enhance the bandwidth penalty and improve the spatial diversity based on utilizing a sub-optimal allocation for the relay virtual distance among the destination and source nodes that communicate over a flat Rayleigh fading channel in two dual-hop mixed relaying cooperative networks. Table 1 below introduces a comparative summary for some of the presented researches and studies during the last few years. The comparison is performed employing different criteria, including; type of modulation, type of cooperative diversity, finally the main outcomes achieved in each of the considered research.

## VI. CONCLUDING REMARKS

As a conclusion, this survey paper reviewed the cooperative diversity and adaptive modulation techniques with different diversity schemes in wireless communication system. These techniques are the most two commonly used ones in improving the performance of the wireless communication system in terms of several criteria, including; BER, SNR, SE and throughput. The paper highlighted the concepts of cooperative communications and adaptive modulation techniques and investigated their processes in improving the achievable performance. Several recent works that are related to the survey topic and conducted by the researchers in the literature were introduced and analyzed in terms of their concepts, main methods and their results. Set of main factors were used to evaluate and compare the performance of these studies, which are, modulation type, diversity type, fading distribution, importance and main outcomes. From the literature comparisons, all proposed models and schemes confirmed the effectiveness of applying cooperative diversity in enhancing the wireless system performance and the usefulness of adaptive modulation in compensating the throughput degradation occurred due to using the additional resource at the relay node. It can now be stated that combining adaptive modulation and cooperative diversity is essential for further improvement of the wireless system performance.

Table 1.Summary Table For Recent Works

| Previous Study | Modulation Type | Cooperative Type | Contributions |
|---|---|---|---|
| [20] | 4-QAM, 16-QAM | DF with MRC | Clear improvement in the performance maintaining other performance criteria constant. |
| [21] | M-PSK, M-PAM, M-QAM | DF | Closed formula for relaying threshold |
| [22] | M-QAM | DF | Closed formulas for OP, BER and SE. |
| [23] | M-QAM | AF | Applying AF cooperative to Adaptive Modulation to improve the throughput |
| [24] | QPSK and BPSK | AF | Best power allocation scheme |
| [25] | M-QAM | AF/SC | Deriving a closed formula for SNR threshold required to activate different modulation modes |
| [26] | M-QAM | AF | Exact SE formula. Derivation of System PDF formula |
| [27] | $2^{M}-\text{PSK}$ | DF | Exact and Approximate rules for average rate |
| [28] | M-QAM | AF | optimum switching levels and fixed switching levels in adaptive modulation |
| [29] | M-QAM | DF | BER-SC and SNR-SC systems |
| [30] | M-QAM | DF | Derivation for the probability of packet loss and also for system throughput for both Hybrid Automatic Repeat Request (HARQ) and cooperative HARQ (CHARQ) |
| [31] | M-PSK, M-QAM | AF | A model for Inter-vehicular cooperative communication was developed. |
| [32] | 64QAM, QPSK, 16QAM | DF/MRC | Novel encryption algorithm for physical layer was presented. |
| [33] | M-QAM | single relay | Studying the fading effect in feedback channel |

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