Smart Relay Protocols for Throughput Optimization using AMC in LTE-Advanced Systems

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***Abstract*— We propose an Adaptive Modulation and Coding (AMC) scheme using relay protocols AF, DF and DMF. The AMC scheme is used for improving the throughput and reliability of a communication system, using different modulation and coding schemes. We analyze the performance of relay protocols with the AMC scheme and observe that relay protocols with the AMC scheme are capable of providing better average throughput at a lower Signal to Noise Ratio (SNR) level as compared to the conventional scheme with no AMC. We perform Monte Carlo simulations based on 3GPP Long Term Evolution-Advanced (LTE-A) parameters to prove the performance comparison of adaptive Modulation and Coding Scheme (MCS) relay protocols with non-adaptive MCS relay protocols. The simulation results of the proposed system with adaptive MCS prove that among the Amplify-and-Forward (AF), Decode-and-Forward (DF) and De- Modulate-and-Forward (DMF), the DMF protocol performs best, at a lower SNR value and higher average throughput.**

Keywords-AF; DF; DMF; AMC; LTE-A.

I. INTRODUCTION

In recent years, relaying technology in cellular systems has received significant interest. Relay based network architectures show promising interest in potential and practical applications as LTE-Advanced [1-3]. Cooperative communications can exploit the distributed spatial diversity in multiuser systems to combat the impairments of wireless channels. This is particularly useful when each node can only be equipped with a single antenna. Without channel feedback, the conventional cooperative protocols, such as Amplify-and-forward (AF), Decode-and-forward (DF), etc, can offer a diversity gain by allowing nodes a fair opportunity to transmit messages through their own channel [4-6]. On the other hand, if the Channel State Information (CSI) is available to the senders, the system can re-allocate the radio resource among the senders to improve the communication efficiency. Furthermore, all the nodes are allowed to adapt their data rates to match the channel conditions, such that the throughput is maximized [7-8]. Motivated by this fact, we consider adaptive modulation for various protocol systems. Adaptive Modulation and Coding (AMC) [9-13] can provide high spectral efficiency, meanwhile the reliability of data can be guaranteed. Thus, adaptation features make it attractive for further research in several areas, in particular if a high data rate is among the expected results. Our proposal consists then, in the combination of MIMO and AMC schemes in one single system: Adaptive-MCS. The optimal selection of the coding rate, modulation and relay protocols scheme result is an improvement of the data rate and system reliability. The goal is to maximize the data throughput and system efficiency.

The structure of the paper is organized as follows: Section 2 describes the system model and adaptive MCS with Relay. Section 3 explains the proposed criteria for adaptive MCS selection in the relay system, and Section 4 presents the simulation results and analysis. Finally, conclusions are discussed in Section 5.

II. SYSTEM MODEL AND ADAPTIVE MCS WITH RELAY

Assume that the channel gains are completely known at the transmitter and the receiver and remain unchanged during a packet transmission. In a block fading channel, it is feasible to implement a reverse link to send back channel information, and the assumption is practical. At the relay node, we process three protocol types AF, DF and the DMF protocol. The AF and DF protocols are considered as conventional protocols in the fixed relay system which are already adapted by the LTE-A. We analyze the consistency and efficiency of the DMF protocol with MCS comparing the results with conventional designed algorithms.

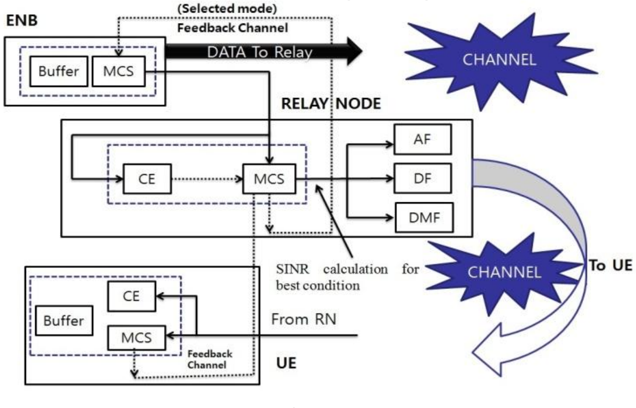

Figure 1. System Model of Relay with AMC based system

In Figure 1, we describe the structure of the Adaptive-MCS system with RN operation. At the Evolved Node B (eNB), the data is coded, interleaved, modulated and then, transmitted through the channel. Once at the receiver the channel condition is estimated with an SNR criterion, and this information is sent back to the transmitter, which decides which MCS level to use. The previous channel condition parameters are stored in a buffer. When the signal arrives at the Relay Node (RN), we select the protocols for various scenarios by first analyzing the channel parameters given by the Channel Evaluator (CE) from the RN–UE link. As per the performance of CE, the suitable MCS level is chosen for the best average throughput performance. Choosing the MCS level means to select a specific code rate and modulation scheme according to the estimation of the channel conditions. Based on the idea of pre-evaluated channel quality, we select the favorable relay protocol. This data is then sent to the User Equipment (UE). The UE also analyzes the CE, based on the channel condition between RN-UE links. If the channel condition is favorable, a high order of modulation and code rate are used. Otherwise, a low order of modulation and code rate are selected. With the appropriate MCS level, AMC can obtain both excellent throughput performance and quality for a specific channel condition.

III. PROPOSED CRITERIA FOR ADAPTIVE MCS SELECTION AND PROTOCOL DESIGN

Adaptive Modulation and Coding is performed according to several SINR regions. Here, we first discuss the region boundary for the modulation regarding the modulation adaptation among various schemes of modulation as QPSK and 16-QAM, with a code rate of 1/3 and 3/4.Let Υ_{sr} and Υ_{rd} denote the received SINR of the SR and RD link. P_{SR} & P_{RD} can be the error probability for the Source-Relay link and Relay-Destination link, respectively. If the RN can obtain data correctly with the probability of $(1\text{-}P_{SR})$, the final errors are calculated from the detection of the combined SD and RD link, P_{SD}. When the relay cannot acquire the data correctly at the SR link the probability is given by, P_{SD}. Thus, the total BER for this state is given by (1)

$$P_e = (1 - P_{SR})P_{SD} + P_{SR} \qquad (1)$$

We know that BER of M-QAM modulation can be obtained as (3)

$$\mathrm{P} = \alpha \mathrm{Q}\sqrt{\beta\gamma} \qquad (2)$$

where, $\mathrm{Q(x)} = \frac{1}{\sqrt{2\pi}}\int_{\mathrm{x}}^{\infty} \mathrm{e}^{\frac{-\mathrm{u}^2}{2}}\,\mathrm{du}$, where α and β are decided by the modulation scheme. But, the above scheme is complex for inversion. So, to simplify the above design and performance analysis, we model the expression, where n is the MCS level, as

$$\mathrm{BER_n}(\gamma) \cong \alpha_{\mathrm{n}} \exp(-\mathrm{b_n}\gamma) \qquad (3)$$

Here, we analyze various characteristics of the scheme comprising the Adaptive-MCS with Relay.

A. *Precoding Scheme*

The pre-coding scheme is located at the eNB. This improves the system performance by using the estimated channel information calculated at the RN. There are several techniques used for pre-coding, such as Pre-Zero Forcing (ZF) and Pre-Minimum Mean Square Error (MMSE).

B. *Relay Protocols with AMC*

The relay protocols considered in our research paper are AF, DF and DMF. We will now evaluate various relay protocols with AMC. Figure 2 shows a flowchart of the Relay scheme with AMC. Firstly, the Channel State Information (CSI) is calculated based on the link condition and estimation. Then each protocol is selected as per the situation since all protocols have the same amount of maximum throughput. Suppose, we select the DMF protocol. Then, we check the given MCS level. In the MCS level, we then check the type of the code rate and modulation. When satisfied as defined by the condition, we again check the CSI for the next link of relay and the UE, as stored in the buffer at the relay node. Based on the estimation of the CSI, we make the error check of the present CSI and previous CSI. If the state is true we can then calculate the final throughput estimate as per the given MCS level; otherwise, we need to recheck the MCS level and append the new CSI value in the relay node. Then, we need to verify the MCS level for the RN-UE link. Once the throughput is estimated, the new data frame, which is needed to be transmitted to the UE with lower error probability, needs to be verified. The dotted part in the flowchart shows the main performance area in the algorithm.

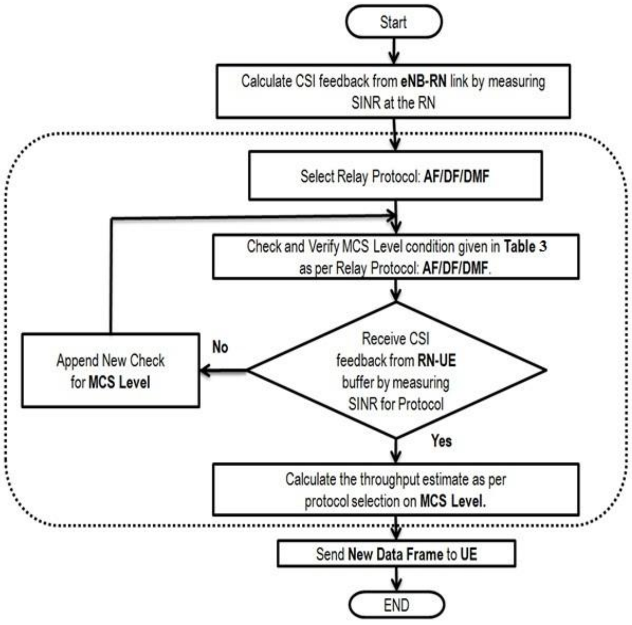

Figure 2. Flow Chart of AMC with Relay Scheme

C. *AF with MCS*

Simply called an AF protocol, the relay tends to scale the received version of the signal and transmits an amplified version of it to the destination or UE. It is the most basic type of fixed relay. It simply amplifies the received data and then forwards it to the UE. The relay is usually not capable of performing in a bad channel condition as it amplifies the noise factor of the received data vector. But in order to compare its performance with a new DMF protocol, we use AF for analysis as a reference case of the standard known protocol. When MCS is applied to the AF with various code rates and modulation schemes we can observe the progressive improvement in the case of adaptive MCS [10]. As given in Figure 1, when we select the AF protocol, then as per the channel condition, the SINR value is estimated from the channel evaluator, by using the precoding scheme at the RN and the UE.

D. *DF with MCS*

The relay node is for the relay to decode the received signal, re-encode it, and then retransmit it to the receiver. This kind of relaying is termed as a fixed decode-and-forward (DF) scheme, which is often simply called a DF scheme.

In the basic DF relaying scheme, we implement SINR estimation using precoding methodology, which actually evaluates the channel and helps to estimate the SINR value with channel quality. The decoding operation is repeated multiple times which helps in improving the system performance by noise and interference reduction.

E. *DMF with MCS*

DMF protocol signal processing is an alternative to DF signal processing to reduce receiver power consumption due to channel decoding at the relay as well as to minimize the overall delay at the destination. In the DF schemes previously described, the relay forwards the source’s message only if it is able to successfully decode. However, in many applications, channel decoding may not be desirable at the relays either due to limited transceiver capabilities or due to lack of knowledge of the channel codebook. In this case, the signals transmitted by the source can only be detected or demodulated on a symbol-by-symbol basis. At this position there is a need for a relay protocol capable of performing much better in decoding performance. So, we design a new protocol capable of performing in both cases whereby in the bad decoding case it is capable of maintaining the high error bits decoding with soft decoding and the higher modulation scheme.

IV. SIMULATION RESULTS

The simulation results are based on the link level Monte Carlo simulations. Noise components are the same at all channel links, but channel fading component changes increase and decrease, based on the links, as eNB-RN link and RN–UE link characteristics. Table I shows the simulation parameters based on 3GPP LTE-Advanced 20 MHz bandwidth.

TABLE I. SIMULATION PARAMETERS FOR 20MHZ

Parameter	Value
Carrier Frequency	2 GHz
Bandwidth	20 MHz
Subcarrier spacing	15 KHz
Sub frame Duration	1 ms
FFT Size	2048
No. of subcarriers/PRB	12
Channel	EPA, EVA, ETU
Modulation scheme	QPSK,16 QAM
Noise	AWGN
Relay Node (RN)	1
Relaying Protocol	AF, DF, DMF

A. *FER, SER and BER Analysis of AF,DF and DMF Protocols*

We will now discuss the error performance and analysis of all three protocols in order to clarify their behavior in our adaptive MCS relay system.

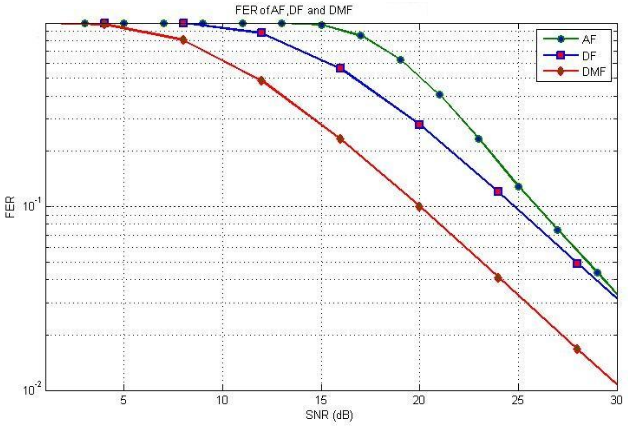

Figure 3. FER results with AF,DF and DMF protocols.

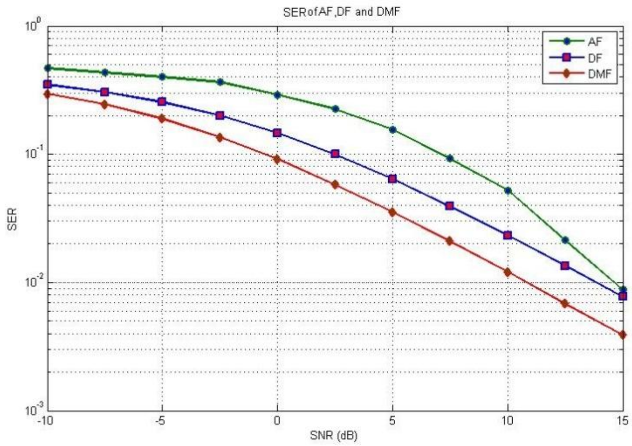

Figure 4. SER results with AF,DF and DMF protocols.

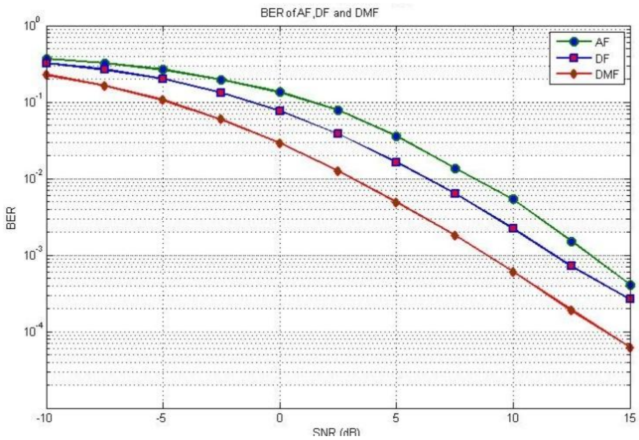

Figure 5. BER results with AF,DF and DMF protocols.

Figure 3 presents the Frame Error rate (FER) performance for the 3 kinds of protocols. We can clearly observe that the performance of the DMF protocol shows a very high trade off compared to AF and DF protocol. The tradeoff between AF and DF at higher SNR shows very little error performance advantage but on the other hand the DMF protocol shows explicit performance.

Figure 4 analyzes the Symbol Error Rate (SER) performance analysis of the AF, DF and DMF protocol. Compared to Figure 3 the performance of AF, DF and DMF show slight improvement in performance. Te simulation examines the error probability based on each symbol transmission. Therefore, compared to the FER performance this figure demonstrates better results, as the error encountered in the symbol rate is much more reduced in comparison to the frame error of each case.

Figure 5 shows the Bit Error Rate (BER) analysis, which still shows better error performance for DMF compared to the AF and DF protocols. Here, we can observe that even at an improved error performance than compared than to the FER or SER, AF and DF performance are very close at lower SNR values, whereas, the performance of DMF still shows better results than the conventional protocols.

B. *Non-Adaptive MCS with AF,DF and DMF Protocols*

Table II shows the Non-Adaptive MCS level table, with various MCS level for AF, DF and DMF protocols based on the code rate, as turbo coding with 1/3 and 3/4. The modulation schemes followed in this case are QPSK and 16-QAM. We observed various values of maximum throughputs in different code rates and nodulation schemes.
The maximum throughput achieved by all the coding schemes and modulation schemes are different at various levels. The maximum throughput in all MCS is independent of the nature of protocol.

TABLE II. NON-ADAPTIVE MCS WITH RELAY

MCS Level	Protocol	Code Rate	Modulation	Max. Throughput (Mbps)
1	AF	1/3	QPSK	14.4
2	AF	3/4	QPSK	21.6
3	AF	1/3	16-QAM	28.8
4	AF	3/4	16-QAM	43.06
5	DF	1/3	QPSK	14.4
6	DF	3/4	QPSK	21.6
7	DF	1/3	16-QAM	28.8
8	DF	3/4	16-QAM	43.06
9	DMF	1/3	QPSK	14.4
10	DMF	3/4	QPSK	21.6
11	DMF	1/3	16-QAM	28.8
12	DMF	3/4	16-QAM	43.06

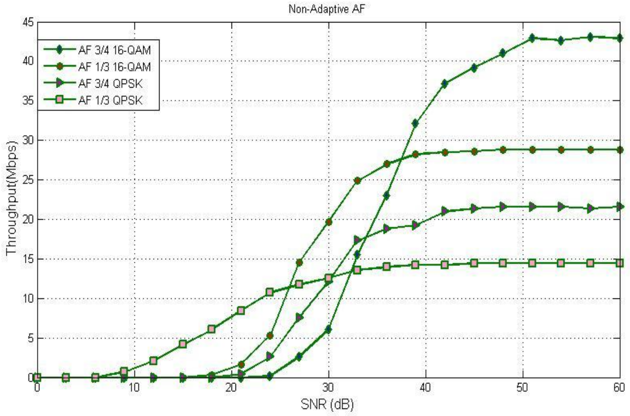

Figure 6. Throughput of Non Adaptive MCS AF Protocol.

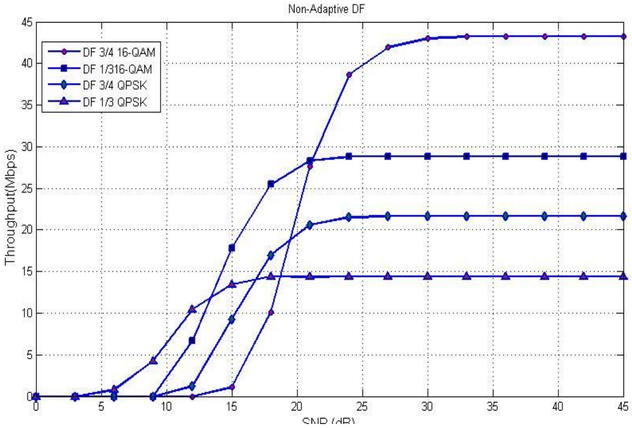

Figure 7. Throughput of Non Adaptive MCS DF Protocol.

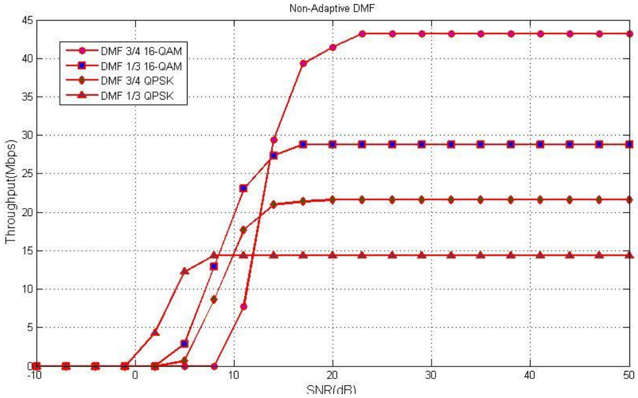

Figure 8. Throughput of Non Adaptive MCS DMF Protocol.

Figure 6 shows the maximum throughput values at different code rates for the AF protocol. The maximum throughput for code rate 1/3 with QPSK is observed, of approximately 14.4 Mbps. As the code rate is increased in the case of the same modulation, we can observe an increase in throughput at 21.6 Mbps. However, we have to compromise with SNR performance in this case. Similarly, with the increase in the modulation scheme, we can observe the increase in throughput rate. Finally, we observed that the higher the code rate and modulation, the higher the throughput but we have compromised the SNR performance which is gained at a very high SNR.

Figure 7 shows the performance analysis for the Non - Adaptive MCS DF protocol. The maximum throughput is the same in the case of AF and DF, as seen in Table 2. But, as we observe the values of SNR tradeoff we can see a considerable gain in the throughput case. We can observe that better decoding schemes improve the relay performance for relay code rate and modulation.

Figure 8 shows the throughput of the Non-Adaptive MCS DMF protocol, as the case of AF and DF. We can understand that the code rate and modulation is the same for all protocols and so is the maximum throughput as seen in Table 2. If we look at the SNR Performance we can see that the DMF protocol achieves higher throughput at lower SNR values.

C. Non-Adaptive MCS with AF,DF and DMF Protocols

Table III shows the values for the Adaptive MCS level for the AF, DF and DMF Protocol for various values for code rate and modulation scheme. We made observations and analysis on the basis of Signal-to-Noise-Ratio (SNR) and Average Throughput in Mega bit per second (Mbps).The rate are chosen based on the best code rate and best modulation scheme provided, with the highest throughput order [10].

TABLE III. ADAPTIVE MCS WITH RELAY

MCS Level	Protocol	Code Rate	Modulation	SNR (dB)	Avg. Through-put (Mbps)
1	AF	1/3	QPSK	21	12.384
2	AF	1/3	16-QAM	36	26.976
3	AF	3/4	16-QAM	51	42.984
4	DF	1/3	QPSK	12	10.468
5	DF	1/3	16-QAM	21	27.65
6	DF	3/4	16-QAM	30	42.984
7	DMF	1/3	QPSK	8	14.4
8	DMF	1/3	16-QAM	14	27.36
9	DMF	3/4	16-QAM	23	42.984

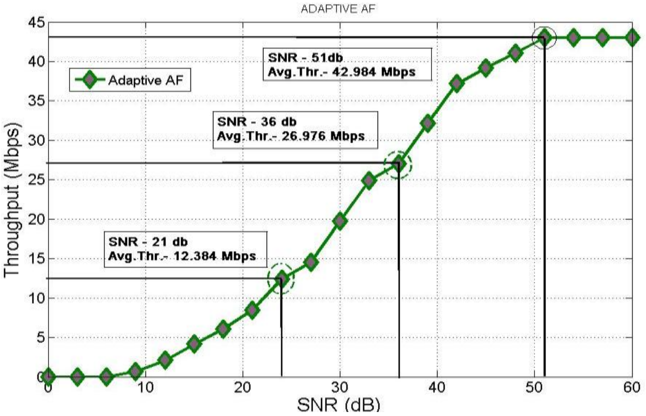

Figure 9. Adaptive Thorughput of adaptive MCS AF Protocol

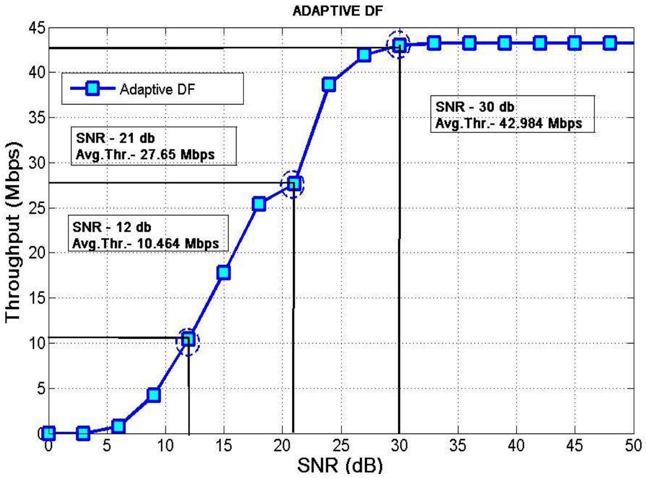

Figure 10. Adaptive Thorughput of adaptive MCS DF Protocol

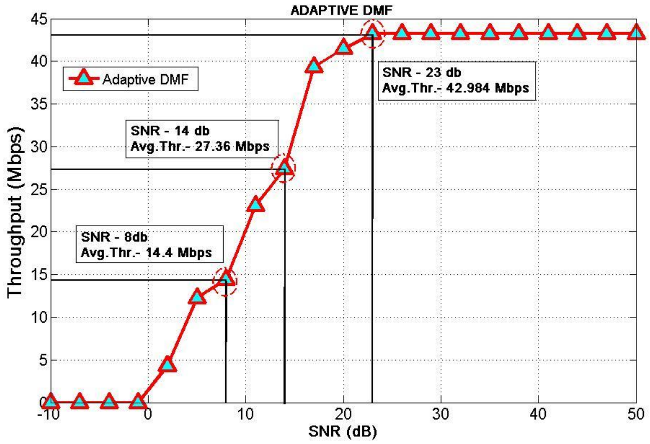

Figure 11. Adaptive Thorughput of adaptive MCS DMF Protocol

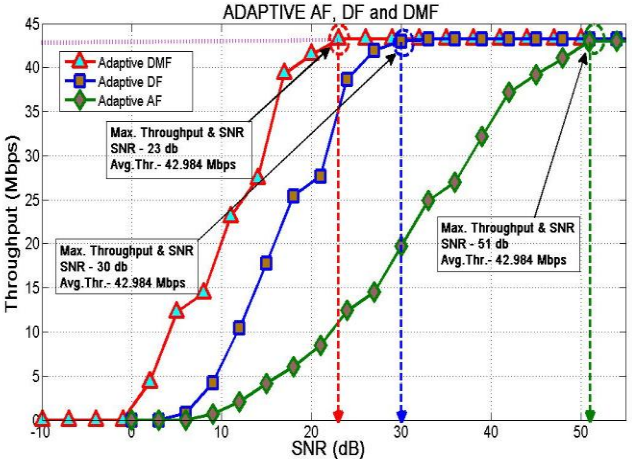

Figure 12. Average Throughput Analysis of Adaptive MCS Relay Protocols

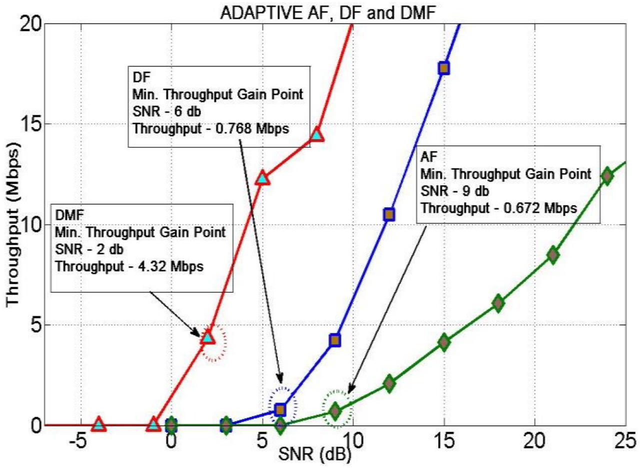

Figure 13. Maximum Throughput Analysis of Adaptive MCS Relay Protocols

Figure 9 shows the average throughput of the adaptive MCS AF protocol. We analyzed the new MCS level for the specified code rate and modulation schemes for the AF case to achieve the average throughput and maximum throughput at the same time. The rapid increase in the throughput is calculated on the basis of maximum throughput achieved at lower code rates and lower modulation schemes. As analyzed points are shown in Figure 9 the MCS level 1on SNR at an average throughput of 21 dB was 12.364 Mbps. Then the MCS level 2 is switched to SNR 36 dB point and an average throughput of 26.976 Mbps. Following this, MCS level 3 is switched until the maximum throughput is achieved at SNR 51dB with an average throughput of 42.984 Mbps.

Figure 10 shows the average throughput of the adaptive MCS DF protocol. The rapid gain in average throughput is observed similarly to the case of AF. As analyzed points are shown in Figure 10 the MCS level 4 is selected first on SNR at 12 dB at an average throughput of 10.468 Mbps, then the MCS level 5 is switched to SNR 21 dB point and average throughput of 27.65 Mbps, and then to the MCS level 6 is switched till the maximum throughput is achieved at SNR 30dB and an average throughput 42.984 Mbps. As far as the maximum throughput is considered it is the same for all protocols.

Figure 11 shows the average throughput of the adaptive MCS DMF protocol. The rapid gain in average throughput is observed best in the case of DMF. As analyzed points are shown in figure 11 the MCS level 7 is selected first on SNR at 8 dB at an average throughput of 14.4 Mbps, then the MCS level 8 is switched to SNR 14 dB point and average throughput of 27.36 Mbps, and then the MCS level 9 is switched till the maximum throughput is achieved at SNR 23db and an average throughput of 42.984 Mbps. The maximum throughput is considered the same for all protocols but the SNR gain is best in the case regarding the DMF protocol

Figure 12 shows the Maximum throughput analysis comparing all the protocols in the case of the adaptive relay with MCS. Here, we observe that the DMF protocol shows a gain of 7 dB compared to the DF protocol. DMF attains the maximum throughput at the SNR of 23 dB and the DF gains maximum throughput at 30 dB. Similarly, as compared to the DF and DMF, AF gains maximum throughput at 51dB which is far worse than the case of DF and DMF clearly shows an SNR gain of 21 dB.

Figure 13 shows the performance of the AF, DF and DMF Adaptive MCS relay with minimum average throughput. This is in contrast with the Maximum throughput case where DMF and DF show very close performance but the performance of AF and DF show a dramatic change in gain and prove AF as the worst. In this case, DMF shows the Minimum throughput gain at 2 dB with 4.32 Mbps, whereas DF shows a throughput gain at SNR 6 dB with 0.768Mbps and AF shows SNR 9 dB and a throughput of 0.672 Mbps. This shows that in contrast of the maximum throughput, the minimum throughput demonstrates that the DMF protocol has consistent performance at high and low SNR values.

V. CONCLUSION

We propose an AMC scheme using relay protocols like AF, DF and DMF. The behaviors of these protocols are analyzed on parameters of FER, SER, BER, maximum throughput, average throughput and minimum throughput. We use the AMC scheme for improving throughput and reliability, because of the nature of different modulation and coding schemes. The simulation results of the proposed system with adaptive MCS prove that among the AF, DF and DMF protocols, the DMF protocol performs best specifically at a lower SNR value and also provides better average throughput. We observed that the proposed DMF protocol is capable of performing with the best performance in lower and high SNR values and with high consistency and provides the best throughput efficiency. The main consideration point in the proposed mechanism is the application of the DMF protocol, which when implemented with the AMC scheme shows outstanding results compared to the conventional AF and DF schemes.

ACKNOWLEDGMENT

This research was supported by the MSIP (Ministry of Science, ICT & Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (NIPA-2013-H0301-13-3005) supervised by the NIPA (National IT Industry Promotion Agency. This study was financially supported by Chonnam National University, 2012. This research is supported by Korea Research Council for Industrial Science and Technology under B551179-12-07-00.

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