Performance of cooperative relay protocol in 5G mobile communication network over Rayleigh fading channel

Akinyinka Olukunle Akande and Cosmas Kemdirim Agubor

Department of Electrical and Electronic Engineering,
Federal University of Technology Owerri,
P.M.B 1526, Imo State, Nigeria
Email: akandeoluk@gmail.com
Email: kemdirim2014@gmail.com
*Corresponding author

Wasiu Akande Ahmed

SNARS Research Laboratory,
Beihang University, Beijing,
P.M.B.100191, China
Email: wasto2007@gmail.com

Olalekan Ogunbiyi

Department of Electrical and Computer Engineering,
Kwara State University, Malete,
Ilorin, Nigeria
Email: biyikan@gmail.com

Olusola Kunle Akinde

Department of Electronic and Electrical Engineering,
The First Technical University, Ibadan,
Oyo State, Nigeria
Email: olusola.akinde@tech-u.edu.ng

Abstract: This paper presents the performance of a new cooperative relay protocol in mobile network over Raleigh environment. Characteristically, the 5G network at 28 GHz covers short distances due to its shorter wavelength. Extending network coverage area and improvement of signal quality is a necessity. In this work, high performance hybrid relay nodes were proposed to improve quality of the signal and increase the signal coverage distance. Mathematical expression was successfully derived for new hybrid decode amplify forward (HDAF) protocol. The destination node combines received symbols from hybrid relay nodes and source node using maximal ratio combiner (MRC) for optimal performance. The performance of the developed model was evaluated using bit error rate (BER), outage probability (P_{out}) and processing time (P_{time}) at different signal to noise ratio (SNR).

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Comparatively the developed HDAF protocol performed better than DF and AF by having a lower BER, P_{out} and P_{time} values. The result also shows that HDAF relay protocol has the potential to mitigate signal interference and extend the coverage area in 5G network.

Keywords: 5G network; amplify-forward; bit error rate; BER; mobile network; maximal ratio combiner; MRC; outage probability; processing time; Raleigh; relay nodes; signal to noise ratio; SNR.

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Biographical notes: Akinyinka Olukunle Akande received his BTech in Electronic and Electrical Engineering from Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, MEng in Electrical and Electronic Engineering and a PhD in Communication Engineering from University of Ilorin and LAUTECH, respectively. He is presently a Lecturer at Federal University of Technology Owerri. His research area is in 5G/6G wireless communication technologies and resource management in cognitive radio networks.

Cosmas Kemdirim Agubor received his BEng, MEng and PhD degrees in Electrical and Electronic Engineering. He was an Engineer with the Nigerian Telecommunications Limited (NITEL) and rose to the rank of an Assistant Manager. He is currently an Associate Professor in the Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria. His research area is in wireless communication with special interest in Antenna systems.

Wasiu Akande Ahmed has a Master and PhD in Wireless/Satellite Communication, at School of Instrumentation and Opto-electronics Engineering, Beihang University, China. He also had MEng Electrical/ Electronics and BEng Electrical/Computer Engineering from University of Ilorin and Federal University of Technology, Minna, Nigeria in 2014 and 2007 respectively. He lectures at Centre for Space Science and Technology Education. He won 2020 excellent and second best graduating PhD. student.

Olalekan Ogunbiyi received a PhD in Electrical Engineering from University of Ilorin in 2018. Earlier, he obtained his Bachelor's and Master's in Electrical and Electronics Engineering from the same University in 2009 and 2013 respectively. His research interests and specialisation include automatic control system and embedded system. He lectures in the department of Electrical and Computer Engineering, Kwara State University, Nigeria.

Olusola Kunle Akinde received his MEng and PhD in Computer and Electronic Engineering at the Federal University of Technology, Owerri, Nigeria. He is currently a Lecturer with the Department of Electrical and Electronic Engineering, The First Technical University, Ibadan, Nigeria. His research interests include real-time embedded and distributed systems, intelligent systems, security and monitoring systems.

1 Introduction

Mobile wireless communication technology has witnessed a remarkable growth in the number of users in the past two decades. These have brought notable improvement in voice and data communications (Dong et al., 2016). The rapid use of applications of wireless technology, such as live video streaming, zoom meeting, Facebook, Twitter, and Instagram is evident in this direction. The future generation demands higher data rates (HDR) to enhance high quality of service (QoS) in mobile network (Wang et al., 2017). The demand for HDR in mobile radio system is a big task to network provider. In this case, a better technique is needed to achieve high data rates in mobile network. The increase in data rate and reduction of latency are important factors for a system migrating to 5G mobile communication network (Jinjin et al., 2017).

Recently, wireless communication is highly demanded and everyone want to be connected online everywhere at any time in search of useful information. As a result of this, wireless communication system is designed to ensure uninterrupted service delivery to the mobile users even at a very high speed (Qiang et al., 2016). However wireless communication suffers from channel impairment, such as signal attenuation, interference, and multipath propagation (Qamar and Hindia, 2019). These challenges have been seen to have led to the degradation of the system performance in recent times. Based on this fact, diversity techniques and cooperative relaying are some of the numerous methods to mitigate network problem and poor signal coverage (Jianhua and Chensi 2016).

Cooperative relay technology is an important technique to improve spectrum efficiency in wireless network (Akyildiz et al., 2016). Relay system is capable of amplifying signal due to channel obstruction, and extend network coverage (Khafagy et al., 2015; Jiang et al., 2016). The amplify-forward (AF) and decode-forward (DF) protocols are relay schemes that amplify and retransmit signals in wireless system to improve signal power at the destination (Jiang et al., 1016). In AF protocol, the noisy signal is first amplified by cooperative relay, and retransmits the signal to the receiver, while DF protocol decodes the signal information, re-encodes it, and then forwards it to the destination (Ray et al., 2009). However, wireless communication systems are confronted with some channel problems, such as multipath, interference, and signal attenuation. The diversity techniques, such as MRC, equal gain combiner (EGC), and Selection Combiner (SC) are deployed to obtain strong and reliable signal at the receiver.

The MRC has the ability to weigh all received signal from the branches and then sum them up to obtain a better performance and more quality signal at the receiver (Hiu et al., 2015). The modulation technique is a method of sending the baseband signal into high frequency for effective transmission of information in the channel. Some of the frequently used modulation schemes are BPSK, quadrature amplitude modulation (QAM), and QPSK (Hiu et al., 2015). The relay protocols transmit signal information from source to improve network performance in the channel (Temesvaria and Peter, 2019; Yarrabothiu and Telagathoti, 2019). In this case, the relay nodes can increase the covering distance, and also reduce signal power loss (Jehuda, 2007).

The relay cooperative communications can be deployed to mitigate multipath fading and shadowing effects in mobile channel. The relay strategy has shown that the coverage of cellular network can be extended without extra bandwidth, or higher mobile transmission power (Chandra et al., 2016; Shahid et al., 2017). The idea is to transmit signal with the help of friendly neighbouring user's node called relay. The users cooperate in transmitting messages to the receiver. This concept allows network operator

to install relay nodes at a distance between the base and mobile station to improve QoS and network coverage (Chandra et al., 2016).

The existing models lack the capability to produce good network coverage in 5G network as a result of its shorter wavelength (Dong and Zepermick, 2009). In this case, cooperative relay when deployed can achieve increase signal coverage and robust network information at the destination (Asshada et al., 2019). Cooperative relay is also a very good tool in wireless communication system, which can be deployed to solve different channel impairment (Honhxing et al., 2019; Gilan and Nguyen 2020). Some of the challenges of 5G network include coverage, interference, and security issues (Khan et al., 2012; Bia et al 2015; Alejel 2016). The problem here is that 5G antenna has the capacity to handle large number of users and high data rate, but the signal covers short distances (Zhang et al., 2016; Mudhusud et al., 2017).

In this work, a new HDAF model is proposed, and mathematical expression for the system was developed. The BPSK and QPSK modulation scheme was deployed with MRC containing matched filter to obtain a robust and non-overlapping signal. A computer simulation was carried out using MATLAB 2018a software. The developed new Hybrid Decode Amplify Forward (HDAF) protocol was evaluated using metrics, which includes BER, P_{out}, and P_{time}, at different SNR over Raleigh fading channel.

These parameters are suitable metrics for the determination of the performance of a digital communication system. The BER comparison of the proposed model with existing models shows a better performance of the proposed model. It was observed that the proposed HDAF model gave lower values of BER with increase in SNR compared to corresponding values of DF and AF protocols. This was also same when P_{out} and P_{rime} were used for the comparison. The result of the comparison shows that the proposed model is better than the existing ones.

The developed hybrid relay protocol has the capacity to amplify and decode the signal based on the condition of the information broadcasts to the destination. In the first phase of decode-forward relay, if the signal information is decoded correctly by the DF protocol, it is re-encoded and forwarded to the destination. This means that signal level did not fall below the set threshold level, otherwise, AF protocol will forward the amplified signal to the destination combiner. Moreover, to overcome challenges of poor network coverage, a new hybrid 5G compatible relaying protocol is essential to enhancing better network coverage and throughput. In general, deployment of the relay nodes is paramount for the improvement of network coverage. Hence, there is a need to design a better model to provide better signal coverage and to mitigate interference, due to large numbers of antenna in 5G network.

2 Related works

Chandra et al. (2016) presented the performance analysis of the outage probability in AF relay network. The authors compared direct signal from source with signals through relay nodes at the destination. The result showed that outage probability of the signal through relay nodes reduced with selection combining and maximal ratio combining diversity methods. The author did not propose any new model for better performance of the

network. The performance of adaptive DF and AF relay protocols were investigated in Dong and Zepermick (2009). The results showed that the performance of adaptive DF and AF depended on the channel conditions from source to the destination. Mathematical model for symbol error probability was derived for the relay protocols, but no new hybrid protocol was presented in the published work.

Asshada et al., (2019) discussed the review of cooperative relay system for next generation network. It was reported that cooperative relay may be used to achieve better network performance in mobile systems. Gilan and Nguyen (2020) also discussed the performance of the decode forward (DF) protocol for symbol transmission. The author did not report any new relay model in the published work. Hongxing et al., (2019) presented the analysis of cooperative relay and energy transfer to improve the performance of mobile communication network. The outage probability expression was derived using statistical tool. The authors observed that the statistical based outage probability algorithm reduced compared to the corresponding traditional algorithms. The conventional DF protocol was considered for signal transmission.

Bia et al., (2015) presented an incremental decode-forward relay protocol for cooperative communication. The author obtained expression for outage probability, which was evaluated using BER, but no new protocol inform of DF, or AF was published in the research. Alejel (2016) developed a closed-form mathematical expression for Bit Error Probability (BEP). The author worked on performance of the BEP and did not obtain any new expression for cooperative relay protocol. Khan et al., (2012) presented the performance analysis of cooperative communication protocols with single and multi-relay selection strategy. The focus was on analysis of the BER in cooperative communications. It was reported that multi-relay cooperation performed better than single node cooperation relay scheme. The study was on conventional cooperative relay selection and no new model was presented to improve network performance.

Zhand et al., (2016) proposed a relay selection strategy for DF protocol to mitigate noise amplification and error propagation. The results showed that the proposed strategy effectively reduce BER of the system. The authors did not propose any new protocol in the published work. Mudhusud et al., (2017) presented the review of some techniques for improving the network capacity and network coverage, and some challenges of the 5G network were also discussed. The review of the previous work was carried out, yet no new model was presented in the published work.

Hindia et al., (2019) discussed the interference cancelation in 5G relay network using stochastic geometrical technique. It was reported that the deployment of relay protocol is one of the effective solutions to solve the problem of signal coverage and spectral efficiency in 5G network. The results showed that outage probability reduced compared to the existing multiple-antenna network system. Again, it was reported that based on the proposed model the nearby base station suffers from network interference. Yuan et al., (2020) presented the analytical expressions of the outage probability and throughput for cooperative DF protocol. The result gave better performance for higher values of the SNR. In this case, no new protocol was proposed. The study was on conventional DF relay protocol using outage probability and throughput as performance metrics.

Table 1 Summary of findings from literature review

S/N	*Author (year)*	*Research description*	*Research gap*	*Remarks*
1	Chandra et al. (2016)	Worked on signal outage probability using MRC diversity method.	Poor network performance was identified. No new model was proposed for better performance	The focus is proposing a new model for better network performance
2	Zepermick et al. (2009)	Performance of adaptive DF and AF protocols was investigated	Although mathematical model for relay protocol was derived. No new hybrid protocol was presented.	A new hybrid protocol was derived. No new hybrid protocol was presented.
3	Asshada et al. (2019)	Reviewed cooperative relay system	No new model was proposed	A new model is necessary to achieve better performance.
4	Gilan and Nguyen (2020)	Work was on DF protocol for symbol transmission	No relay model was suggested	The new hybrid to be proposed involve relay modelling.
5	Hongxing et al. (2019)	Cooperative relay and energy transfer to improve network performance, Outage probability was derived using statistical tool	Conventional DF was considered in the analysis	The HDAF model is an improvement of the conventional DF model.
6	Bia et al. (2015)	Incremental DF relay protocol for cooperative communication was presented	There was no new DF or AF protocol suggested.	A new network protocol will enhance network performance.
7	Alejel (2016)	Work was on closed-form mathematical expression for Bit Error Probability (BEP)	Mathematical expression was obtained but no expression for cooperative relay protocol was reported.	In deriving expression for HDAF, cooperative relay protocol will be derived.
8	Khari et al. (2012)	Focused on analysis of the BER in cooperative communication	Work was on conventional cooperative relay protocol. No new method proposed for network improvement	The proposed HDAF will enhance network Performance.
9	Zhand et al. (2016)	DF protocol to mitigate noise amplification and error propagation	The authors relied on relay selection strategy. No new protocol was published to improve network performance	The proposed HDAF will enhance mobile network performance.
10	Hindia et al. (2019)	Cancelation in 5G relay network using stochastic geometrical technique was presented.	The proposed model had a disadvantage of being susceptible to network interference.	The proposed HDAF model can mitigate network issue by reducing signal interference.
11	Yuan et al. (2020)	Investigated outage probability and Throughput for cooperative DF protocol	Although the result of study gave better performance in terms of SNR, the study was on conventional DF and no new protocol was suggested.	HDAF to be proposed is an improvement on DF and AF relay protocols.

From the literature, most of the work done were on performance evaluation of conventional relaying protocol, symbol error probability, and outage probability. Most of the authors obtained an expression for hybrid outage probability, which was evaluated using BER, but no new hybrid relaying model inform of DF or AF was published in the research paper. Hence, the conventional relaying and the previous models published may not accurately solve the problem of interference, poor signal coverage, network capacity, path loss, and signal attenuation in 5G mobile network. The communication system cannot reliably transmit a signal from the transmitter to the receiver due to signal loss caused by channel obstruction. There is need to obtain a better protocol that can adequately compensate for the power loss in mobile communication system.

The above shortcomings have motivated this research for a new HDAF protocol in 5G mobile network. The proposed protocol is different from existing models and suitable for deployment because it can mitigate multipath propagation, increase throughput and network coverage. Also, it has ability to drastically reduce outage probability within few seconds of signal processing time. The introduction of HDAF which has the ability to obtain improved performances compared to DF and AF protocol is the major contribution of this work.

2.1 Summary of related work

The summary of the related work reviewed comprises of research description, research gap, and proposed work are presented in Table 1

2.2 Research questions

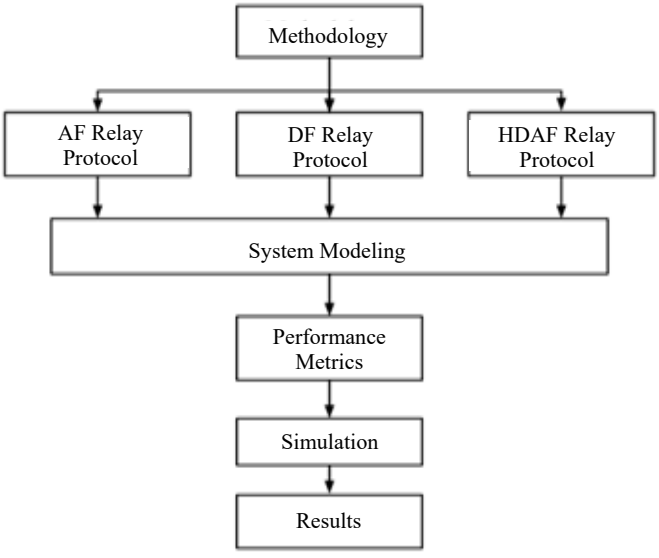
The following are the research questions

- How does the performance of HDAF protocol perform better than DF and AF with respect to their BER value?
- What makes the transmitted signal capable of providing good QoS?
- How does the HDAF perform better than AF and DF in terms of signal processing time?
- How does HDAF compare with conventional AF and DF protocols in term of BER performance?
- What is the difference in processing time performance between HDAF, AF, and DF protocols using a QPSK scheme?

3 Methodology

The research methods used in the study are shown in the block diagram in Figure 1. It includes mathematical modelling of AF Relay, DF Relay and HDAF protocol. System model was adopted which incorporates the protocol already modelled. Signal combining methods were introduced and performance metrics were used for system performance analysis. The result was obtained by carrying out a simulation process in the hybrid model using MATLAB

Figure 1 Block diagram of the research methodology



3.1 Amplify-forward (AF) relay protocol

The system consists of the source (S), relay (R), and the destination (D). These relays are half-duplex with single antenna, and complete transfer of the signal information takes place in two phases. In phase 1, the source transmits its message directly to both the relay and destination nodes. The output transfer symbol is expressed by Ray et al., (2009) as;

$$y_{s,r} = \sqrt{P_1} h_{s,r} x + \eta_{s,r} \tag{1}$$

$$y_{s,d} = \sqrt{P_1} h_{s,d} x + \eta_{s,d} \tag{2}$$

where, (y_{sr}) is the output transfer symbol from source to relay, (y_{sd}) is the transfer symbol from source to destination. h(s_r) and h (s, d) are the channel coefficient in Rayleigh fading environment between the S→R and S→D, with variances σ_{sr}^2 and σ_{sd}^2, respectively, P_1 is the transmission power, and x is the transmitted symbol. The terms $\eta_{s,r}$ and $\eta_{s,d}$ denote the AWGN with zero-mean, and variance N_0

AF protocol amplifies the transmitted symbol, and forwards it to the destination to compensate for signal loss due to obstruction from the source and relay (Ray et al., 2009; Chandra et al., 2016). The relay protocol does that with the help of the signal amplifying factor and is given as;

$$\beta_r = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \tag{3}$$

where, β_r is AF amplifying factor and P is the signal power

In the second phase, the amplified source signal is then re-transmitted to the destination using AF amplifying factor (Nasaruddin and Roslidar 2012; Thatha 2015). The output signal information, $y_{r,d}$ is given by;

$$y_{r,d} = \beta_r \sqrt{P_2} h_{r,d} y_{s,r} + \eta_{r,d} \tag{4}$$

where, $h_{r,\,d}$ is the channel coefficient, modelled as zero-mean independent complex gaussian random variables (CGRV) with variance σ_{rd}^2, $y_{s,r}$ is the transmitted signals from S→R, and $\eta_{r,\,d}$ is the AWGN with variance, N_0.

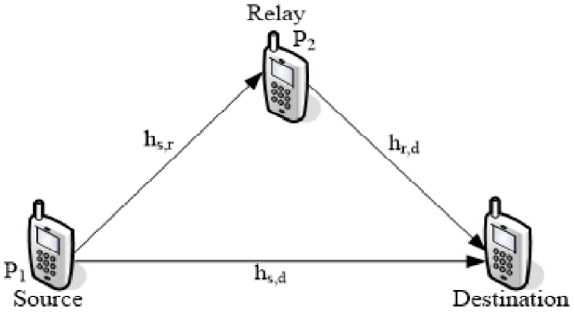
Therefore, substitute equation (3) into equation (4), which represent the relay signal to the destination. The expression is given in Salman et al. (2019) as;

$$y_{r,d} = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2} h_{r,d} y_{s,r} + \eta_{r,d} \tag{5}$$

where, $h_{r,\,d}$ is the channel coefficient ($S \rightarrow D$), P_2 is the signal power ($S \rightarrow D$).

A simplified cooperative communication with three terminal is given in Figure 2.

Figure 2 Simplified cooperative communications



By substituting equation (1) into equation (5), the received output signal $y_{r,\,d}$ at the destination, is presented as:

$$y_{r,d(AF)} = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2} h_{r,d} \left(\sqrt{P_1} h_{s,r} x + \eta_{s,\,r}\right) + x + \eta_{r,d} \tag{6}$$

$$y_{r,d(AF)} = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2 P_1} h_{s,r} h_{r,d} + \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2} h_{r,d} \eta_{s,\,r} + \eta_{r,d} \tag{7}$$

$$y_{r,d(AF)} = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2 P_1} h_{s,r} h_{r,d} x + \eta'_{r,d} \tag{8}$$

The terms $\eta_{s,\,r}$ and $\eta_{r,\,d}$ in equation (6), and equation (7) are independent noise. The equivalent noise $\eta_{r,\,d}$ is expressed as;

$$\eta'_{r,d(AF)} = \left(\frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \sqrt{P_2} h_{r,d} h_{s,r} x + \eta_{r,\,d} \right) \tag{9}$$

With variance

$$N'_0 = \left(\frac{P|h_{s,r}|^2}{P|h_{s,r}|^2 + N_0} + 1 \right) N_0 \tag{10}$$

It should be noted that two copies of signal (x) both from the source link and relay protocol device are received at the destination. The MRC combines transmitted symbols at the destination depending on the number of relay devices in the system

3.2 Decode-forward (DF) relay protocol

In DF phase 1, the source sends out signal information to the relay and destination nodes. The signal $y_{s,\,r}$ is received according to equation (1), while the received signal at the destination is $y_{s,\,d}$ as expressed in equation (2). In DF phase 2, the relay decodes the signal, re-encodes it, and forward the information with power P_2 to the destination. In this case, DF relay can only decode the source signal, when the SNR of the source signal exceeds, or equal the threshold value, otherwise, the relay remains dormant. If relay decodes source signal correct, then, $P_1 = P_2$, otherwise $P_2 = 0$.

The output signal at the destination without amplification factor in DF phase 2 is given by Nguyen et al., (2019) as;

$$y_{r,\,d(DF)} = \sqrt{P_2} h_{r,d} * y_{s,\,r} + \eta_{r,\,d} \tag{11}$$

where, $y_{r,\,d(DF)}$ is the output signal, $y_{s,\,r}$ is the transmitted symbol, $h_{r,\,d}$ is the channel coefficient with variance σ_{rd}^2, $\eta_{r,\,d}$ is AGWN with variance N_0.

By substituting $y_{s,\,r}$, in equation (1) into equation (11) and expanding to obtain output signal at the destination through relay node yields;

$$y_{r,d(DF)} = \sqrt{P_2} h_{r,d} \left(\sqrt{P_1} h_{s,r} x + \eta_{s,\,r} \right) + x + \eta_{r,d} \tag{12}$$

$$y_{r,d(DF)} = \sqrt{P_1 P_2} h_{s,r} h_{r,d} x + \sqrt{P_2} h_{r,d} \eta_{s,\,r} + \eta_{r,\,d} \tag{13}$$

$$y_{r,d(DF)} = \sqrt{P_1 P_2} h_{s,r} h_{r,d} x + \eta'_{r,\,d} \tag{14}$$

The terms $\eta_{s,\,r}$ and $\eta_{r,\,d}$ in equation (12) and (13) are independent noise. The equivalent noise $\eta_{r,\,d}$ is expressed as;

$$\eta'_{r,\,d(DF)} = \sqrt{P_2} h_{r,d} \eta_{r,\,d} + \eta_{r,\,d} \tag{15}$$

With variance

$$N'_0 = \left(\frac{P|h_{s,r}|^2}{P|h_{s,r}|^2 + N_0} + 1 \right) N_0 \tag{16}$$

The signal (x) from the source and relay devices are received at the destination. MRC technique combines copies of the transmitted symbols at the destination depending on number of relay devices in the system.

3.3 Hybrid decode and forward (HDAF) protocol

The communication system consists of the Source, Relay, and the Destination. In phase 1, the source transmits signal information to the hybrid relay and destination. In this case, equations (1) and (2) represent the transmitted signals $y_{s,r}$ and $y_{s,d}$, to the hybrid relay and source to destination, respectively. In hybrid phase 2, new HDAF relay protocol was obtained with the combination of the AF and DF protocols for better and reliable signal at the destination. This was achieved by substituting equation (14) into (8) to obtain the transmitted signal from hybrid relay 1. The output of hybrid relay 1 ($y_{r1,\ d(H)}$) at the destination is expressed as;

$$y_{n,\ d(H)} = \frac{\sqrt{P}}{\sqrt{P\left|hs,r\right|^2 + N_0}} \sqrt{P_2 P_1} h_{s,r} h_{r,d} \left(y_{r,\ d(DF)}\right) + \eta'_{r,d} \tag{17}$$

$$y_{n,\ d(H)} = \frac{\sqrt{P}}{\sqrt{P\left|hs,r\right|^2 + N_0}} \sqrt{P_2 P_1} h_{s,r} h_{r,d} \left(\sqrt{P_2 P_1} h_{s,r} h_{r,d} x + \eta'_{r,d}\right) + \eta'_{r,d} \tag{18}$$

$$y_{n,\ d(H_i)} = \beta_{r(AF)} \left(\sqrt{P_1 P_2}\right)^2 \left|h_{s,r} h_{r,d}\right|^2 (x) + \beta_r \sqrt{P_2 P_1} h_{s,r} h_{r,d} x + \eta'_{r,d} + \eta'_{r,d} \tag{19}$$

where, AF protocol amplify factor, $y_{n,\ d(H_i)} = \beta_{r(AF)} = \frac{\sqrt{P}}{\sqrt{P\left|hs,r\right|^2 + N_0}}$, $P = P_1 = P_2$, P_1 is the signal power at the source, P_2 is the hybrid signal power, x is the transmitted symbol, $h_{s,r}$ and $h_{s,d}$ are the channel coefficients, $y_{r1,\ d}$ (H_i) is the output of hybrid relay 1, and β_r is the signal amplification factor.

The terms $\eta'_{s,\ r}$ and $\eta'_{r,\ d}$ in equation (19) are independent noise. The equivalent hybrid noise ($\eta'_{r,\ d\ (H)}$) is expressed as;

$$\eta'_{r,d(H)} = \frac{\sqrt{P}}{\sqrt{P\left|hs,r\right|^2 + N_0}} \sqrt{P_1 P_2} h_{r,d} \eta'_{r,d} + \eta'_{r,d} \tag{20}$$

With variance

$$\eta'_{0(H)} = \left(\frac{P\left|hs,r\right|^2}{P\left|hs,r\right|^2 + N_0} + 1\right) N_0 \tag{21}$$

The output signal $y_{r1\ ,d}$ (H_i) is for individual HDAF relays link that are expected to forward the transmitted symbol directly to the destination as presented in equation (19). However, the received symbol at the hybrid relay 2 due to the hybrid relay 1 is also relevant. The output of the hybrid relay 2 ($y_{r1,\ r2\ (H)}$) is given by;

$$y_{n_1,\ r_2(H)} = \frac{\sqrt{P}}{\sqrt{P\left|hs,r\right|^2 + N_0}} \left(h_{n_1,\ r_2} y_{s,\ n_1}\right)_{AF} \sqrt{P_1 P_2} \left(h_{n_1,\ r_2} y_{s,\ n_1}\right)_{DF} \eta_{n_1 r_2} \tag{22}$$

$$y_{n_1,\ r_2(H)} = \beta_{r(AF)} \sqrt{P_2 P_1} \left|h_{n_1,\ r_2} y_{s,\ n_1}\right|^2 + \eta_{n_1 r_2} \tag{23}$$

where, $y_{r1,\,r2\,(H)}$ is the transmitted symbol from relay 1 to 2, $y_{s,\,r1}$is the source transmitted symbol to relay 1, and $h_{r1,\,r2}$ is the inter-relay channel coefficient with variance $\sigma^2_{n_1,\,r_2}$. The two copies of information from the hybrid relay 2 and source link are received at the destination.

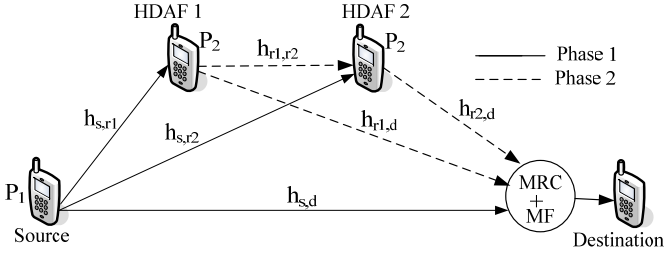
3.4 System model

The system model focuses on the two-relay protocol scenario, which is implemented in three phases.

- In phase 1: the source beams out the transmitted symbol to two hybrid relays, and destination node.
- In phase 2: hybrid relay 1 forwards received signal to the hybrid relay 2, and the destination. Hybrid relay 2 combines transmitted symbols from source, and hybrid relay 1 using MRC method.
- In phase 3: the MRC with noise filter combines and forward the amplified transmitted symbols from the hybrid relay 1, hybrid relay 2, and the source to the destination.

HDAF protocol conveniently acts to decode, amplify, and forward source signal to the destination combiner. HDAF protocol either in AF or DF relay mode may remain silent or transmit symbols according to the quality of the signal received by the hybrid device. The transmitted signal that falls below the threshold value cannot be correctly decoded by DF relay protocol. In this case, the DF relay remains dormant, while AF relay amplifies the signal, and forward it to the designation combiner. MRC at the destination jointly detects, combines, and maximises the output SNR. The MRC finally add the entire signal paths and obtain the average. The resulting average instantaneous SNR obtained from the MRC is received by the user at the destination. The two-relay node model is shown in Figure 3.

Figure 3 Two-relay cooperative communication model



Based on the input analysis and channel coefficients information, the output of the MRC combiner in two-relay scenario can be expressed as;

$$\overline{y}_d = \overline{\alpha}_1 y_{s,\,d} + \overline{\alpha}_2 y_{n_1,\,d(H)} y_{n_1,\,r_2(H)} + y_{r_2,\,d(H)} \tag{24}$$

The terms α_1 and α_2 is combining factors applied to maximise the combined SNR given by Hoang et al. (2018) as:

$$\overline{\alpha}_1 = \frac{\sqrt{P_1} h^*_{s,d}}{N_0} \tag{25}$$

$$\overline{\alpha}_1 = \frac{\left(\dfrac{\sqrt{P}}{\sqrt{P\left|h_{s,r1}\right|^2 N_0}} \right)_{AF} * \sqrt{P_2}\left|h^*_{s,n} h^*_{s,n,r2}\right|}{\left(\dfrac{P_2\left|h_{n,r2}\right|^2}{P_1\left|h_{s,r_i}\right| + N_0} + 1 \right) N_0} \tag{26}$$

In phase 3, the MRC combines and forward the transmitted symbols from the source, hybrid relay 1 and hybrid relay 2 to the destination. The transmitted symbol at relay 2 to the destination is expressed as;

$$y_{r2,\ d(H)} = \sqrt{P_2} h_{r\,2,d} \frac{\overline{y}_d}{\sqrt{K^2 + K}} + \eta_{r2,d} \tag{27}$$

The term '*k*' is a signal normalised factor from source through relays and to the destination, which is given in Hui et al. (2015) as:

$$K = \frac{\dfrac{P_1 P_2}{P_1\left|h_{s,r1}\right|^2 + N_0} + \left|h_{s,r1}\right|^2 \left|h_{n,r_2}\right|^2}{\left(\dfrac{P_2\left|h_{n,r_2}\right|^2}{P_1\left|h_{s,r_i}\right|^2 + N_0} + 1 \right) N_0} + \frac{P_2\left|h_{s,r_2}\right|^2}{N_0} \tag{28}$$

Finally, the MRC detector with matched filter (MF) adds all the signal paths and send-out the average as the output to the user at the destination.

3.5 Performance metrics

Outage Probability (P_{out}), BER, and signal Processing Time (P_{time}) are metrics used to evaluate the performance of the modified model. Outage probability (P_{out}) of a communication channel is the probability that a transmitted signal is not supported (out of range of BS in cellular communications) or abruptly cut-off due to variable channel capacity. Outage probability is defined as the probability that information rate is less than the required threshold information rate. It is the probability that signal outage will occur in the channel within a specified time period. The outage probability is a key performance measure for real time traffic in mobile radio networks and is also considered as more critical then drop call probability. Pout was used to effectively monitor the transmitted symbol from the source to the destination.

The BER is mostly used for digital system analysis. The BER as a performance metric is a suitable choice considering the fact that the system model being investigated is a digital system. Processing time (P_{time}) was used because MATLAB will be used in the simulation of the proposed model. MATLAB software can effectively determine the processing time in seconds indicating time taken between transmission and reception of signal.

3.5.1 Signal outage probability

The presumption that transmitted signal power will fall below the set threshold value along the channel is known as signal outage probability. The first and second time slot of the HDAF protocol is subjected to Rayleigh fading due to the nature of the mobile radio channel. The MRC combiner obtains maximum signal level at the destination based on number of the relays (Proakis and Salehi 2008; Salman et al., 2019). The output SNR of the MRC combiner follows Raleigh fading and is given by:

$$f_{\Upsilon ij}\left(\gamma_{MRC}\right)=\frac{1}{\overline{\gamma}_{ij}}e^{-\left(\frac{-\gamma}{\overline{\gamma}_{ij}}\right)},\ i\in[s,r],\ j\in[r,d] \tag{29}$$

where, $f_{\gamma j}$ (γ_{MRC}) is the output instantaneous SNR for MRC, γ is the SNR of the transmitted symbol, and $\overline{\gamma}_{ij}$ is the average SNR. The probability density function of the MRC (pdf_{MRC}) in Raleigh fading channel is obtained by substituting y_{r1}, $d(H_i)$ into equation (29), which is expressed as;

$$Pdf_{f\gamma ij}\left(\gamma_{MRC}\right)=\frac{1}{\overline{\gamma}_{\eta,d(H_i)ij}}e^{-\left(\frac{-\gamma\eta_{,d(H_i)}}{\overline{\gamma}_{\eta,d(H_i)ij}}\right)} \tag{30}$$

where, $Pdf_{f\gamma j}$ (γ_{MRC}) is the pdf of the MRC, γ_{r1}, d (H_i) is the SNR at the MRC for HDAF relay, $\overline{\gamma}_{n,d(H_i)ij}$ is the average SNR of HDAF relay protocol.

The mathematical expression for the outage probability in Raleigh fading environment can be written as;

$$P_{out}=\int_0^{\gamma_{th}} f_{\gamma ij}(\gamma)d\gamma \tag{31}$$

where, $f(\gamma_{ij})$ (γ) denotes the PDF of SNR, γ_{th} is the predefined threshold value.

3.5.2 Bit error rate

The BER is the number of errors that occur in the total number of transmitted bits. It is the total error bits received per unit time over communication channel due to different channel impairments (Nguyen et al., 2019). The probability of the bit error rate in BPSK modulation over AWGN, is expressed by Proakis and Salehi (2008) as;

$$P_b=\frac{1}{2}erfc\sqrt{\frac{E_b}{N_0}} \tag{32}$$

where, *erfc* is the error function (complementary), E_b/N_o is the SNR per bit, E_b is the energy per bit (J), and N_o is the noise power (J/s).

The energy to noise ratio $y=\frac{|h|^2 E_b}{N_0}$, is the effective bit in the channel. The effective bit error probability in the channel is expressed as;

$$P_{b/h}=\frac{1}{2}erfc\sqrt{y} \tag{33}$$

where, $y = \dfrac{|h|^2 E_b}{N_0}$

Therefore, BER in BPSK and QPSK modulation scheme, assuming additive white gaussian noise (AWGN) can be expressed as:

$$BER = \frac{1}{2} erfc\sqrt{y} \tag{34}$$

3.5.3 Processing time

Processing time P_{time} is the time in seconds for MATLAB software to process the simulation for the conventional and hybrid model. P_{time} is the time taken for information to get to the destination from the source. The processing times for AF, DF and HDAF cooperative communication models were compared with each other to identify the better model with less processing time.

3.6 Simulation process

The simulation of the proposed hybrid model was implemented using MATLAB R2018a software. The online binary data with modulation scheme, and other network parameters were used for the simulation. The HDAF combines both DF and AF relay protocols. In this case, if the HDAF protocol decode the source signal successfully, the DF part of the hybrid relay re-encodes and forward transmitted symbol to the destination. A situation where source signal is not correctly decoded, AF part of the hybrid relay amplify the signal and forward to the receiver. This is achieved in 5G network at 28 GHz millimetre-wave frequency band in Rayleigh fading environment. The performance curve for DF, AF, and HDAF protocols were plotted in terms of BER, P_{out}, and P_{time} versus SNR. The network parameters are presented in Table 2.

Table 2 Simulation parameters

Parameters	*Variables*
Modulation scheme	QPSK, BPSK
Number of relays	2
Carrier frequency	28000 MHz
Filter type	Matched filter
Combiner	MRC
Number of symbols	20,000
Signal-to-noise ratio	(0: 2:20)
Bandwidth of symbol	500 KHz
$P = P_1 = P_2$	1W
Threshold	2 dB

4 Results and discussion

The results of the BER, P_{out}, and P_{time} were obtained for DF, AF, and HDAF protocol at different SNR and 28 GHz millimetre-wave frequency. The MRC combines the transmitted symbol from the first relay, second relay and the source, which is subsequently received at the destination.

Figure 4 BER against SNR for DF, AF, and HDAF for r = 2 and BPSK modulation scheme (see online version for colours)

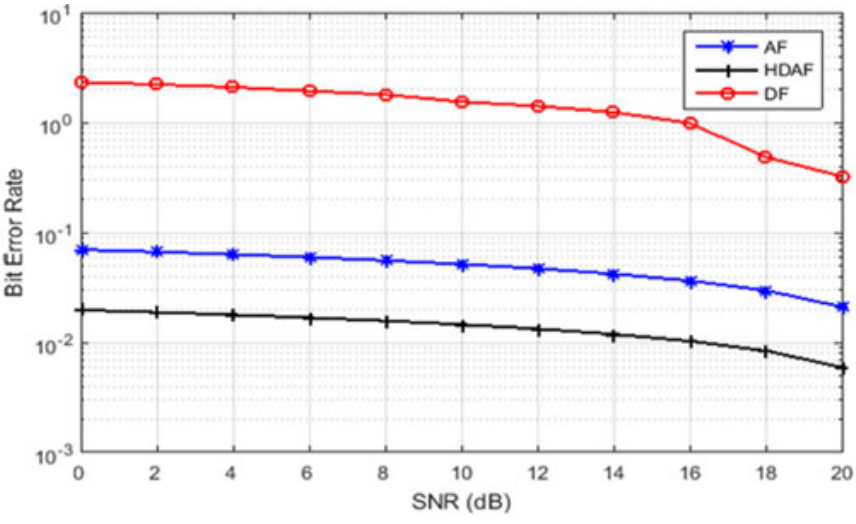


Table 3 Bit error rate at R = 2 and BPSK modulation

SNR (dB)	*DF (dB)*	*AF (dB)*	*HDAF (dB)*
0	2.33	0.070	0.020
2	2.22	0.067	0.019
4	2.09	0.063	0.018
6	1.93	0.060	0.017
8	1.79	0.056	0.016
10	1.54	0.052	0.015
12	1.41	0.047	0.013
14	1.24	0.042	0.012
16	0.99	0.036	0.010
18	0.48	0.030	0.008
20	0.32	0.021	0.006

Figure 4 depicts BER against SNR with BPSK (2-PSK) modulation scheme. The BER values for DF protocol were 2.09 dB, 1.79 dB, 1.41 dB, 0.99 dB, and 0.32 dB at SNR of 4, 8, 12, 16, and 20, respectively. The corresponding values of the BER for AF protocol were 0.063 dB, 0.056 dB, 0.047 dB, 0.036 dB, and 0.021 dB. The HDAF protocol show better performance compared to DF, and AF with BER values of 0.018 dB, 0.016 dB,

0.013 dB, 0.010 dB, and 0.006 dB for different SNR. It was also observed that the BER reduces with increase in SNR for HDAF protocols. This will mitigate the effect of signal interference in 5G mobile network. The detailed result is presented in Table 3.

Figure 5 Signal outage probability against SNR for df, AF, and HDAF for γ= 2 and BPSK modulation scheme (see online version for colours)

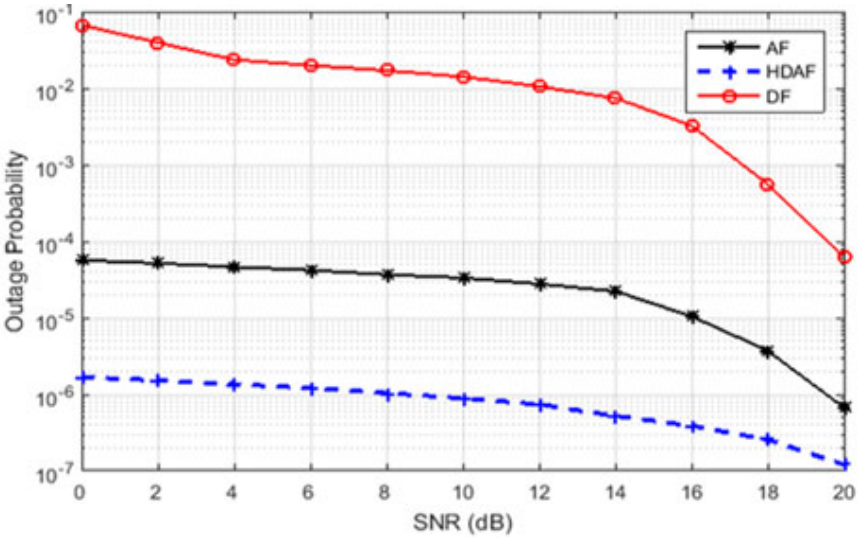


Table 4 Outage probability at R = 2 and BPSK modulation

SNR (dB)	*DF (dB)*	*AF (dB)*	*HDAF (dB)*
0	0.067	5.67E-05	1.69E-06
2	0.039	5.18E-05	1.52E-06
4	0.024	4.64E-05	1.36E-06
6	0.020	4.19E-05	1.20E-06
8	0.018	3.66E-05	1.04E-06
10	0.014	3.32E-05	8.91E-07
12	0.011	2.78E-05	7.40E-07
14	0.007	2.23E-05	5.23E-07
16	0.0033	1.05E-05	3.89E-07
18	0.0006	3.72E-06	2.57E-07
20	0.0001	6.76E-07	1.21E-07

Figure 5 presents P_{out} values against SNR values with BPSK scheme. The P_{out} values for DF protocol were 0.024 dB, 0.018 dB, 0.011 dB, 0.0033 dB, and 0.0001 dB at SNR of 4, 8, 12, 16, and 20, respectively, while the corresponding values for AF protocol were 4.64E-05 dB, 3.66E-05 dB, 2.78E-05 dB, 1.05E-05 dB, and 6.76E-07 dB. The HDAF protocol gave better results compared to DF and AF with P_{out} values of 1.36E-06 dB, 1.04E-06 dB, 7.40E-07 dB, 3.89E-07 dB, and 1.21E-07 dB at different SNR. The result shows that P_{out} decreases with increase in SNR. In this case, the cooperative relay is capable of amplifying weak signals due to obstructions, and extend network coverage. It

means that the transmitted symbol has enough strength to cover more distance without power loss. The detailed P_{out} result is presented in Table 4.

Figure 6 Processing time against SNR for DF, AF, and HDAF for R = 2 and BPSK modulation scheme (see online version for colours)

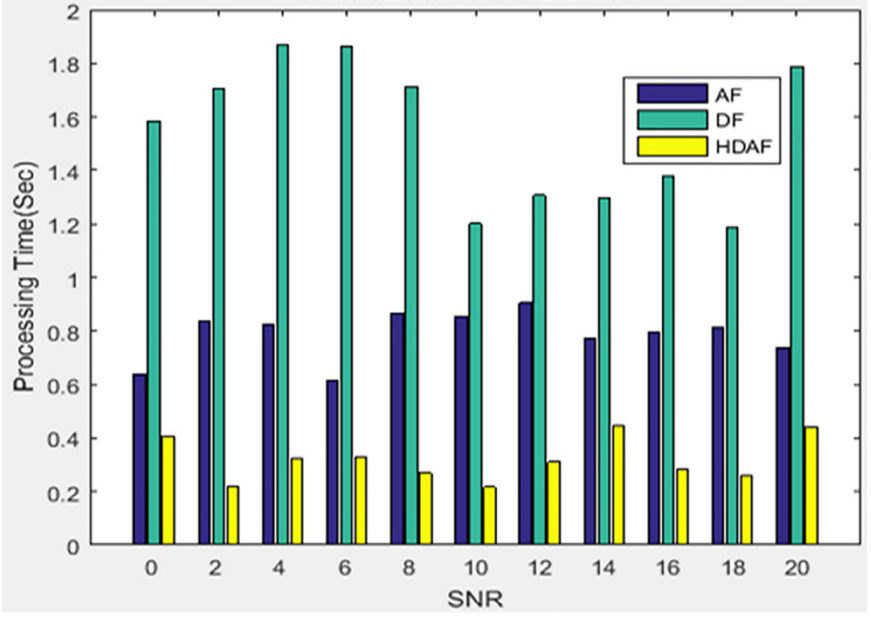


Figure 6 depicts P_{time} against different values of the SNR. The P_{time} values for DF were 1.87 sec, 1.71 sec, 1.31sec, 1.38sec, and 1.79 sec at SNR of 4, 8, 12, 16, and 20, respectively. The corresponding values of P_{time} for AF were 0.83sec, 0.62sec, 0.91sec, 0.79 sec, and 0.74 sec. The HDAF performed better than DF and AF protocols with P_{time} values of 0.32 sec, 0.27 sec, 0.31 sec, 0.28 sec, and 0.44 sec. The hybrid relay gave lower P_{time} compared to the existing protocol. The result is presented in Table 5.

Table 5 Processing time at R = 2 and BPSK modulation

SNR (dB)	*DF (sec*	*AF (sec)*	*HDAF (sec)*
0	1.58	0.64	0.41
2	1.71	0.83	0.22
4	1.87	0.82	0.32
6	1.87	0.62	0.33
8	1.71	0.87	0.27
10	1.20	0.85	0.22
12	1.31	0.91	0.31
14	1.30	0.77	0.45
16	1.38	0.79	0.28
18	1.19	0.81	0.26
20	1.79	0.74	0.44

Figure 7 BER against SNR for DF, AF, and HDAF for R = 2, and QPSK modulation scheme (see online version for colours)

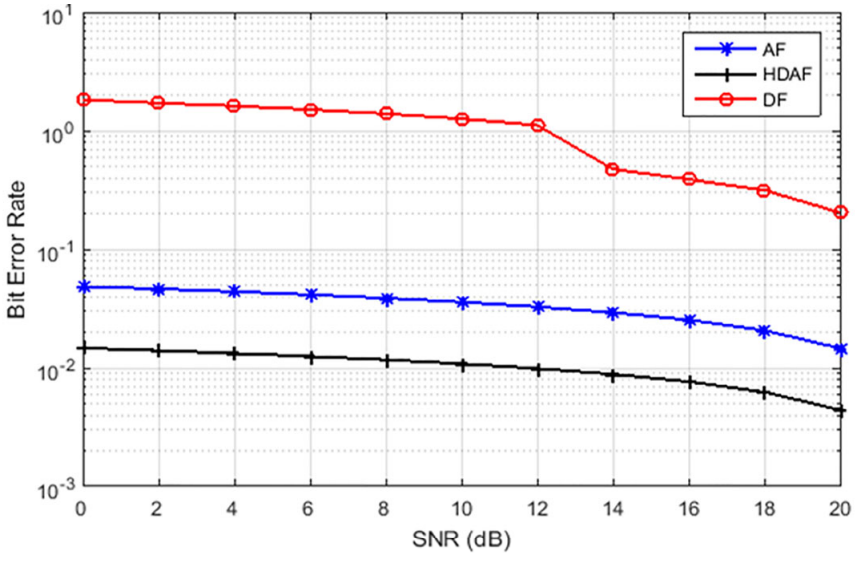


Figure 7 presents BER against SNR with QPSK (4-PSK) scheme. BER values for DF protocol are 1.615 dB, 1.389 dB, 1.113 dB, 0.389 dB, and 0.204 dB at SNR of 4, 8, 12, 16, and 20, respectively, while the values for AF protocol are 0.044 dB, 0.039 dB, 0.033 dB, 0.025 dB, and 0.015 dB. The results show that HDAF protocol performed better than DF and AF with BER values of 0.013 dB, 0.012 dB, 0.010 dB, 0.008 dB, and 0.004 dB. It was observed that the BER decreases as SNR increases. This means that HDAF protocol enhances signal quality at the receiver. The detailed BER result is given in Table 6.

Table 6 Bit error at R = 2 and QPSK modulation

SNR (dB)	*DF (dB)*	*AF (dB)*	*HDAF (dB)*
0	1.826	0.049	0.015
2	1.710	0.046	0.014
4	1.615	0.044	0.013
6	1.511	0.041	0.013
8	1.389	0.039	0.012
10	1.263	0.036	0.011
12	1.113	0.033	0.010
14	0.475	0.029	0.009
16	0.389	0.025	0.008
18	0.316	0.021	0.006
20	0.204	0.015	0.004

Figure 8 Outage probability against SNR for DF, AD, and HDAF for R = 2, and QPSK modulation scheme (see online version for colours)

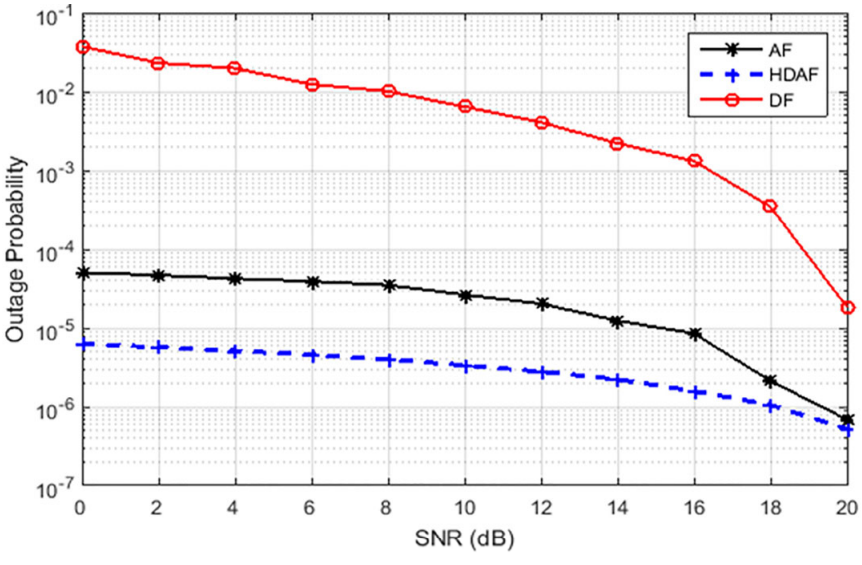


Figure 8 depicts the plot of P_{out} against different SNR with QPSK (4-PSK) scheme. The P_{out} for DF protocol are 0.198 dB, 0.0101 dB, 0.0041 dB, 0.0013 dB, and 1.85E-05 dB at SNR of 4, 8, 12, 16, and 20, respectively, while the values of the P_{out} for AF protocol are 4.26E-05 dB, 3.51E-05 dB, 2.03E-5 dB, 8.52E-06 dB, and 6.90E-07 dB. The results obtained for HDAF protocol are better than DF and AF with P_{out} values of 5.14E-06 dB, 4.00E-06 dB, 2.80E-06 dB, 1.59E-06 dB, and 5.26E-07 dB. The result shows that P_{out} reduces with increase in SNR. The BER show less possibility of outages, hence improve QoS. The detailed result is presented in Table 7.

Table 7 Outage probability at R = 2 and QPSK modulation

SNR (dB)	*DF (dB)*	*AF (dB)*	*HDAF (dB)*
0	0.0374	5.06E-05	6.29E-06
2	0.0231	4.68E-05	5.71E-06
4	0.0198	4.26E-05	5.14E-06
6	0.0124	3.91E-05	4.57E-06
8	0.0101	3.51E-05	4.00E-06
10	0.0064	2.65E-05	3.37E-06
12	0.0041	2.03E-05	2.80E-06
14	0.0022	1.24E-05	2.23E-06
16	0.0013	8.52E-06	1.59E-06
18	0.0003	2.13E-06	1.05E-06
20	1.85E-05	6.90E-07	5.26E-07

Figure 9 Processing time against SNR for DF, AF, and HDAF for R = 2, and QPSK modulation scheme (see online version for colours)

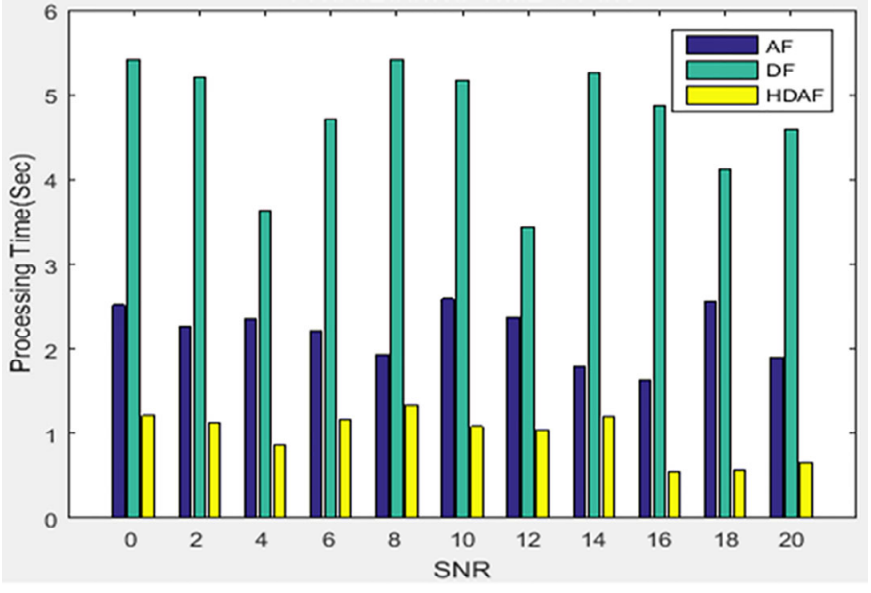


Figure 9 shows P_{time} against SNR with QPSK (4-PSK) modulation scheme. The values of P_{time} for DF protocol are 3.62 sec, 5.42 sec, 5.25 sec, 4.88 sec, and 4.59 sec at SNR of 4, 8, 12, 16, and 20, respectively, while the values of P_{time} for AF protocol are 2.35 sec, 1.94sec, 2.35sec, 1.64sec, and 1.90sec. The HDAF relay processing time is lower compared to DF and AF with P_{time} values of 0.86sec, 1.34sec, 1.05sec, 0.55sec, and 0.66sec. The results show that transmitted symbol reached its destination faster than the existing protocols. It means that with hybrid protocol the transmitted signal will cover more distances using small processing time. The detailed result is presented in Table 8.

Table 8 Processing time at R = 2 and modulation

SNR (dB)	*DF (sec)*	*AF (sec)*	*HDAF (sec)*
0	5.42	2.52	1.21
2	5.21	2.26	1.13
4	3.62	2.35	0.86
6	4.72	2.22	1.17
8	5.42	1.94	1.34
10	5.17	2.59	1.09
12	3.44	2.37	1.05
14	5.25	1.79	1.20
16	4.88	1.64	0.55
18	4.12	2.56	0.56
20	4.59	1.90	0.66

5 Conclusions

In this research, the performance evaluation of the DF, AF, and HDAF relay protocols have been investigated. A closed-form expression for a new HDAF protocol has been developed and simulated using appropriate parameters. The existing DF and AF were hybridised to obtain a new HDAF relay protocol. Mathematical expression was also obtained for outage probability in the Rayleigh fading environment. The MRC containing MF combines the quality signal at the destination. Simulation of the decode forward (DF), amplify forward (AF), and HDAF relay protocols were carried out using MATLAB 2018a software. The performance of the protocols was evaluated using P_{out}, BER and P_{time}.

The result obtained answered the research questions postulated. The BER values for HDAF are lower than that of both AF and DF, hence better performance. The lower BER is also an indication of less signal outages and minimal interference compared to conventional protocols, thus improved QoS. In terms of signal processing time HDFA was seen to be faster than AF and DF protocols having shown lesser processing time. With QPSK scheme the processing time for AF and DF were longer than that of HDAF. This shows that HDAF has the potential for fast signal transmission over wide coverage areas.

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