Computers, Materials & Continua
DOI:10.32604/cmc.2022.022139
Article

Tech Science Press

Optimal Hybrid Precoding Based QoE for Partially Structured Massive MIMO System

Farung Samklang, Peerapong Uthansakul, Monthippa Uthansakul* and Patikorn Anchuen

School of Telecommunication Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand
*Corresponding Author: Monthippa Uthansakul. Email: mtp@sut.ac.th

Received: 28 July 2021; Accepted: 03 September 2021

Abstract: Precoding is a beamforming technique that supports multi-stream transmission in which the RF chain plays a significant role as a digital precoding at the receiver for wireless communication. The traditional precoding contains only digital signal processing and each antenna connects to each RF chain, which provides high transmission efficiency but high cost and hardware complexity. Hybrid precoding is one of the most popular massive multiple input multiple output (MIMO) techniques that can save costs and avoid using complex hardware. At present, network services are currently in focus with a wide range of traffic volumes. In terms of the Quality of Service (QoS), it is critical that service providers pay a lot of attention to this parameter and its relationship to Quality of Experience (QoE) which is the measurement of the overall level of user satisfaction. Therefore, this paper proposes hybrid precoding of a partially structured system to improve transmission efficiency and allocate resources to provide network services to users for increasing the user satisfaction under power constraints that optimize the quality of baseband precoding and radio frequency (RF) precoding by minimizing alternating algorithms. We focus on the web browsing, video, and Voice over IP (VOIP) services. Also, a Mean Opinion Score (MOS) is employed to measure the level of user satisfaction. The results show that the partially structured system provides a good user satisfaction with the network's services. The partially structured system provides high energy efficiency up to 85%. Considering web service, the partially structured system for 10 users provides MOS at 3.21 which is higher than 1.75 of fully structured system.

Keywords: Massive MIMO; quality of experience (QoE); mean opinion score (MOS); quality of service (QoS); hybrid precoding; partially structured system

1 Introduction

MIMO is a communications technology that has been used since 4G. The basic principle of MIMO is the use of more than one antenna to transmit and receive data. This technique is able to support the use of mobile phones in larger quantities. However, a 5G system involves higher data density to support user requirements compared to the 4G system. This introduces the need of using more than 100 antennas to transmit and receive data, so called massive MIMO system and multi-directional beamforming. It can alter the magnitude and phase for signal control, allowing the antenna to focus on each user. Another outstanding wireless technology in massive MIMO is millimeter wave (mmWave), which operates in a frequency range of 30–300 GHz and allows high-speed data transmission. The conventional precoding technologies use many RF chains in only digital precoding, resulting in a loss of power consumption and consequent costs at the Base Stations (BS) [1]. Many researchers have focused on hybrid precoding, which is a combination of digital and analog systems that reduce the number of RF chains without sacrificing the efficiency of transmission [2,3]. For Orthogonal Frequency-Division Multiplexing (OFDM) technique in massive MIMO wireless communications, each subcarrier is modulated at a low symbol rate reducing multipath fading, high Signal to Noise Ratio (SNR). This can eliminate Inter Symbol Interference (ISI) [4–6].

The hybrid precoding has two structures: fully and partially structured systems. The fully structured system has a higher spectral efficiency than the partially structured system [7,8]. This is because there is more than one RF chain connected to the same antenna while more phase shifters and circuits are needed to be added in analog precoding causing an increase in power consumption and hardware complexity. However, for the partially structured system in the RF chain, the signal travels through fewer phase shifters, resulting in lower spectral efficiency but higher energy efficiency [9–11]. The work presented in [12] has demonstrated that the partially structured system in terms of spectral efficiency outperforms analog beamforming, particularly when the signal-to-noise ratio (SNR) value is high. For the partially structured system, the authors of [13] have proposed an alternative minimization method to optimize energy efficiency of baseband/RF precoding leading to the partially structured system of hybrid precoding which provides better energy efficiency than both fully and partially structured systems of Orthogonal Matching Pursuit-Sparse Precoding & Combining (OMP) algorithm [14]. The OMP algorithm can find the optimal array response vector, but there are some limitations of signal distribution and sparsity constraints in analog precoding.

The goal of 5G wireless communication is to provide high throughput for long-distance transmission while improving QoS performance. The QoS is the management bandwidth or network channel management to optimize the performance of an audio, video, and network quality service, where parameters such as packet loss, jitter, and delay are considered. To improve transmission quality for high QoS [15], beamforming technology has been proposed to Small Cell Access (SCA) in terms of dynamic and static under power constraint with the results indicating higher energy efficiency and data rate than the zero-forcing (ZF) method. This is because ZF has space constraints in the analog front-end and power consumption [16]. Consequently, QoS is an important parameter for operators to understand users in order to manage the service quality and efficiency to meet the user requirements.

The QoE is a customer-oriented service which is an important factor in user satisfaction or experience. When a consumer is dissatisfied with a network's service, the QoS has to be improved. Sometimes, even if the QoS value is high, the users may not be satisfied at the time since the area is dense with many users. So, in the relationship of both parameters to optimize the network service, we must evaluate several factors related to both QoE and QoS. For assessing QoE in the subjective part, a Mean Opinion Score (MOS) can be used to express the level of user satisfaction. In general, MOS ranks from 1 to 5 levels as 5 is excellent and 1 is poor [17]. Currently as mobile Internet services are rapidly growing, QoE services such as web browsers on chrome, online games, YouTube, and voice conference may pose subsequent problems. Therefore, a method for improving the network must be presented to meet the needs of users [18,19]. In [20], the authors have presented an improvement in QoE quality in terms of Voice over Internet Protocol (VoIP) services with software-defined networking (SDN) by forwarding data path control and improved coders/decoders (CODECS) performance of VoIP service. The QoE user satisfaction is also predicted using an Artificial Neural Network (ANN) and resource blocks (RBs) with Particle Genetic (PGA) [21,22] to allocate QoS and data precision. As a result, the average QoE satisfaction for each service can be increased. To increase user satisfaction with respect to QoE, techniques presented in [23] employ OFDMA to support low data rates of multiple users (Multiple Access) and use Radio Resource Allocation (RRA) for downlink to ensure fairness to users and optimum user satisfaction. In addition, the authors in [24] have used heterogeneous network techniques which combine a variety of wireless communication nodes, such as Macro Cell, Small Cell, DAS, and Wireless LAN as well as the [15] to allocate QoS network resources. As a result, when user satisfaction increases with the increase of the SCA, it may be costly because the SCA uses higher computational power than 50% of total power at the BS [25].

The partially structured system is getting much attention both in implementation and simulation as mentioned above. However, although the partially structured system can simplify the system and achieve high energy efficiency, the partially structured system has not been measured whether it is efficient enough to meet the user needs. From the work presented in [24], although the heterogeneous technique is used to optimize user satisfaction, its increased cost and energy constraints also optimize user satisfaction.

In this paper, we propose a partially structured system of hybrid precoding in Massive MIMO-OFDM because it is flexible for designing, low complexity, and provides a bandwidth efficiency to achieve high bitrates. Also, we consider an improvement in the quality of user experience and network resource allocation to suit users. There are three services on focus: web browsing, video, and VOIP [20,23,24]. This paper concerns only three services including web browsing, video, and VOIP [20,23,24]. The reason is that three services are expected to be the most popular baseline services over 5G networks with fast connections and high-bandwidth connections [24]. The followings are the contributions of this work:

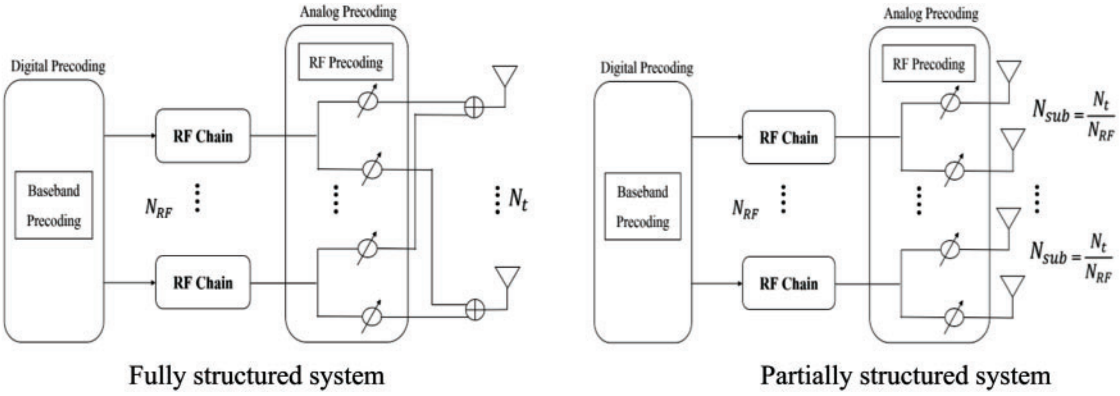
- Improvement in baseband and RF precoding under power constraints, and the appropriate number of RF chains to reduce power consumption on the massive MIMO-OFDM system in downlink.
- Improvement in the quality of experience for all three services to achieve user satisfaction and cost-effective use of network resources.
- Comparison in partially structured system to indicate that hybrid precoding provides higher energy efficiency and user satisfaction than OMP algorithm.

The rest of this paper is organized as follows. In Section 2, the system model involving the hybrid precoding and service model are discussed. Then, Section 3 shows the optimization of partially structured precoding. Section 4 presents the optimization of QOE-based precoding followed by the simulation results discussed in Section 5. Finally, Section 6 concludes the paper.

2 System Model

2.1 Hybrid System Model

The hybrid precoding is a massive MIMO-OFDM system technique. As seen in Fig. 1, it has two structures: fully and partially structured systems. For energy efficiency and reduction of hardware complexity, we recommend that the partially structured system is suitable for massive MIMO systems.



Fully structured system

Partially structured system

Figure 1: The hybrid precoding of massive MIMO a) Fully structured system b) Partially structured system

We focus on the massive MIMO system's downlink where N_t is the number of transmitting antennas, N_r is the number of receiving antennas and N_{RF} is the number of RF chains. The $N_{sub} = N_t/N_{RF}$ is connected to the partially structured system in one RF chain. In the system, there is a digital baseband precoding $\boldsymbol{F}_{BB} \in C^{N_{RF} \times K}$ where K is the number of mobile users and the RF precoding $\boldsymbol{F}_{RF} \in C^{N_t \times N_{RF}}$ is block diagonal matrix $\boldsymbol{F}_{RF} = diag\{f_1, \ldots f_i, \ldots f_{RF}\}$ where $f_i = (N_t/N_{RF}) \times 1$ complex. For the problem of the non-convex [6,12] to solve the use of the decoupling program between transmitting and receiving, the received signal can be written as [13]

$$\mathrm{y}_k = \boldsymbol{H}_k \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,k} \boldsymbol{s} + n_k, \quad k = 1, 2, 3, \ldots, K \tag{1}$$

where $\mathrm{y}_k \in C^{N_r}$, $\boldsymbol{H}_k \in C^{N_t}$ the channel matrix associated with Channel State Information (CSI) between the BS and K mobile users, $\boldsymbol{s} \in C^{N_t \times 1}$ is vector of transmitting and n_k is additive white Gaussian noise, i.e., assuming without the loss of generality and $\sigma_k^2 = 1$. The channel matrix of massive MIMO-OFDM is

$$\boldsymbol{H}_k = \sqrt{\frac{\mathrm{N}_t N_r p_k}{N_{cl} N_{ray}}} \sum_{c=0}^{N_{cl}} \sum_{r=1}^{N_{ray}} \alpha_{cr} \boldsymbol{a}_r (\theta_{cr} \vartheta_{cr})^H e^{-\frac{j2\pi cr}{K}}, \tag{2}$$

where N_{ray} is the amount of rays in each cluster between the BS and K mobile users, N_{cl} is the amount of clusters between the BS and K mobile users, p_k is the path loss between the BS and K mobile users α_{cr} is the complex gain of rth ray in the cth propagation cluster and $\theta_{cr}, \vartheta_{cr}$ are the azimuth (elevation) angles of departure and angles of arrival (AoDs/AoAs). We decompose $\boldsymbol{H}_k = \mathrm{U} \forall \mathrm{V}^H$ by Singular value decomposition (SVD) where U and V are complex orthogonal matrix, $\forall$ is a diagonal matrix and a subscript H is a conjugate transpose. The data rate can be expressed as

$$R_k = BW \sum_{k=1}^{K} \log_2 (1 + SINR_k), \tag{3}$$

where BW is bandwidth and $SINR_k$ is the Signal to Interference plus Noise Ratio, which can be written as

$$SINR_k = \frac{\boldsymbol{H}_k \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,k} \boldsymbol{F}_{BB,k}^H \boldsymbol{F}_{RF}^H \boldsymbol{H}_k^H}{\sum_{k=1}^{K} \sum_{j \neq k}^{K} \boldsymbol{H}_k \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,j} \boldsymbol{F}_{BB,j}^H \boldsymbol{F}_{RF}^H \boldsymbol{H}_k^H + \sigma_k^2}. \tag{4}$$

2.2 Energy Efficiency

Spectral efficiency is a measurement of the data transmission performance which can be achieved over a given BW. Even theoretically, the spectral efficiency of fully structured system is also higher. However, in large MIMO systems, energy consumption is also an important indicator. It can consider the relationship between the data rate and the total power consumption, also known as energy efficiency can be expressed as

$$EE = \frac{R_k}{P_{BB} + N_{RF}(P_{RF} + P_{DAC}) + N_t P_{PA} + N_t P_{PS}}, \tag{5}$$

where the total power consumption of the partially structured system shown in [26]. The P_{BB} is the power for the baseband precoding, P_{RF} is the power of RF chains, P_{DAC} is the power digital to analog converter, P_{PA} is the power of power amplifier and P_{PS} is the power of a phase shifter. In the power parameters, we assume as follows: $P_{BB} = 5$ mW, $P_{RF} = 30$ mW, $P_{DAC} = 200$ mW, $P_{PA} = 20$ mW, $P_{PS} = 30$ mW.

2.3 Service QoE Model

The QoE is a tool for measuring the overall level of user satisfaction or quality of experience with a communication network service. This can indicate that the quality of transmission signals is good or should be improved by assessing the satisfaction of each user. If communication is hampered during the now playing service, the network fails. When QoE is used to measure the level of satisfaction, the user may experience the good level of satisfaction without the utilization of high bandwidth or throughput. The QoE is regarded as a user-oriented service in which the QoS parameters are directly/indirectly contributed to their impact QoS which is a network-oriented performance parameter about hardware-software and in the physical layer i.e., $SINR$, PLR and delays.

In this work, we also present the QoE for three services: web browsing, video H.242, and VOIP. The MOS as shown in Tab. 1 is employed.

Table 1: The MOS score with user satisfaction

MOS	User satisfaction
5	Excellent
4	Best
3	Good
2	Fair
1	Poor

2.3.1 Web Browsing Service

The QoE for web browsing is essential to measure user satisfaction since most people use the Internet as an indispensable part of their everyday lives, as a result, web surfing QoE can assist service providers in determining whether network circumstances are influencing user satisfaction. The MOS of web browsing service can be expressed as [23,24]

$$MOS_{web} = -K_1 In(d(R_{web})) + K_2, \tag{6}$$

where MOS_{web} is the satisfaction level of user, as shown in Tab. 1 where K_1 and K_2 are constant correlated with MOS_{web} in order to have a score of 1 to 5 and $d(R_{web})$ have a correlation with web-related factors like the round trip time (RTT), the web page size (FS), the data rate (R_k), the maximum segment size (MSS) by TCP and HTTP are protocols that is used by $d(R_{web})$ equation as follows [24]

$$d(R_{web}) = 3RTT + \frac{FS}{R_k} + L\left(\frac{MSS}{R_k} + RTT\right) - \frac{2MSS(2^L - 1)}{R_k}, \tag{7}$$

where $L = \min[L_1, L_2]$ is the parameter of the number of slow start cycles with idle periods, where the parameter of L_1 and L_2 are the number of cycles which are taken for the congestion window to reach the bandwidth-delay product (BDP) and the number of slow start cycles required until the entire web page size is transferred, respectively. They are defined as [24]

$$L_1 = \log_2\left(\frac{1}{2} + \frac{R_k RTT}{2MSS}\right) \tag{8}$$

$$L_2 = \log_2\left(\frac{1}{2} + \frac{FS}{4MSS}\right). \tag{9}$$

In [24] and [27], the RTT in 5G is negligible and we only consider a few user experiences. Therefore, the use of Eq. (6) in web browsing service can be rewritten as

$$MOS_{web} = K_1 In\left(\frac{R_k}{FS}\right) + K_2. \tag{10}$$

2.3.2 Video Service

The use of video streaming of H.264/AVC video codec is a highly efficient codec that provides high-quality images and a minimum bandwidth for the recording and distribution of full HD video and audio. The video codec H.264/AVC uses the estimation of Peak Signal-to-Noise Ratio ($PSNR$) which is a quality measurement as shown in Eq. (11) [28,29]

$$PSNR = m + n\sqrt{\frac{R_k}{p}}\left(1 - \frac{p}{R_k}\right), \tag{11}$$

The parameter m, n and p are characterized as a specific video stream [28]. The relationship between $PSNR$ and MOS of video can be expressed as follows [24]

$$MOS_{video} = d\log(PSNR) + e, \tag{12}$$

The parameters d and e are constant correlated with MOS_{video} in order to have a score of 1 to 5 with following conditions in the video MOS values

$$MOS_{video}(PSNR_k) = \begin{cases} 1; & PSNR_k \leq PSNR_1 \\ d\log(PSNR) + e; & PSNR_1 < PSNR_k < PSNR_{4.5} \\ 4.5; & PSNR_k \geq PSNR_{4.5} \end{cases} \tag{13}$$

In the design of video streaming, $PSNR_{4.5} = 42$ dB is Excellent and $PSNR_1 = 30$ dB is Poor, which are calculated from the coding chrominance component [29].

2.3.3 VoIP Browsing Service

VoIP employs the AMR-WB audio codec, which provides high-quality speech for HD VoIP as well as real-time multi-channel implementation. The model of AMR-WB implicates R-factor defined as follows [20,30–32]

$$R_{factor} = R_o - I_s - I_d - I_{eff} - A_f, \tag{14}$$

where R_o is the basic signal to noise ratio, I_s is the sum of all impairments which might simultaneously happen less or more with the voice transmission and this factor is set$=0$, I_d is the delay impairment factor showing all impairments due to voice signal delay, A_f is the advantage factor, I_{eff} is the effective equipment impairment factor, by I_e is the equipment impairment factor at zero packet-loss, B_{pl} is the packet-loss robustness factor and P_{pl} is the packet loss rate.

$$I_{eff} = I_e + (129 - I_e) \times \left(\frac{P_{pl}}{P_{pl} \times B_{pl}}\right). \tag{15}$$

The VOIP of MOS model relates to R_{factor} as the WB audio codec in ITU-T G.107.1. This has a maximum value of $R_o = 129$ by $R_o = R_{factor}/1.29$ [31,32]. The MOS of VOIP service can be written as follows

$$MOS_{VOIP} = 1 + 0.035R + R(R - 60)(100 - R)(7 \times 10^{-6}). \tag{16}$$

where R has the score criteria as shown in Tab. 2. summarizes the MOS score of VOIP on the scale 1 to 5 can be obtained as follows

$$MOS_{VOIP}(R) = \begin{cases} 1; & R < 0 \\ 1 + 0.035R + R(R - 60)(100 - R)(7 \times 10^{-6}); & 0 < R < 100 \\ 4.5; & R > 100 \end{cases} \tag{17}$$

Table 2: The MOS score of VOIP [31,32]

MOS	User satisfaction	R
4.3–5.0	Excellent	90–100
4.0–4.3	Best	80–90
3.6–4.0	Good	70–80
3.1–3.6	Fair	60–70
2.6–3.1	Poor	50–60
1–2.6	Bad	Less than 50

3 Optimization of a Partially Structured Precoding

For the partially structured system, we focus on the optimized fully digital precoding matrix $\boldsymbol{F}_{opt}$ and the precoding of digital/analog by minimizing the euclidean distance method between $\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}$ and $\boldsymbol{F}_{opt}$ expressed as [13,33]

$$\underset{\boldsymbol{F}_{RF},\boldsymbol{F}_{BB}}{\text{minimize}}\,||\boldsymbol{F}_{opt}-\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F$$

$$\text{subject to}\begin{cases}\boldsymbol{F}_{RF}\in diag\{f_1,\ldots f_i,\ldots f_{RF}\}\\ ||\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F^2\le P_c,\end{cases} \tag{18}$$

where P_c is a maximum power constant. We use alternating minimization method to optimize $\boldsymbol{F}_{RF}$ and $\boldsymbol{F}_{BB}$, that alternate minimizing using a straightforward method for solving the minimal value of a function involving two more variables. The parameters $\boldsymbol{F}_{RF}$ and $\boldsymbol{F}_{BB}$ as shown in Eq. (18) can be used to optimize the spectral efficiency and energy efficiency based on power constraints

3.1 Analog Precoding

The analog precoding is the part that amplifies the downlink signal and controls the transmit power. The phase of the signal is only changed by the $\boldsymbol{F}_{RF}$ precoding matrix, there is a power constraints and structure of $\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}$ Eq. (18), we can find the $\boldsymbol{F}_{RF}$ by multiplying the row of $\boldsymbol{F}_{BB}$, so the $\boldsymbol{F}_{RF}$ constraint can be rewritten as

$$||\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F^2\le\frac{N_t}{N_{RF}}||\boldsymbol{F}_{BB}||_F^2\le P_c. \tag{19}$$

Thus, the alternating minimizing of closed-form solution for $\boldsymbol{F}_{RF}$ analog precoding expressed as

$$\underset{\boldsymbol{F}_{RF}\in C^{N_t\times N_{RF}}}{\text{minimize}}\;||\boldsymbol{F}_{opt}-\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F$$

$$\text{subject to }\boldsymbol{F}_{RF}\in diag\{f_1,\ldots f_i,\ldots f_{RF}\}, \tag{20}$$

Furthermore, the column property of $\boldsymbol{F}_{RF}$ in Eq. (19) can be rewriting as

$$\begin{gathered}\underset{\boldsymbol{F}_{RF}\in C^{N_t\times N_{RF}}}{\text{minimize}}\;||\boldsymbol{F}_{opt}-\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F\\ phase(\boldsymbol{F}_{opt})=phase(\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}),\end{gathered} \tag{21}$$

$phase(\boldsymbol{F}_{opt})$ is the operation to achieve each $\boldsymbol{F}_{opt}$ matrix element phase and $\boldsymbol{F}_{RF}$ property, hence

$$\begin{gathered}phase(\boldsymbol{F}_{RF(i,f)})=phase\left(\boldsymbol{F}_{opt(i,:)}\boldsymbol{F}_{BB(i,:)}{}^{H}\right),\\ 1\le i\le N_t,\quad f=\left\lceil i\frac{N_{RF}}{N_t}\right\rceil.\end{gathered} \tag{22}$$

3.2 *Digital Precoding*

In the digital baseband, the downlink signal and transmitted power can be controlled using the signal processing part in the precoding. To optimize the digital precoding, the value of $\boldsymbol{F}_{RF}$ is fixed to solve the solution of baseband and the value of $\boldsymbol{F}_{BB}$ is set to the maximum power constant. Then, the Eq. (18) can be written as

$$\underset{\boldsymbol{F}_{BB}\in C^{N_{RF}\times K}}{\text{minimize}} \; ||\boldsymbol{F}_{opt}-\boldsymbol{F}_{RF}\boldsymbol{F}_{BB}||_F$$

$$\text{subject to} \quad ||\boldsymbol{F}_{BB}||_F^2 \leq \frac{N_{RF}P_c}{N_t}, \tag{23}$$

From [13] and Eq. (23), the problem is a nonconvex quadratically constrained quadratic program (QCQP). Let $\boldsymbol{z}=[vec(\boldsymbol{F}_{BB})t]^T, \boldsymbol{Z}=\boldsymbol{z}\boldsymbol{z}^H, \varsigma=I_K\otimes\boldsymbol{F}_{BB}, f_{opt}=vec(\boldsymbol{F}_{opt}),\ t^2=1$, where $\boldsymbol{G}_1$, $\boldsymbol{G}_2$ and $\boldsymbol{Q}$ are symmetric matrices

$$\boldsymbol{G}_1=\begin{bmatrix} I_{n-1} & 0 \\ 0 & 0 \end{bmatrix}, \quad \boldsymbol{G}_2=\begin{bmatrix} 0_{n-1} & 0 \\ 0 & 1 \end{bmatrix}, \quad \boldsymbol{Q}=\begin{bmatrix} \varsigma^H\varsigma & -\varsigma^H f_{opt} \\ -f_{opt}^H\varsigma & f_{opt}^H f_{opt} \end{bmatrix},$$

$n=KN_{RF}+1$ complex Hermitian matrices expressed as $\underset{\boldsymbol{Z}\in\mathbb{R}^n}{\text{minimize}}\, Tr(\boldsymbol{Q}Z)$

$$\text{subject to} \quad \begin{cases} Tr(\boldsymbol{G}_1\boldsymbol{Z}) \leq \dfrac{N_{RF}P_c}{N_t} \\ Tr(\boldsymbol{G}_2\boldsymbol{Z})=1 \\ \boldsymbol{Z}=0, \quad \text{Rank}(\boldsymbol{Z})=1, \end{cases} \tag{24}$$

As shown in Eq. (24), the problem is that Rank (Z) $=1$which is not easy to achieve. So, we will use the semidefinite program (SDP) method as follows

$$\underset{\boldsymbol{Z}\in\mathbb{R}^n}{\text{minimize}}\, Tr(\boldsymbol{Q}Z)$$

$$\text{subject to} \quad \begin{cases} Tr(\boldsymbol{G}_1\boldsymbol{Z}) \leq \dfrac{N_{RF}P_c}{N_t} \\ Tr(\boldsymbol{G}_2\boldsymbol{Z})=1 \\ \boldsymbol{Z}\geq 0. \end{cases} \tag{25}$$

Algorithm 1 is to optimize the partially structured precoding as the Alternating Minimization Algorithm of analog precoding on Eq. (20) and digital precoding on Eq. (23).

Algorithm 1: Optimize the Partially Structured Precoding as the Alternating Minimization Algorithm of Analog Precoding and Digital Precoding.

```
Input: $F_{opt}$
1. Random phase of $F_{RF}^{(i)}$, $i = 0$
2. Repeat

3. fix $F_{RF}^{(i)}$, to find $F_{BB}^{(i)}$ by Eq. (25)

4. fix $F_{BB}^{(i)}$, to find the new $F_{RF}^{(i)}$
5. until the criterion stops
```

4 Optimize QOE-Based Precoding

This section optimizes the QoS parameters to high the spectral efficiency of all three services. To optimize the MOS of service, the MOS minimum threshold based on Eqs. (10), (12) and (16). which in optimizing as we know that QoS are related to QoE, we will consider SINR by defining the minimum $SINR_{\min}$ as a constant with alternating maximize methods for user satisfaction, which can be written as follows

$$\underset{\boldsymbol{F}_{RF},\boldsymbol{F}_{BB,k,j}}{\text{minimize}}\, MOS_k$$

$$\text{subject to} \quad \begin{cases} \dfrac{\boldsymbol{H}_k \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,k} \boldsymbol{F}_{BB,k}^H \boldsymbol{F}_{RF}^H \boldsymbol{H}_k^H}{\sum_{k=1}^{K} \sum_{j \neq k}^{K} \boldsymbol{H}_k \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,j} \boldsymbol{F}_{BB,j}^H \boldsymbol{F}_{RF}^H \boldsymbol{H}_k^H + \sigma_k^2} \geq SINR_{\min} \\ \sum_{k=1}^{K} \sum_{j \neq k}^{K} \boldsymbol{F}_{RF} \boldsymbol{F}_{BB,k,j} \leq P_c, \end{cases} \tag{26}$$

where MOS_k represents all three services: web browsing, video and VOIP. The purpose of this paper is to achieve a high data rate using an alternating maximized method. In the part of optimizing $SINR$ for user satisfaction, the baseband precoding and RF precoding $\boldsymbol{F}_{RF}\boldsymbol{F}_{BB,k,j}$ are considered while remaining the maximum power constraint of systems P_c. We optimize the user satisfaction for all three services as shown in Algorithm 2

Algorithm 2: Optimized QoE-Based Precoding

```
Input: $F_{RF}$, $F_{BB}$
1. Optimize the $SINR^i$ Eq. (4) , $i = 1$
2. Repeat
3. Find maximize $R_k^i$ from Eq. (3) under in Eq. (26)
4. until the criterion stops
5. SINR_new $= SINR^i$, use the new $SINR$ value into Eq. (3)
6. Substitute Eq. (3) into the $MOS_k$ equation in Eqs. (10), (12) and (16).
```

5 Simulation Results

In this section, the proposed system with partial structure of hybrid precoding for the downlink in the massive MIMO-OFDM system is discussed. We present numerical simulations which have parameters as shown in Tab. 3. In this massive MIMO-OFDM system, we consider 64 sub-channels. In terms of energy efficiency compared to the number of RF chains, the spectral efficiency is compared with SNR. To analyze three services, we compare the partially structured system of hybrid precoding and the fully-structured system of OMP precoding, which are referred to the method presented in [14].

From Fig. 2, we consider the energy efficiency *vs.* the number of RF chains in massive MIMO systems. When comparing the hybrid precoding's energy efficiency, it can be seen that the partially structured system provides higher energy efficiency than a fully structured system. Also, when the RF chains are less, the systems can save more energy. The energy efficiency of fully and partially structured systems decreases with an increase in the number of RF chains in which the partially structured system provides a higher percentage up to 85% compared to fully structured system with an average number of 16 RF chains.

Table 3: Numerical simulation parameters

parameter	value
Transmitting antennas	144
Receiving antennas	36
Amount of rays in each cluster	10
Amount of clusters	5
Number of RF chains	4
path loss	3.5
Maximum power constant	33 dBm
Bandwidth	300 kHz
Frequency	28 GHz

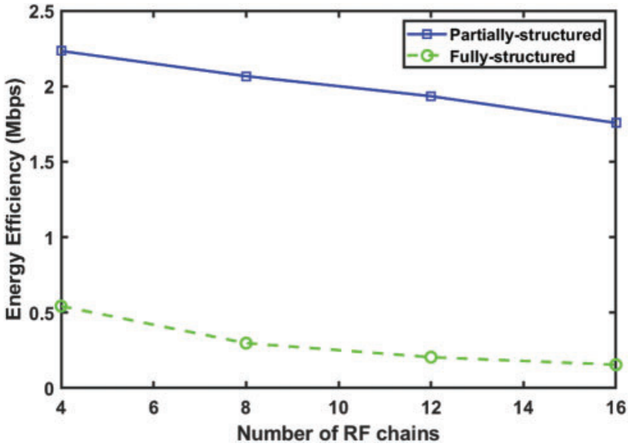


Figure 2: Energy efficiency in massive MIMO systems versus the number of RF chains for hybrid precoding in fully and partially structured systems

Fig. 3 shows the partially structured system based on different number of transmitted antennas with the spectral efficiency, when comparing the number of transmitted antennas as follows: $N_t = 32 : N_r = 32$, $N_t = 64 : N_r = 64$ and $N_t = 144 : N_r = 36$. Usually, the following numbers of antennas are commonly used for the massive MIMO in BS for Nokia, Ericsson [34]: $N_t = 32$ and $N_t = 64$. As seen in Fig. 3, the system performance for all three cases increases for $N_t = 32$, $N_t = 64$ and $N_t = 144$ in which the spectral efficiency increases when the SNR value and the number of antennas increases. Also, $N_t = 144$results in the system becoming high resistance to noise interference. The spectral efficiency of $N_t = 144$ provides higher efficiency than $N_t = 32$ and $N_t = 64$ with a percentage of 64.19% and 51.84% respectively, compared to the average of SNR from -20 to 10 dB.

5.1 Web Browsing Service

For the parameters for web browsing service shown in Eq. (9), we assume the number of users $K = 10$ and the web page size of the website according to [23]. The web page size most accessible by users are $FS =$ 18, 30, 50, 100, 200, 320, 400, 500, 650, and 1000 Kbyte. We consider the minimum spectral efficiency and maximum spectral efficiency are 2 bps/Hz and 7 bps/Hz respectively. So, we use parameters of $K_1 = 3.1929$ and $K_2 = 29.9216$. The average web page size is $FS = 320$ Kbyte.

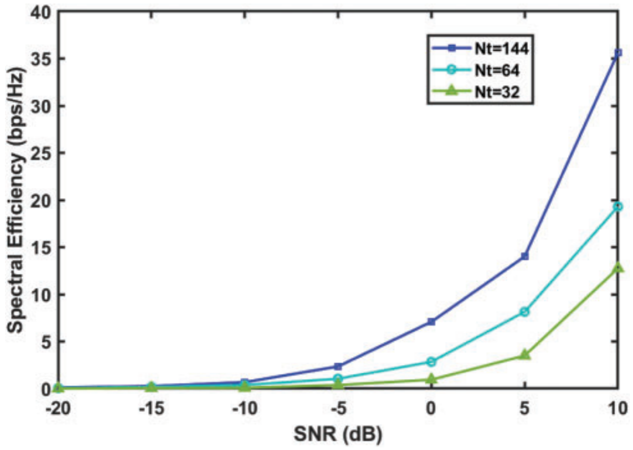


Figure 3: Spectral efficiency versus received SNR in massive MIMO systems for three different number of transmitted antennas $N_t = 32$, $N_t = 64$ and $N_t = 144$

Fig. 4 shows the MOS of web browsing service with respect to the number of users. In this figure, we compare the partially structured system of hybrid precoding with the fully structured system of OMP precoding in massive MIMO systems. The partially structured system provides a higher MOS web than the fully structured system. Also, the size of the web page grows greater, the level of MOS decreases. This means that, for the number of users is 10 with a web page size of 1000 Kbyte, a larger data rate is necessary due to the lowest satisfaction. However, the partially structured system with the number of 10 still regards the MOS for web = 3.21 and MOS web of OMP precoding = 1.75. The OMP algorithm of fully structured system can find an optimal array vector. Where the space constraints of analog precoding at a low RF chain affects low spectrum.

As a result, the MOS of user satisfaction is less compared to hybrid precoding of the partially structured system which processes both digital and analog precoding at RF chain = 4.

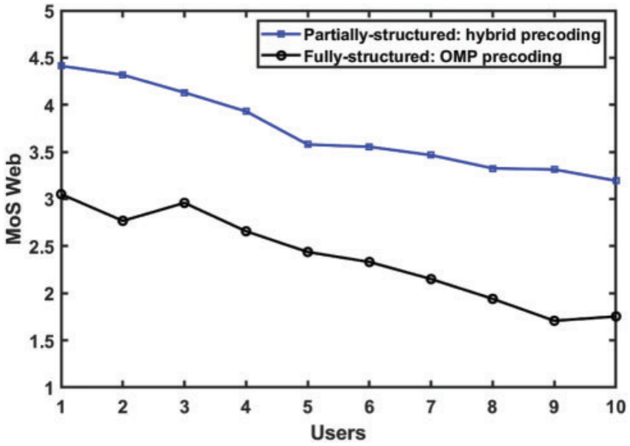


Figure 4: MOS Web versus the number of users for the partially structured system of hybrid precoding and the fully structured system of OMP precoding

5.2 *Video Service*

In terms of video service for parameters concerned in Eqs. (11) and (12), we assume the parameters m, n, and p which are 9.45, 5.24 and 0.23 respectively. For the parameters d = 27.37 and e = −39.43 from the H.264/AVC video codec standard with maximum PSNR = 42 dB and minimum PSNR = 30 dB.

According to Fig. 5 shows the MOS of video service with respect to the number of users. It obviously can be seen that the partially structured system of hybrid precoding provides a higher satisfaction MOS video than the fully structured system of OMP precoding. We aim to give a high data rate without approaching the fairness techniques for each user. Note that the level of MOS video shown in Fig. 5 is not equal for all users because the bitrate is changed by the randomness of interference and nonlinear element. As a result, the graph is a variation of MOS at 10 users.

5.3 *VOIP Service*

For the part of simulation for VOIP service, the E-model at 100 ms in Eq. (14) follows ITU-T G.107.1 and ITU-T G.113. We set $A_f = 0$, $\mathrm{I}_d = 4.2552$ ms, $B_{pl} = 16.1$ and $I_e = 11$. The parameters involved in finding the packet loss rate as the bytes and $RTT = 20$ ms.

Fig. 6 illustrates the MOS VOIP with respect to the number of users compared with the fully structured system of OMP precoding in massive MIMO systems. The results are similar to the video service in which the partially structured system of hybrid precoding provides better user satisfaction than the fully-structured of OMP precoding. However, MOS Video shown in Fig. 5 provides higher user satisfaction than MOS VOIP because VOIP requires a higher data rate.

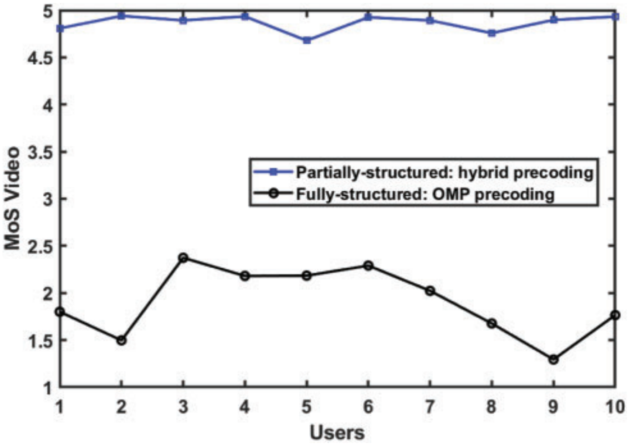


Figure 5: MOS Video with the number of users for partially structured system of hybrid precoding and the fully structured system of OMP precoding

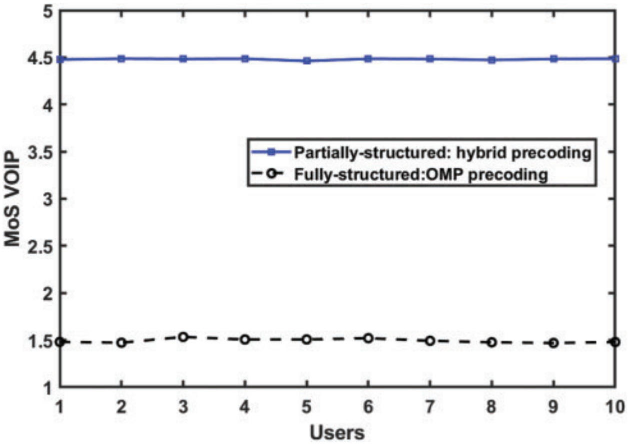


Figure 6: MOS VOIP with the number of users for the partially structured system of hybrid precoding and the fully structured system of OMP precoding

6 Conclusion

This paper has proposed the hybrid precoding of a massive MIMO-OFDM system for the partially structured system. The optimized solution of a partially structured system under power constraints can achieve a high data rate for user satisfaction, when considering three services on the web browsing, video, and Voice over IP (VOIP) services. The simulation results have shown that increasing the number of transmitted antennas can reduce signal interference, resulting in high spectral efficiency which leads to better QoE for user satisfaction. Moreover, the partially structured system provides higher user satisfaction than OMP precoding for the fully structured system. Also, the partially structured system still provides energy efficiency up to 85% and reduces complexity in a massive MIMO system.

Funding Statement: This work is supported by SUT Research and Development Funds and by Thailand Science Research and Innovation (TSRI).

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

[1] A. Salh, L. Audah, N. Shah and S. Hamzah, "Adaptive antenna selection and power allocation in downlink massive MIMO systems," *International Journal of Electrical and Computer Engineering*, vol. 7, no. 11, pp. 3521–3528, 2017.

[2] P. Uthansakul and A. A. Khan, "On the energy efficiency of millimeter wave massive MIMO based on hybrid architecture," *Energies*, vol. 12, no. 11, pp. 2227–2238, 2019.

[3] P. Uthansakul and A. A. Khan, "Enhancing the energy efficiency of mmWave massive MIMO by modifying the RF circuit configuration," *Energies, MDPI Open Access Journal*, vol. 12, no. 22, pp. 1–23, 2019.

[4] X. Gao, L. Dai, S. Han, I. Chih-Lin and R. W. Heath, "Energy-efficient hybrid analog and digital precoding for mmWave MIMO systems with large antenna arrays," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 4, pp. 998–1009, 2016.

[5] X. Zheng, Y. Wang and W. Liu, "Partially connected hybrid precoding design for millimeter wave MIMO systems," *Journal of Physics: Conference Series*, vol. 1325, no. 1, pp. 012057, 2019.

[6] Y. Feng, Y. Jiang, S. Han, C. I. and R. W. Heath, "Hybrid precoding for massive MIMO systems using partially-connected phase shifter network," in *Int. Conf. on Wireless Communications and Signal Processing (WCSP)*, Xi'an, China, pp. 1–6, 2019.

[7] J. Du, W. Xu, H. Shen, X. Dong and C. Zhao, "Hybrid precoding architecture for massive multiuser MIMO with dissipation: Sub-connected or fully-connected structures?," *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 5465–5479, 2018.

[8] L. N. Ribeiro, S. Schwarz, M. Rupp and A. L. F. de Almeida, "Energy efficiency of mmWave massive MIMO precoding with low-resolution DACs," *Journal of Selected Topics in Signal Processing*, vol. 12, no. 2, pp. 298–312, 2018.

[9] P. Uthansakul and M. E. Bialkowski, "Multipath signal effect on the capacity of MIMO, MIMO-oFDM and spread MIMO-oFDM," in *Int. Conf. on Microwaves, Radar and Wireless Communications*, Warsaw, Poland, vol. 3, pp. 989–992, 2004.

[10] R. A. Pitaval, B. M. Popovic, M. Mohamad and R. Nilsson, "Spectrally-precoded OFDM for 5G wide-band operation in fragmented sub-6 GHz spectrum," *ArXiv Preprint ArXiv:1606.00623*, vol. 1606.00623, pp. 1–12, 2016.

[11] L. Zhao, K. Li, K. Zheng and M. O. Ahmad, "An analysis of the tradeoff between the energy and spectrum efficiencies in an uplink massive MIMO-oFDM system," *Transactions on Circuits and Systems II: Express Briefs*, vol. 62, no. 3, pp. 291–295, 2014.

[12] X. Yu, J. C. Shen, J. Zhang and K. B. Letaief, "Alternating minimization algorithms for hybrid precoding in millimeter wave MIMO systems," *IEEE Journal of Selected Topics in Signal Processing*, vol. 10, no. 3, pp. 485–500, 2016.

[13] X. Ge, J. Sun, X. Gharavi and J. Thompson, "Joint optimization of computation and communication power in multi-user massive MIMO systems," *IEEE Transactions on Wireless Communications*, vol. 17, no. 6, pp. 4051–4063, 2018.

[14] O. E. Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi and R. W. Heath, "Spatially sparse precoding in millimeter wave MIMO systems," *IEEE Transactions on Wireless Communications*, vol. 13, no. 3, pp. 1499–1513, 2014.

[15] S. Ragunathan and P. Dananjayan, "Qos and sum rate maximization in heterogeneous massive MIMO network," in *IEEE Int. Conf. on System, Computation, Automation and Networking (ICSCAN)*, Pondicherry, India, pp. 1–4, 2019.

[16] R. W. Heath, R. Thay, H. Kim and H. Ju, “An overview of signal processing techniques for millimeter wave MIMO systems,” *IEEE Journal of Selected Topics in Signal Processing*, vol. 10, no. 3, pp. 436–453, 2014.

[17] D. Wu, Q. Wu, Y. Xu and Y. C. Liang, “QoE and energy aware resource allocation in small cell networks with power selection, load management and channel allocation,” *IEEE Transactions on Vehicular Technology*, vol. 66, no. 8, pp. 7461–7473, 2017.

[18] M. Fiedler, T. Hossfeld and P. Tran-Gia, “A generic quantitative relationship between quality of experience and quality of service,” *IEEE Network*, vol. 24, no. 2, pp. 36–41, 2010.

[19] P. Casas, M. Seufert, F. Wamser, B. Gardlo, A. Sackl *et al.*, “Next to you: Monitoring quality of experience in cellular networks from the end-devices,” *IEEE Transactions on Network and Service Management*, vol. 13, no. 2, pp. 181–196, 2016.

[20] D. Kwon, N. Gonzalez-Prelcic, S. Rangan, W. Roh and A. Sayeed, “Qoe-based adaptive mVoIP service architecture in SDN networks,” in *the Seventh Int. Conf. on Communication Theory*, Nice, France, pp. 62–67, 2014.

[21] P. Uthansakul, P. Anchuen, M. Uthansakul and A. A. Khan, “Estimating and synthesizing QoE based on QoS measurement for improving multimedia services on cellular networks using ANN method,” *IEEE Transactions on Network and Service Management*, vol. 17, no. 1, pp. 389–402, 2020.

[22] P. Uthansakul, P. Anchuen, M. Uthansakul and A. A. Khan, “Qoe-aware self-tuning of service priority factor for resource allocation optimization in LTE networks,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 1, pp. 887–900, 2020.

[23] M. Rugelj, U. Sedlar, M. Volk, J. Sterle, M. Hajdinjak *et al.,* “Novel cross-layer QoE-aware radio resource allocation algorithms in multiuser OFDMA systems,” *IEEE Transactions on Communications*, vol. 62, no. 9, pp. 3196–3208, 2014.

[24] H. Abarghouyi, S. M. Razavizadeh and E. Bjornson, “Qoe-aware beamforming design for massive MIMO heterogeneous networks,” *IEEE Transactions on Vehicular Technology*, vol. 67, no. 9, pp. 8315–8323, 2018.

[25] X. Ge, J. Yang, H. Gharavi and Y. Sun, “Energy efficiency challenges of 5G small cell networks,” *IEEE Communications Magazine*, vol. 55, no. 5, pp. 184–191, 2017.

[26] A. Li and C. Masouros, “Hybrid precoding and combining design for millimeter-wave multi-user MIMO based on SVD,” in *IEEE Int. Conf. on Communications (ICC)*, Paris, France, pp. 1–6, 2017.

[27] J. A. del Peral-Rosado, F. Gunnarsson, S. Dwivedi, S. M. Razavi, O. Renaudin *et al.*, “Exploitation of 3D city maps for hybrid 5G RTT and GNSS positioning simulations,” in *ICASSP IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Barcelona, Spain, pp. 9205–9209, 2020.

[28] L. U. Choi, M. T. Ivrlac, E. Steinbach and J. A. Nossek, “Sequence-level models for distortion-rate behaviour of compressed video,” in *IEEE Int. Conf. on Image Processing*, Genova, Italy, pp. II–486, 2005.

[29] A. Saul and G. Auer, “Multiuser resource allocation maximizing the perceived quality,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, no. 6, pp. 1–15, 2009.

[30] A. Raja, R. M. A. Azad, C. Flanagan and C. Ryan, “A methodology for deriving VoIP equipment impairment factors for a mixed NB/WB context,” *IEEE Transactions on Multimedia*, vol. 10, no. 10, pp. 1046–1058, 2008.

[31] D. Nguyen, H. Nguyen and É. Renault, “A new non-intrusive model for measuring VoLTE quality based on wideband E-model,” *Communications on Applied Electronics*, vol. 5, no. 8, pp. 1–8, 2016.

[32] D. Nguyen and H. Nguyen, “A dynamic rate adaptation algorithm using WB E-model for voice traffic over LTE network,” in *IEEE Conference on Wireless Days*, Toulouse, France, pp. 1–6, 2016.

[33] N. Souto, J. Silva, J. Pavia and M. Ribeiro, “An alternating direction algorithm for hybrid precoding and combining in millimeter wave MIMO systems,” *Journal of Physics Communications*, vol. 34, pp. 165–173, 2019.

[34] R. Chataut and R. Akl, “Massive MIMO systems for 5G and beyond networks-overview, recent trends, challenges, and future research direction,” *Sensors*, vol. 20, no. 10, pp. 2753, 2020.