POWER - EFFICIENT MASSIVE MIMO - OFDM FRAMEWORK FOR IIOT NETWORKS

Balamurugan Easwaran

Associate Professor, Department of Computer Science and Mathematical Sciences, University of Africa,Toru Orua,Nigeria.E-mail:Balamurugan.easwaran@uat.edu.ng

Abstract - In wireless communications industry, worldwide bandwidth scarcity has led to the development and application of wireless network infrastructure, known as massive Multiple-Input Multiple-Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) system. Massive MIMO is one of the essential technologies for the next-generation networks, which combine both transmitter and reception antennas with relatively simple processing to ensure great spectral and energy efficiency. Power-Efficient (PE) MIMO-OFDM antenna systems are widely used in commercial communication systems since operating costs, and carbon sites may be reduced. For battery-restricted Industrial Internet of Things (IIoT) devices, enhancing PE is particularly critical. The transmitting and receiving elements of large MIMO-OFDM IoT networks are observed, and several successful approaches have been categorized. It has been regarded the uplink Reference Power Control (RPC) as an uplink aspect. Lowering uplink RPC can yield IoT battery savings but increases channel estimate inaccuracy. The Peak-to-Average Power Ratio (PAPR) decrease in the OFDM signal and the downlink RPC is considered as a downlink aspect. Although the real PE advantage in the system context has been demonstrated in the minimal study, these processes have been considered efficient PE techniques. Furthermore, unmanned aerial vehicles (UAVs) have been employed for using radiofrequency energy transfer to prolong battery-limited IoT devices. Numerous findings demonstrate that the mathematical model is in excellent agreement with the simulation results and may thus be utilized for the improvement of PE.
Keywords: Massive MIMO, OFDM, Power Efficiency, IIoT, PAPR.

1 INTRODUCTION

A wireless system that can consistently sustain high connectivity between the data center and IIoT devices is necessary to realize the effective industrial network of things (IIoT) [1] [2]. The most promising technology for preserving hyperconnectivity and enhancing the power consumption of IIoT's network is a Massive MIMO Antenna System with several transmitter (TX) antennas [3-8]. Massive MIMOs can be used in network infrastructure to collect associated IIoT data reliably. Massive MIMO provides much more channel gain by utilizing a beamforming technique or enhances spectral efficiency (SE) through spatial data transmissions.

Since PE is typically defined as the SE to the energy consumption ratio, boosting SE can deliver significant advantages when SE increases while maintaining an adequate energy consumption or lowering power use while maintaining SE[9]. The power amplifier (PA) is generally the strongest hungry device among a signal transmission system's several power consumption components. It is worth noting that at the current base station (BS), one sample signal transmission system[10], the PA accounts for 50-80 percent of overall energy usage. Thus, the PE of large MIMO antenna systems is highly crucial to PA operations [11].

Also, OFDM is a strong modulation technique utilized for many wireless Standards, including IEEE 802.11/16, Long Term Evolution (LTE), Advanced Television Systems Committee (ASTC) 3.0, etc. OFDM offers a powerful modeling approach. The large MIMO-antenna system may be coupled with OFDM [12] since most high-rate signals are OFDM. However, OFDM is intended for efficient modulation at high bandwidth and does not take the system's PE into account[13]. Because it orthogonally packages many subscribers in a restricted bandwidth, there is a significant PAPR issue that severely restricts PA efficiency. This problem is highly significant in practice, and several researchers have tried to resolve it [14].

Two ways of dealing with this problem exist in principle. First, a nonlinear gadget is used to improve the PA's sequential frequency range. Before PA, the nonlinear device may be found, and the coordinating device-PA can be straightforward to a specific extent. It is known as a digital pre-distortion (DPD)[15] which is a nonlinear device. The DPD is a costly device and must be used for each antenna. Thus the huge MIMO-OFDM antenna system is difficult to deploy. The second method is to employ a PAPR decomposition method which decreases the PAPR of the OFDM signal by using nonlinear devices to eliminate nonlinear distortion. PA is one of the TX nonlinear representative devices. PAPR reduction methods may often be split into systems for distortion and non-deformation[16].

By distorting the signal, the distortion system decreases the PAPR of the signal. One example of the

PAPR reduction technique for distortion is clipping[17]. The signal PAPR is reduced without corrupting the information. One prominent distortion-free PAPR reduction scheme is the rotation-based approach, such as selective mapping (SLM)[18]. In general, deformation systems are simpler and more efficient. For example, large MIMO-OFDM antenna systems have been suggested to be used for complex systems. The distortion technique does, however, accompany signal distortion, which can lower the receiver data rate significantly (RX).

This paper shows the major contributions:

• For different circumstances, closed PE equations are obtained using a large battery-based MIMO-OFDM IIoT network. The calculated approximations additionally incorporate the distortion of slicing from the technique of cutting PAPR.

• Based on the calculated PE approximations, PE efficiency for different scenarios in large battery constrained IIoT-based MIMO-OFDM networks has been provided. In addition, the RF power transfer model is also included using UAVs.

The remaining document is organized as follows. Section 2 explores related works on PE-based MIMO-OFDM systems. Power-Efficient (PE) MIMO-OFDM antenna systems for IIoT have been explained in section 3. Section 4 consists of the analysis and findings obtained from the proposed model. Finally, the conclusion and possible studies have been outlined in Section 5.

2 RELATED WORKS

MIMO systems form part of new wireless networks and have been widely employed in recent years to achieve great spectrum efficiency and energy efficiency[19]. However, before the development of MIMO, most Single-Input-Output (SISO) systems had extremely low performance and could not accommodate a highly reliable number of users. As a result, a range of novel MIMO technologies, such as single-user MIMO (SU-MIMO)[20] and multi-user MIMO (MU-MIMO) [21] networks, have been created to meet this huge demand. Nevertheless, these new techniques are not sufficient to meet the rising requirements [22-24].

In recent years, wireless users have risen rapidly, generating billions of data that must be processed more effectively. Moreover, thousands of IoT devices contribute to data flow and have different applications for smart care, smart home, and smart energy[25]. By the end of 2020, the connected devices are projected to be over 50 billion. The existing 4G/LTE network MIMO technologies cannot manage this enormous data traffic flow faster and more reliable in this area. Thus, a massive MIMO technique is considered in the 5G network as the possible solution to solve large data and user traffic[26]. Various research on massive MIMO systems and their advantages have been done.

Massive MIMO is the most exciting 5G technology beyond the wireless age. Massive MIMO is an advanced technology in modern wireless networks that combine hundreds and thousands of antennas on the BS and simultaneously utilizes tens of users[27]. MIMO's additional antennas assist in focusing power on a limited geographical area to deliver higher spectral efficiency and productivity.

In recent years, a rising class of study has taken place because the design of an energy-efficient wireless network is one of the main challenges in IoT networks. In the MIMO context,[28] authors developed a method to maximize the PE of MIMO-OFDM systems with low complexity link adaption. They demonstrated that the PE is an almost concave single-peak transmitting power function and created an iterative technique for finding a near-optimal transmitting power. Through realistic simulations at the end-to-end bits, the algorithm's complexity has been lowered by the magnitude of several orders, but the loss of performance has been very small.

The authors of [29] presented a new MIMO PE optimization method by using active antenna transmissions and optimizing the transmission covariance under fixed active transmitting antenna sets. The optimization of covariance in the transmittances provided a sequence of concave-convex division algorithms to provide a globally optimal energy-efficient iterative water-filling method. The technique and the associated performance of the large MIMO systems with non-ideal hardware have also been reported. The authors demonstrated that the enormous degrees of freedom provided by massive MIMOs might be exploited to reduce transmission power and support significant hardware impairments that enable cheap and energy-efficient antenna components to be used.

3 POWER-EFFICIENT MASSIVE MIMO-OFDM FRAMEWORK FOR IIOT NETWORKS

Huge IoT networks based on MIMO-OFDM are very promising; however, the PE should be carefully examined to benefit fully from the massive MIMO-OFDM system. The PE is closely linked to operating costs; thus, the huge IoT-based MIMO-OFDM network is impossible to implement without PE enhancement, despite its vast SE benefits. However, in the MIMO-OFDM-based IoT networks, both downlink and uplink PE can be improved. This can bring down the cost and enhance the battery duration and usefulness of sensor-like IoT devices. To this end, the PE efficiency of a large MIMO OFDM-based IoT network in different circumstances should be thoroughly examined. The system features power control in the uplink/downlink and PAPR mitigation. Moreover, energy transmission UAVs are often used for battery-limited IoT devices. The results might be very helpful for the design process.

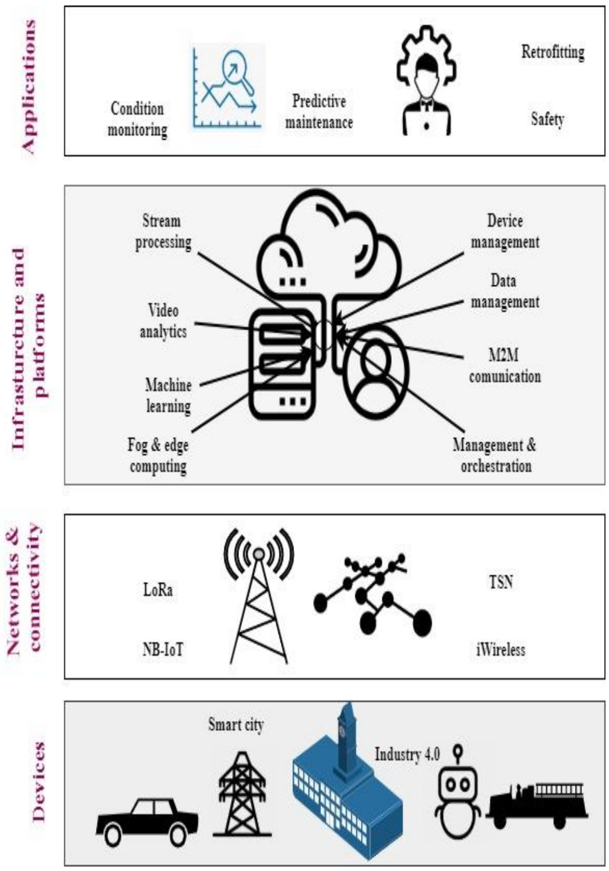


Figure 1 IIoT network model with applications

Fig. 1 depicts the IIoT network model with applications. For the IIoT Center to be a highly reliable, highly secure, reasonably close, intelligent IIoT application to be developed with industrial networking technologies, standard communication and communication mechanisms, machine-to-machine communication, Fog/Edge/ Cloud computer infrastructure, device management, and data orchestration, and platforms for data analysis.

3.1 IoT Model

Fig 2 shows the IoT model that has been utilized in this work. The base station (BS), user equipment (UE), and UAV have been treated as one single isolated cell with three entities.

With N transmitting antennas, the BS has enormous MIMO-OFDM capabilities and is implemented in data centers. UE is IoT based device, while the number of UE is V. V is typical for a channel hardening impact to be less than N. There are other entities like UAV, which can transmit power to the UEs to prolong the duration of the battery. The UAV count is significantly less than UEs. All UEs and UAVs are linked to the BS. As no relays and D2D links are available, UEs are directly linked to the BS.

Both UEs and BS have been linked to UAVs. There are several UAVs, so UEs only stand in the vicinity of the UAVs. The range of N is between 100 and 700, and N is adjustable. The bigger N increases the SE, but the energy consumption is also increased. The signal can be cut off to minimize the non-linearity of the signal and enhance PE. The TX power can also be changed, and the transmission power range is from 5 to 50W in the downlink. The power range is 150mW to 250mW for uplink transmission. The frequency of the carrier signal is 3GHz. Bandwidth and time are 10 msec and 200 kHz, respectively. The drone speed is 15 meters per second.

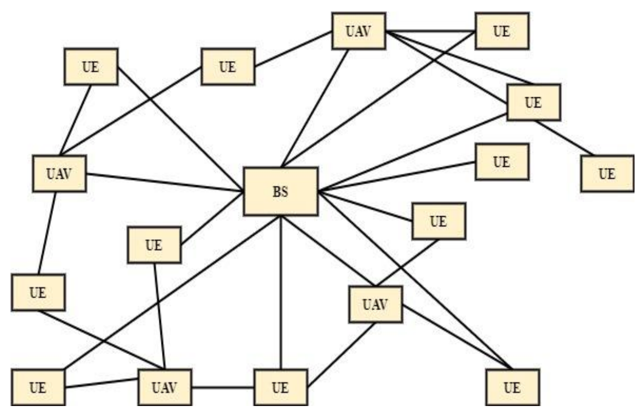


Figure 2 IoT network

3.2 Precoding

The precoding procedure is essential if large MIMO signals are transferred to numerous dispersed IoT devices to decrease inter-user interference (IUI). Matched filtering (MF) and Zero Forcing (ZF) systems are the two typical linear precoding schemes used in the massive MIMO system. The signal which is transmitted from the antenna is denoted as

$$Y = \varphi XT \tag{1}$$

X is the precoder matrix of dimensions $N \times V$ used to minimize the interference, φ is the normalized transmitted power. N and V denote the number of base station antennas and number UEs associated with the BS, respectively. T is the information signal matrix given by

$V \times 1$. For precoding using MF, the values of $X = H^h$ and $\varphi \approx \frac{1}{\sqrt{NV}}$. The values of $X\ and\ \varphi$ for ZF precoding is given by $X = H^h/(HH^h)$ and $\varphi \approx \sqrt{(\frac{N-V}{V})}$ respectively.

3.2 Proposed PE Model for Massive MIMO-OFDM

An efficient power consumption model is required for IIoT applications to be implemented in a massive MIMO-OFDM system. The total power consumption in the base station is given by

$$P_{t,bs} = P_{amp} + N.P_{RF} + P_{LF} \quad (2)$$

$P_{t,bs}$ is the total power consumed by the BS antenna. P_{amp} is the power consumed by the power amplifier. P_{RF} and P_{LF} are the RF power consumption and message signal or baseband power consumption, respectively. N is the number of antennas in the BS. It has been observed that, as the value of N increases, the beamforming is better, which leads to reduced power consumption by the PA. However, P_{RF} increases as the value of N is increased.

The total power consumption in the UE is given by

$$P_{t,UE} = V.P_{amp}^{UL} + V.P_{RF}^{UL} + V.P_{LF}^{UL} \quad (3)$$

V denotes the number of UEs associated with the BS. P_{amp}^{UL}, $P_{RF}^{UL}\ and\ P_{LF}^{UL}$ are the uplink power consumption of PA, RF, and message signal, respectively. Unlike, $P_{t,bs}$ the total power consumption of UE $P_{t,UE}$ is directly proportional to the number of UEs (V).

The PE of the amplifier has been obtained based on its efficiency, which is defined by

$$\gamma(\%) = \frac{\pi}{4 * P_{sip}} * 100 \quad (4)$$

Where P_{sip} is the square root of saturation input power (SIP). SIP is the proportion of the maximum allowable input power to the mean power of the amplifier and is given by

$$SIP(dB) = 10log_{10}\left(\frac{P_{allowable}}{P_{mean}}\right) \quad (5)$$

The higher value of γ gives reduced power consumption of the amplifier. Also, a higher value of SIP can minimize the noise, but PE gets minimized. The TX power in the downlink (P_{TRX}^{DL}) in terms of efficiency is given by

$$P_{TRX}^{DL} = \gamma_{BS} P_{amp} \quad (6)$$

γ_{BS} is the efficiency of base station. P_{amp} is the power consumed by power amplifier. Similarly, the uplink power of RPS (P_{RPS}^{UL}) in terms of efficiency is given by

$$P_{RPS}^{UL} = \gamma_{UE} P_{amp}^{UL} \quad (7)$$

γ_{UE} is the efficiency of user equipment.

Minimizing the PAPR helps to increase efficiency (γ). P_{TRX}^{DL} can be increased while keeping the value of P_{amp} as constant. The message signal or low-frequency power consumption is always lesser than amplifier and RF power consumption. The message signal or low-frequency power consumption (P_{LF}) is given based on floating-point operations as follows:

$$\varphi = N.\frac{(D_v BW)}{D_{sy}}.log(U_v BW) + N.\frac{(D_d BW)}{D_{sl}}.\tau_p.log(\tau_p) + N.V.(\frac{D_{sl}}{D_{sy}}.\frac{D_V}{D_d} - \tau_p) \quad (8)$$

BW is the bandwidth. D_{sl}, D_d, and D_v are the slot length, delay spread, and symbol duration without guard interval, respectively. D_{sy} and τ_p are the symbol duration with guard interval and guard interval. N and V denote the number of base station antennas and number UEs associated with the BS, respectively.

The relation between φ and P_{LF} is given by

$$P_{LF} = \frac{\varphi}{\partial} \quad (9)$$

Where ∂ is the efficiency of the signal processing. The power of the UAV with the speed of v for Linear Level Flight (LLF) is given by

$$P_{LLF}(v) = U.(C1.v^3 + \frac{C2}{v}) \quad (10)$$

U is the signal duration, $C1$ and $C2$ are constants, and v is the speed of the UAV. The first term is called parasitic force for controlling the predatory drag because of friction factor, contour drags, and so on, and is proportional to the cubic of v. The second component is known as the influenced power for the lift-induced dragging, i.e., the resultant force acting on the wings, which redirects air to create the uplifting to compensate for the weight of the UAV. So, the power consumption of a single UAV is given by

$$P_{UAV} = \frac{P_{LLF}(v)}{U} = (C1.v^3 + \frac{C2}{v}) \quad (11)$$

The total power consumption of a single UAV is given by

$$P_{UAV}^{total} = \forall.\left(\frac{P_{RPS}^{UL}}{P_{RPS,max}^{UL}}\right).P_{UAV} \quad (12)$$

$\forall$ is the total number of UAVs. The uplink power of RPS is given by P_{RPS}^{UL}. $P_{RPS,max}^{UL}$ is the maximum uplink RPS power for UE. As P_{RPS}^{UL} increases, P_{UAV}^{total} also increases. This is understandable as more UE-RPS power lowers the operational duration of the battery, and hence UAVs have to be moved more often to the power supply. In addition, a configurable variable to simplify the model may be multiplied in real situations. The effectiveness of RF energy conversion may therefore be great, and UAVs can precisely approach IoT devices. The RF power is significantly less than the energy of the drone propulsion and is not taken into account.

4 RESULTS AND DISCUSSION

Numerical results have been presented to illustrate the PE gain of different scenarios by applying the calculations provided in the previous section and comprehensive MATLAB simulation. Table 1 presents the simulation settings used in this section.

Table 1 Simulation parameters to analyze the performance of the proposed PE MIMO-OFDM system

Parameters	Values
Bandwidth $\boldsymbol{BW}$	15MHz
Coherence time	10 msec
Coherence bandwidth	200kHz
Number of transmitting antennas (N)	100 to 700
Downlink TRX power $\boldsymbol{P_{TRX}^{DL}}$	5 to 50 W
Uplink RPS power $\boldsymbol{P_{RPS}^{UL}}$	150mW to 250mW
Signal carrier frequency	3GHz
Speed of UAV ($\boldsymbol{v}$)	10 m/sec
Total number of UAVs (∀)	2 to 10
Precoding	MF, ZF

The case of industrial IIoT networks has also been examined to cover a variety of conditions. The needed coverage of intelligent machines may be less than a dozen meters for IIoT networks, and several objects and barriers could be avoided. This reduces the UAV speed to 15 m/s, even if the consumption of the UAV is more than twice as high as the lowest amount of power consumption.

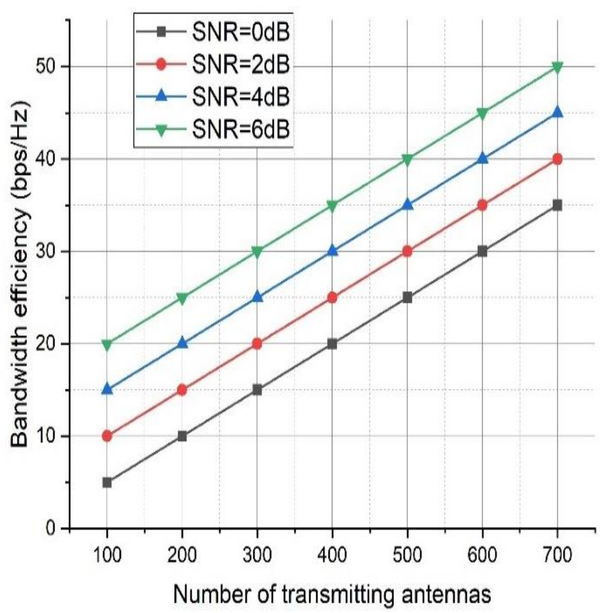


Figure 3 Bandwidth efficiency versus the number of transmitting antennas for varying SNR values

Fig. 3 shows the bandwidth efficiency (bps/Hz) versus the number of transmitting antennas for varying SNR values with MF precoding and PAPR reduction schemes applied. As the number of transmitting antennas increases, the bandwidth efficiency improves. Also, as the SNR value increases, the spectral efficiency increases. An improvement of 5bps/Hz has been achieved for every 2dB increase in SNR value. ZF precoding's bandwidth efficiency is considerably superior to MF precoding performance. For cutting distortion, MF precoding is more resilient than ZF precoding. IUI is already prevalent for MF precoding, and if the distortion is less than IUI, the performance loss is low.

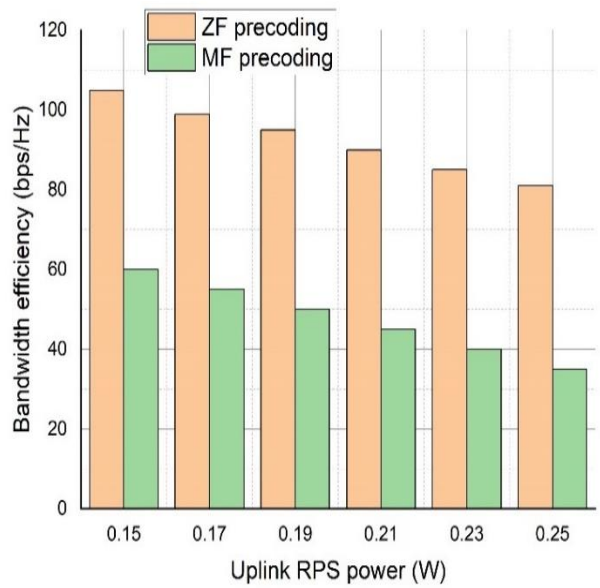


Figure 4 Bandwidth efficiency (bps/Hz) versus uplink RPS power (W) for ZF and MF precoding schemes

Fig. 4 depicts the bandwidth efficiency (bps/Hz) versus uplink RPS power (W) for ZF and MF precoding schemes. As $\boldsymbol{P_{RPS}^{UL}}$ increases, bandwidth efficiency decreases. This is because, when $\boldsymbol{P_{RPS}^{UL}}$ rises, battery charging time increases which leads in the reduction of bandwidth efficiency. In this work, it has been considered data communication is suspended during the recharging period. If not, the bandwidth efficiency of IoT-limited battery devices is the same as IoT-enabled systems, which cannot be compared fairly with the network.

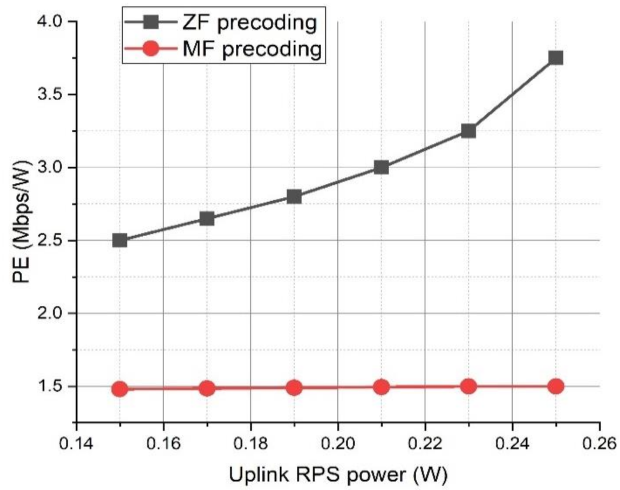
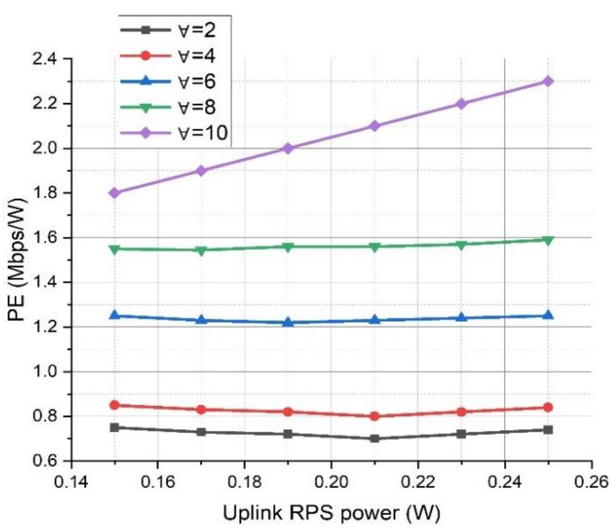
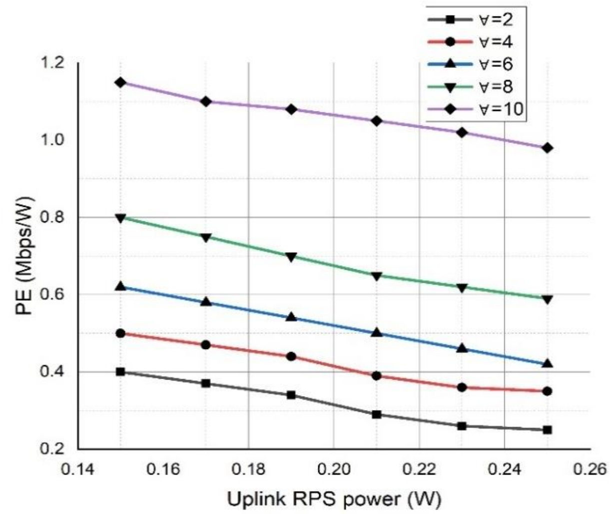


Figure 5 PE (Mbps/W) versus uplink RPS power (W) for ZF and MF precoding schemes

Fig. 5 depicts the plot of PE (Mbps/W) versus uplink RPS power (W) for ZF and MF precoding schemes. The RS uplink power control, as noted, does nothing to enhance PE. The reason is that the loss in bandwidth efficiency caused by channel estimation uncertainty is larger than the power savings resulting from the decrease in $\boldsymbol{P_{RPS}^{UL}}$. Although $\boldsymbol{P_{RPS}^{UL}}$ consumes a substantial share of the power in sensor equipment, loss from bandwidth efficiency is essential when $\boldsymbol{P_{RPS}^{UL}}$ are reduced. Maximum $\boldsymbol{P_{RPS}^{UL}}$ is hence useful for enhancing PE. This is the same as with mobile networks. RPS power boosting is helpful if no interference exists. Uplink RPS power control nevertheless offers reasonably significant advantages with ZF precoding. This is due to battery-limited IoT devices conserving time to recharge. With ZF precoding, a PE improvement of 50.53% has been observed.



(a)



(b)

Figure 6 PE versus uplink RPS power for various UAVs with (a) ZF precoding (b) MF precoding

Fig. 6 (a) shows the plot of PE versus uplink RPS power for various UAVs with ZF precoding. When the necessary number of UAVs ∀ rises with $\boldsymbol{P_{RPS}^{UL}}$, EE increases which are the same as bandwidth efficiency. However, raising $\boldsymbol{P_{RPS}^{UL}}$ does not assist in improving the PE, as the power supply UAV uses a lot of electricity. When the number of UAVs required is minimal, ∀ with ZF precoding, boosting RPS power enhances PE. On the other hand, when the number of UAVs needed rises, there is little performance change by changing uplink RPS power. Fig. 6 (b) shows the plot of PE versus uplink RPS power for varying numbers of UAVs with MF precoding. With MF precoding, it is usually good to reduce the power of uplink RPS at a specific level to enhance PE irrespective of how many UAVs are necessary.

5 CONCLUSION

Power-Efficient (PE) MIMO-OFDM antenna systems are widely used in commercial communication systems since operating costs, and carbon sites may be reduced. For battery-restricted IIoT devices, enhancing PE is particularly critical. The transmitting and receiving elements of large MIMO-OFDM IoT networks are observed, and several successful approaches have been categorized. Lowering uplink RPC can yield IoT battery savings but increases channel estimate inaccuracy. The PAPR decrease in the OFDM signal and the downlink RPC is considered as a downlink aspect. Although the real PE advantage in the system context has been demonstrated in the minimal study, these processes have been considered efficient PE techniques. Furthermore, it has been employed UAVs for using radiofrequency energy transfer to prolong battery-limited IoT devices. As the number of transmitting antennas increases, the bandwidth efficiency improves. Also, as the SNR value increases, the spectral efficiency increases. RPS power boosting is helpful if no interference exists. Uplink RPS power control nevertheless offers reasonably significant advantages with ZF precoding. When the number of UAVs required is minimal, ∀ with ZF precoding, boosting RPS power enhances PE. This is due to battery-limited IoT devices conserving time to recharge. With ZF precoding, a PE improvement of 50.53% has been observed.

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