Hybrid Precoding-Based Millimeter-Wave Massive MIMO-NOMA With Simultaneous Wireless Information and Power Transfer

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***Abstract*:** Non-orthogonal multiple access (NOMA) has been recently considered in millimeter-wave (mmWave) massive MIMO systems to further enhance the spectrum efficiency. In addition, simultaneous wireless information and power transfer (SWIPT) is a promising solution to maximize the energy efficiency. In this paper, for the first time, we investigate the integration of SWIPT in mmWave massive MIMO-NOMA systems. As mmWave massive MIMO will likely use hybridprecoding (HP) to significantly reduce the number of required radio-frequency (RF) chains without an obvious performance loss, where the fully digital precoder is decomposed into a highdimensional analog precoder and a low-dimensional digital precoder, we propose to apply SWIPT in HP-based MIMO-NOMA systems, where each user can extract both information and energy from the received RF signals by using a power splitting receiver. Specifically, the cluster-head selection algorithm is proposed to select one user for each beam at first, and then the analog precoding is designed according to the selected cluster heads for all beams. After that, user grouping is performed based on the correlation of users' equivalent channels. Then, the digital precoding is designed by selecting users with the strongest equivalent channel gain in each beam. Finally, the achievable sum rate is maximized by jointly optimizing power allocationfor mmWave massive MIMO-NOMA and power splitting factors for SWIPT, and an iterative optimization algorithm is developed to solve the non-convex problem. Simulation results show that the proposed HP-based MIMO-NOMA with SWIPT can achieve higher spectrum and energy efficiency compared with HP-based MIMO-OMA with SWIPT.

Keywords— SWIPT, mmWave, massive MIMO, NOMA, hybrid precoding, power allocation, power splitting . Introduction

I INTRODUCTION

Wireless communications is the transfer of information over a distance without the use of enhanced electrical conductors or "wires". The distances involved may be short(a few meters as in television remote control) or long(thousands or millions of kilometres for radio communications).when the context is clear, the term is often shortened to "wireless". It encompasses various types of fixed, mobile and portable two-way radios, cellular telephones, Personal Digital Assistants(PDAs) , and wireless networking. In 1895, Guglielmo Marconi opened the way for modern wireless communications by transmitting the three-dot Morse code for the letter '**S'** over a distance of three kilo meters using electromagnetic waves. From this beginning, wireless communications has developed into a key element of modern society.

compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

In the channel measurements taken at 28 and 38 GHz in , a wide range of delay spreads were observed depending on the measurement location. However, these measurements were taken without significant spatial selectivity; in a (near-) LOS environment, a massive MIMO array can provide a narrow beam that eliminates much of the multipath, in turn significantly reducing the delay spread and potentially reducing the need for equalization. However, since employing mmWave frequencies can allow dramatic increases in user bandwidth to hundreds of megahertz or even a few gigahertz (and hence symbol periods on the order of 1–10 ns or less), it is possible that even with a massive MIMO array, frequency selective fading may need to be addressed through either equalization or modulation.

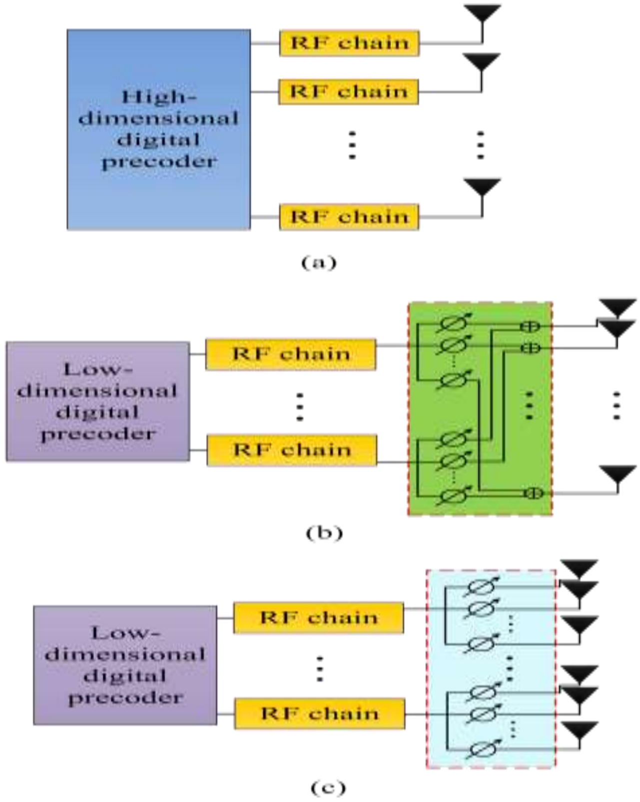
Modulation and Energy Efficiency —As mentioned above, energy efficiency is one of the advantages driving much of the interest in massive MIMO. The high peak-to-average power ratio (PAPR) of orthogonal frequency-division multiplexing (OFDM) works against this advantage, and can impede good downlink performance. A recent study indicates that single-carrier modulation (SCM) can theoretically achieve near-optimal sum rate performance in massive MIMO systems operating at low-transmit-power-to-receiver-noise-power ratios, independent of the channel power delay profile and with an equalization-free receiver [9]. This is interesting for energy efficiency since SCM can be designed to have much better PAPR performance or even a constant envelope waveform. However, the results of [9] are based on the assumption of independent Rayleigh fading channels, which will not hold in the mmWave regime and could jeopardize the "equalization free" result. Furthermore, implementing SCM at mmWave frequencies implies very tight timing constraints on the order of a few nanoseconds or less, which is nontrivial. Thus, the trade-offs involved with using SCM for mmWave massive MIMO need further study

SYSTEM MODEL:

we consider a single-cell downlink mmWave massive MIMO-NOMA system, where the BS is equipped with *N* antennas and *N*RF RF chains to simultaneously serve *K* single-antenna users , and each user is equipped with a power splitting receiver for SWIPT. Fig. 1 shows three architectures of mmWave massive MIMO systems, i.e., the fully digital MIMO as shown in Fig. 3 , the fully-connected HP architecture as shown in Fig. 4, and the sub-connected HP architecture as shown in Fig. 5.

we can see that for the fully digital MIMO, each antenna requires one dedicated RF chain, and thus the number of RF chains is equal to the number of antennas, which results in unaffordable energy consumption and hardware cost. On the contrary, the number of RF chains in HP architectures is less than the number of antennas, which can be realized by a high-dimensional analog precoder and a low-dimensional digital precoder. Specifically, for the fully-connected HP architecture in Fig. 4, each of the NRF RF chain is connected to all N antennas by finite-resolution phase shifters, where NNRF phase shifters are required, and thus the full array gain can be exploited by every RF chain. For the sub-connected HP architecture in Fig. 5, each RF chain is connected to only a subset of N BS antennas, so only N phase shifters are required. In general, the sub-connected architecture is easier to be implemented and will likely be more energy efficient, while it may suffer some performance loss compared to the fully-connected architecture. In this paper, both of the fully-connected and sub-connected architectures will be considered.

In HP-based mmWave massive MIMO systems, the number of beams cannot exceed the number of RF chains, and each beam can only support one user at most [7]. The refore, to fully



The fully digital MIMO as shown in above Fig.1 a & The fully-connected HP architecture and The sub-connected HP architecture as shown in Figs b &c.

II MILLIMETER WAVE PROPAGATION AND CHANNEL MODELS

Propagation aspects are unique at mmWave due to the very small wavelength compared to the size of most of the objects in the environment. Understanding these channel characteristics is fundamental to developing signal processing algorithms for mmWave transmitter and receivers.

1 Distance-based path loss

For free-space propagation, the transmit power, Pt , and far-field receive power, Pr , are related by Friis' Law where the powers are in linear scale, d is the TX-RX separation distance, λ is the wavelength and Gt and Gr are the transmit and receive antenna gains. Friis' Law implies that the isotropic path loss (i.e. the ratio Pt/Pr with unity antenna gains Gr = Gt = 1), increases inversely with the wavelength squared, λ^{-2}

This fact implies that, in absence of directional antenna gains, mmWave propagation will experience a higher path loss relative to conventional lower frequencies. For a given physical antenna aperture, however, the maximum directional gains generally scale as Gr , Gt $\propto \lambda^{-2}$, since more antenna elements can be fit into the same physical area. Therefore, the scaling of the antenna gains more than compensates for the increased free-space path-loss at mmWave frequencies. Compensating for path loss in this manner will require.

III USER GROUPING AND HYBRID PRECODING

Transmissions with high-dimensional antenna arrays – explaining how MIMO is a defining characteristic of mm Wave communication. While free space propagation can be predicted by Friis' Law, the path loss in general environments depend on the particular position of objects that can attenuate, diffract and reflect signals. Ray tracing has been reasonably successful in predicting site-specific mmWave propagation, particularly in indoor settings, for at least a decade . There is also a large body of work in developing mmWave statistical models that describe the distribution of path losses over an ensemble of environmen, with a particularly large number of studies in short-range links in wireless PAN or indoor LAN systems . The most common statistical model describes the average path loss (not including small-scale fading) via a linear model of the form $P L(d) [dB] = \alpha + 10\beta \log10(d) + \xi$, $\xi \sim N(0, \sigma 2)$, (2) where d is the distance, α and β are linear model parameters and ξ is a lognormal term accounting for variances in shadowing. When converting to dB scale, Friis' formula (1) is a special case of the model (2) with $\beta = 2$. Parameters for the model (2) can be found in for short-range and indoor settings.

More recent work has focused on path loss models for longer range outdoor links to assess the feasibility of mmWave picocellular networks, including measurements in New York City.. A surprising consequence of these studies is that, for distances of up to 200 m from a potential lowpower base station or access point (similar to cell radii in current micro- and pico-cellular deployments), the distance-based path loss in mmWave links is no worse than conventional cellular frequencies after compensating for the additional beamforming gain. It was these findings that suggested the mmWave bands may be viable for picocellular deployments and generated considerable interest in mmWave cellular systems . At the same time, the results also show that, should mmWave frequencies be employed in cellular networks, directional transmissions, adaptive beamforming, and other MIMO techniques will be of central importance.

Blocking and outage

While the distance-based path loss of mmWave frequencies can be theoretically compensated by directional transmissions, a more significant challenge is their severe vulnerability to blockage. Materials such as brick can attenuate mmWave signals by as much as 40 to 80 dB and the human body itself can result in a 20 to 35 dB loss Foliage loss can also be significant . Alternatively, humidity and rain fades, common problems for long range mmWave backhaul links , 7 are not an issue in either short-range indoor links or micro-cellular systems with sub-km link distances.

The human body (depending on the material of the clothing) and most building materials are reflective. This allows them to be important scatterers to enable coverage via NLOS paths for cellular systems . For example, measurements in New York City confirm that even in extremely dense urban environments, coverage is possible up to 200 m from a potential cell site. This is good because diffraction – a primary means of coverage in sub 6 GHz systems – is not significant at mm Wave frequencies.

To quantify the effect of blocking, cellular system evaluation can use a two-state model (LOS and NLOS) or a three state model (LOS, NLOS, and signal outage). The probability of a link being in each state is a function of distance. Using the NYC measurements in fits statistical models for this three state model, similar in form to some LOS-NLOS probabilities used in 3GPP LOS-NLOS for heterogeneous networks . Blocking models can also be derived analytically from random shape theory or from geographic information . Using such models, it is possible to evaluate coverage and capacity in mmWave cellular networks analytically using stochastic geometry . A major outstanding issue is characterizing the joint probabilities in outage between links from different cells, which is critical in assessing the benefits of macro-diversity.

Spatial characteristics and multipath channel models

The mmWave MIMO channel can be described with standard multipath models used in lower frequencies . Consider a MIMO system with Nt transmit and Nr receive antennas. For 2D channel models, the transmit and receive antenna arrays are described by their array steering vectors, $aT(\theta T)$ and $aR(\theta R)$ representing the array phase profile as a function of angular directions θR and θT of arriving or departing plane waves.

Beamspace (virtual) system representation

The highly directional nature of propagation and the high dimensionality of MIMO channels at mmWave frequencies makes beamspace representation of MIMO systems a natural choice. The antenna space and beamspace are related through a spatial Fourier transform . We describe the beamspace representation of a 1D array consisting of an N dimensional ULA (extension to 2D arrays are straightforward;. The beamspace (virtual) representation corresponds to system representation with respect to uniformly spaced spatial angles $\vartheta i = i\Delta\vartheta = i/N$, $i = 0, \cdots, N - 1$. The corresponding steering vectors defined by $\{\theta i = \arcsin(\lambda\vartheta i/d)\}$ result in an orthonormal basis for the spatial signal space.

The wideband channel model needs to be further extended if the number of antennas and/or the signal bandwidth becomes sufficiently large . For wideband operation, in general, the spatial angles θR,` and θT,` in the arguments of the steering vectors also include a frequency dependence called beam-squint, that can result in significant degradation in performance . Beam squint is a significant problem for paths for which the dispersion factor $N\alpha\theta` \geq 0.2$ (as applied to the transmit or receive side). A simple multi-beam solution to the beamsquint problem . If this dispersion factor is sufficiently small for all angles within the angular spread, then the frequency dependence of $\theta(f)$ can be ignored.

IV SWIPT WITH POWER SPLITTING

simultaneous wireless information and power transfer (SWIPT) has drawn an upsurge of interests . By SWIPT, mobile users are provided with both wireless data and energy accesses at the same time, which brings great convenience. However, there is one crucial issue for realizing SWIPT systems in practice, i.e., existing receiver circuits cannot decode information and harvest energy from the same received signal independently .

As a result, the receiver architecture design plays a significant role in determining the trade-offs between the end-to-end information versus energy transfer. Two practical receiver designs have been proposed for SWIPT, namely, time switching (TS) and power splitting (PS) With TS, the receiver switches over time between decoding information and harvesting energy, while with PS, the receiver splits the received signal into two streams of different power for decoding information and harvesting energy separately. Based on the PS scheme, a novel integrated receiver architecture for SWIPT ,

where the circuit for radio frequency (RF) to baseband conversion in the conventional information receiver is integrated to the front end of energy receiver via a rectifier, thus achieving a small form factor as well as energy saving. The TS and PS schemes have also been investigated for SWIPT over fading channels to exploit opportunistic information and energy transmissions . It is worth noting that theoretically, TS can be regarded as a special form of PS with only binary split power ratios, and thus in general PS achieves better rate-energy transmission trade-offs than TS . However, in practice PS is implemented differently from TS since the former requires an RF signal splitter while the latter only needs a simpler switcher. Another key concern for SWIPT is drastically decaying power transfer efficiency with the increasing transmission distance due to propogation pass loss.

To tackle this problem, MIMO (multiple-input multiple-output) techniques by employing multiple antennas at the transmitter and/or receiver have been proposed in To significantly improve the power transfer efficiency while still achieving high spectral efficiency for information transmission. Moreover, extende to the case with imperfect channel state information (CSI) at the transmitter.

Under the above two types of constraints at the same time, we study the joint design of transmit beamforming at BS and receive PS ratios at MSs to minimize the total transmission power. First, we derive the sufficient and necessary condition for the feasibility of our formulated problem. Interestingly, it is shown that the feasibility of this problem only depends on the SINR constraints but not on the harvested power constraints.

Next, we apply the technique of SDR to solve this non-convex problem, due to the coupled design variables of both beamforming vectors and PS ratios. We prove that SDR is indeed tight for our problem and 4 thus it yields optimal beamforming solution. Furthermore, we present two suboptimal designs of lower complexity, in which the transmit beamforming vectors are first designed based on the zero-forcing (ZF) and the SINR-optimal criteria, respectively, and then the receive PS ratios are optimized to minimize the transmission power. Finally, we compare the performance of our proposed optimal and suboptimal solutions by simulations

A POWER ALLOCATION

Power allocation plays a vital role in coordinating interference between Device-to-Device (D2D) and cellular communications, and when power allocation meets simultaneous wireless information and power transfer (SWIPT), the energy efficiency of D2D communications can be significantly improved. While numerous research studies have been conducted on D2D power allocation, most of these studies do not take the presence of SWIPT into consideration. Toward a remedy for this issue, we investigate the problem of D2D power allocation with SWIPT power-splitting architecture, and address it by establishing a novel game-theoretic model. Two power allocation mechanisms are proposed to simultaneously allocate transmit power.

B. WIRELESS INFORMATION AND POWER TRANSFER:

Harvesting energy from the environment is a promising approach to prolong the lifetime of energy constrained wireless networks. Among other renewable energy sources such as sola r and wind, background radio-frequency (RF) signals radiate d by ambient transmitters can be a viable new source for wireless power transfer (WPT). On the other hand, RF signals have been widely used as a vehicle for wireless information transmission (WIT). Simultaneous wireless information an d power transfer (SWIPT) becomes appealing since it realizes both useful utilizations of RF signals at the same time, and thus potentially offers great convenience to mobile users.

Despite the recent interest in SWIPT, there remains two key challenges for practical implementations. First, it is assumed in at the receiver is able to observe and extract power simultaneously from the same received signal. However, this assumption may not hold in practice, as practical circuits for harvesting energy from radio signals are not yet able to decode the carried information directly. Due to this potential limitation, the results in actually provided only optimistic performance bounds. To coordinate WIT and WPT at the receiver side, two practical schemes, namely, time switching (TS) and static power splitting (SPS).

Second, the conventional information receiver architecture designed for WIT may not be optimal for SWIPT, due to the fact that WIT and WPT operate with very different power sensitivity at the receiver (e.g., -10dBm for energy receivers versus -60dBm for information receivers). Thus, for a system that involves both WIT and WPT, the receiver architecture should be optimized for WPT. In addition, circuit power consumed by information decoding becomes a significant design issue for simultaneous information and power transfer, since the circuit power reduces the net harvested energy that can be stored in the battery for future use. In particular, the active mixers used in conventional information receiver for RF to baseband conversion are substantially power-consuming. It thus motivates us to propose new receiver architectures which consume less power by avoiding the use of active devices. In this paper, we study practical receiver designs for a point-to-point wireless link with simultaneous information and power transfer .

V RESULT AND DISCUSSION

The performance in terms of spectrum efficiency and energy efficiency of the mmWave massive MIMO-NOMA systems with SWIPT, including both the fully-connected HP andthe sub-connected HP, proposed in this paper is evaluated via simulations. Specifically, the simulation parameters are described as follows:

The system bandwidth is assumed to be 1 Hz, which coincides to the achievable rate.

The BS is equipped with an ULA of N = 64 antennas and NRF =4 RF chains to simultaneously serve $K \geq N$RF users.

All the K uses are grouped into G = NRF = 4 beams, and there are more than one user in each beam.

For the mth user in the gth beam, the channel vector is generated based on (4), where we assume:

1) Lg,m = 3, including one line-of-sight (LoS) component and two non-line-of-sight (NLoS) components

2) B = 4 bits quantized phase shifters are adopted, and the signal-to-noise ratio

SNR(db) is defined as $Pt\%\sigma 2\ v$ [8].

The maximum transmitted power Pt = 30 mW, the minimal achievable rate for each user is $Rfm/10$,

where Rfm is the minimal achievable rate among all users by using fully digital ZF precoding, and the minimal harvested energy for each user is 0.1 mW.

The spectrum efficiency is defined as the achievable sum rate in , and the energy efficiency is defined as the ratio between the achievable sum rate and the total power consumption , i.e.,

EE = Rsum/(Ptr + NRFPRF + NPSPPS + PBB) (bps/Hz/W)

where Ptr is the total transmitted power, PRF is the power consumed by each RF chain, PPS is the power consumption of each phase shifter, and PBB isthe baseband power consumption. Particularly, we adopt the typical values PRF = 300 mW, PPS = 40 mW (4-bit phase shifter), and PBB = 200 mW . NPS is the number of phase

shifters, which is equal to NNRF for the fully-connected HPand N for the sub-connected HP.

In the simulations, we consider the following five typical mmWave massive MIMO systems with SWIPT for comparison:

(1) "SWIPT-Fully digital ZF Precoding", where each antenna is connected to one RF chain, and ZF precoding is adopted;

(2) "SWIPT-Fully-Connected HP-NOMA", where fully-connected HP architecture is used in the proposed mmWave massive MIMO-NOMA systems with SWIPT;

(3) "SWIPT-Fully-Connected HP-OMA", where the system model is similar with "SWIPT-Fully-Connected HP-NOMA", while OMA is performed for users in each beam. Particularly, we represent OMA with FDMA, where users in the same beam are allocated with equal bandwidth;

(4) "SWIPT-Sub- Connected HP-NOMA", where sub-connected HP architecture is used in the proposed mmWave massive MIMO-NOMA systems with SWIPT;

(5) "SWIPT-Sub-Connected HP-OMA", where the system model is similar with "SWIPT-Sub-

Connected HP-NOMA", while OMA is performed for usersin each beam.

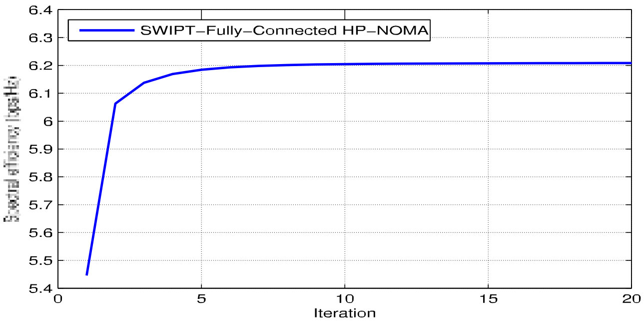


Fig 1. Spectrum efficiency of fully-connected architecture against the number of iterations for the joint power allocation and power splitting optimization

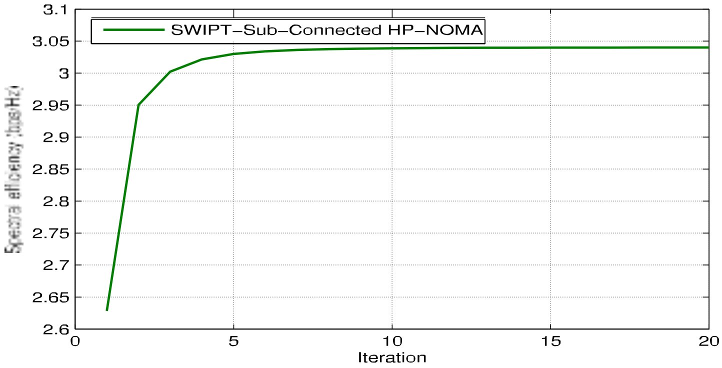


Fig. 2. Spectrum efficiency of sub-connected architecture against the number of iterations for the joint power allocation and power splitting optimization.

As shown in Fig. 1 and Fig.2, the spectrum efficiency tends to be stable after 10 times of iteration, which verifies the convergence of the proposed iterative algorithm as discussed in Section IV. In the following simulations, the number of iteration times for the proposed iterative optimization algorithm is set as 10.

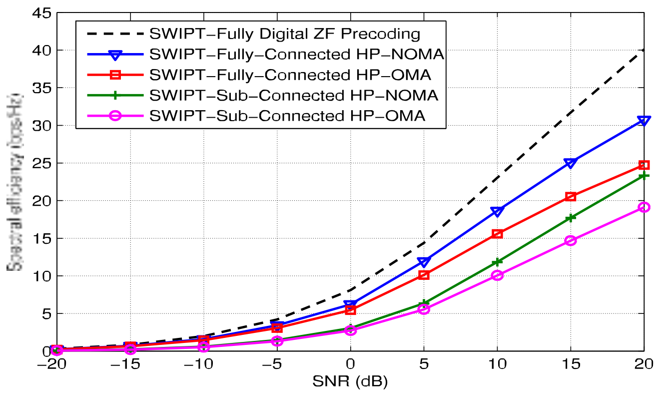


Fig. 3. Energy efficiency against SNR.

Fig. 4 shows the energy efficiency against SNR, where the number of users is also K = 6. We can find that the proposed mmWave massive MIMO-NOMA systems with SWIPT can achieve higher energy efficiency than both mmWave massive MIMO-OMA systems with SWIPT and fully digital MIMO systems with SWIPT. Particularly, the number of RF chains is equal to the number of BS antennas in fully digital MIMO systems, which leads to very high energy consumption, e.g., 300 mW for each RF chain. On the contrary, the number of RF chains is much smaller than the number of antenna in the proposed mmWave massive MIMO-NOMA systems with SWIPT. Therefore, the energy consumption caused by the RF chains can be significantly reduced compared to the fully digital MIMO systems. In addition, we can see from Fig. 7.4 that the sub-connected HP can achieve higher energy efficiency than that of the fully-connected HP, since a less number of phase shifters is adopted in the sub-connected HP.

Fig. 3 shows the spectrum efficiency against SNR of the considered five schemes, where the number of users is K = 6. We can find that the proposed mmWave massive MIMO-NOMA systems with SWIPT can achieve higher spec- trum efficiency than that of mmWave massive MIMO-OMA systems with SWIPT, either for the fully-connected HP or the sub-connected HP, since NOMA can achieve higher spectrum efficiency than that of OMA .

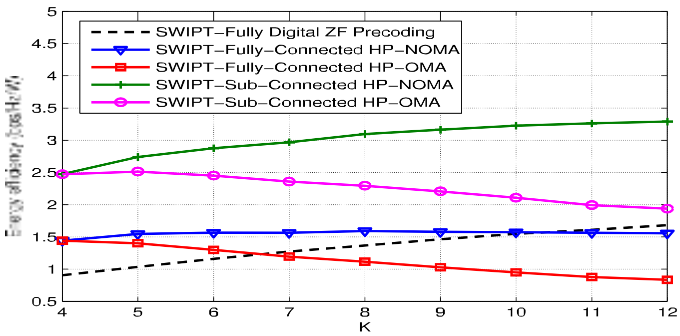


Fig 4 Energy Efficiency against Number of Users

The performance comparison in terms of energy efficiency against the number of users is shown in Fig. 7.5, where SNR is set as 10 dB. We can see that when the sub-connected HP is adopted, the energy efficiency of the proposed mmWave massive MIMO-OMA systems with SWIPT is higher than all of other schemes even the number of users is very large.

VI CONCLUSION

we propose to apply SWIPT in HP-based mmWave massive MIMO-NOMA systems to achieve a trade-off between spectrum efficiency and energy efficiency. To enable the spectrum- and energy-efficient systems, user grouping, hybrid precoding, power allocation, and power split- ting are carefully designed. Specifically, the CHS algorithm is first proposed to select one user for each beam as the cluster head, and then the analog precoding is designed according to the selected cluster heads for all beams. After that, user grouping is performed based on the correlation of users' equivalent channels. Then, the digital precoding is designed by selecting users with the strongest equivalent channel gain in each beam. Furthermore, the joint optimization of power allocation and power splitting is proposed to maximize the achievable sum rate, and an iterative optimization algorithm is developed to solve the non-convex optimization problem. Simulation results show that the proposed mmWave mas- sive MIMO-NOMA systems with SWIPT can achieve higher spectrum and energy efficiency compared with mmWave massive MIMO-OMA systems with SWIPT.

VII FUTURE SCOPE

Our project is implemented for 5G technology implementation to enhance the spectral and energy efficiencies so as to increase the network coverage and easy implementation of 5G network reducing the hardware cost. In the future,we will consider more sophisticated hybrid precoding design for the proposed mmWave massive MIMO-NOMA systems with SWIPT to further improve the performance.

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