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Robust Schemes to Enhance Energy Consumption Efficiency for Millimeter Wave-Based Microcellular Network in Congested Urban Environments

MHD Nour Hindia, Faizan Qamar*, Henry Ojukwu, Rosilah Hassan*, and Kaharudin Dimyati

Abstract—**Future wireless communication networks will be largely characterized by small cell deployments, typically on the order of 200 meters of radius/cell, at most. Meanwhile, recent studies show that base stations (BS) account for about 80 to 95 % of the total network power. This simply implies that more energy will be consumed in the future wireless network since small cell means massive deployment of BS. This phenomenon makes energy-efficient (EE) control a central issue of critical consideration in the design of future wireless networks. This paper proposes and investigates (the performance of) two different energy-saving approaches namely, adaptive-sleep sectorization (AS), adaptive hybrid partitioning schemes (AH) for small cellular networks using smart antenna technique. We formulated a generic base-model for the above-mentioned schemes and applied the spatial Poisson process to reduce the system complexity and to improve flexibility in the beam angle reconfiguration of the adaptive antenna, also known as a smart antenna (SA). The SA uses the scalable algorithms to track active users in different segments/sectors of the microcell, making the proposed schemes capable of targeting specific users or groups of users in periods of sparse traffic, and capable of performing optimally when the network is highly congested. The capabilities of the proposed smart/adaptive antenna approaches can be easily adapted and integrated into the massive MIMO for future deployment. Rigorous numerical analysis at different orders of sectorization shows that among the proposed schemes, the AH strategy outperforms the AS in terms of energy saving by about 52 %. Generally, the proposed schemes have demonstrated the ability to significantly increase the power consumption efficiency of micro base stations for future generation cellular systems, over the traditional design methodologies.**

Keywords—**Micro-cell, energy, 5G, millimeter-wave, cell sectoring, smart antenna**

I. Introduction

IT has been widely speculated that the performance of the next generation of wireless network should meet a transmission speed on the order of 1000 times more; energy consumption on the order of 10 times less and access delay of less than 1 ms which are in compliance with the International Mobile Telecommunications (IMT) standard for the beyond 4G (B4G) wireless networks. To achieve this milestone, research and industrial communities have both suggested that the future wireless systems will take advantages of the numerous emerging technologies, which include exploiting the huge bandwidth available in the millimeter-wave (mm-wave) spectrum space [1], cognitive radio [2], internet of things (IoT) [3] , incorporation of device-to-device (D2D) communications, as well as exploring the large space-time gain of the emerging massive MIMO (multiple-input-multiple-output) antenna systems [4].

Particularly, small cells network and the use of a smart multi-element directional antenna system or massive MIMO have been considered a viable approach in the 5G network owing to the huge energy and spectral advantages they offer, which makes mm-wave communication realizable [5]. On the other hand, D2D communication is also considered a resource-efficient communication strategy for future cellular networks due to its unique features, such as the offered bandwidth, less power, high reliability for short-wavelength (i.e., mm-wave) communication, and limited coverage [6]. Hence, the trio of the small-cell network, mm-wave technology, and D2D communication are called the “Big Three” of the future wireless networks [7]. It is therefore evident that with the intervention of the Big Three, devices operating in 5G networks will enjoy the sufficiently available bandwidth, low propagation power and low access delay, which directly translates to very high signal-to-interference ratio (SIR) performance not comparable to today’s wireless systems [8]. Existing findings reveal that up to 85 – 90 percent of the total network power is consumed by base stations [9]. In order to improve the energy utilization efficiency in existing cellular networks, numerous strategies, such as cell sectorization, BS sleep/wake or antenna muting, beamforming activation, etc., have been employed. In fact, cell sectorization is the process of deploying multi-antenna at the BS to partition the users into different sectors , where each sector is served by a single directional antenna element to improve system efficiency [10]. This has been exemplified in conventional cellular systems, such as the code division multiple access (CDMA), GSM and IS-95, where the concept of cell sectorization is considered a promising technique for enhancing co-channel interference performance and energy consumption efficiency [11].

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The cell sectoring scheme has been applied in cellular systems over the past decades, basically for the purpose of achieving better reuse of network resources (spectrum and energy) [12]. The GSM and IS-95 systems had applied a traditional method that sectors the cell site in 120◦ or 60◦ to achieve a maximum reuse factor. Researchers in [13] have investigated and identified the issue with the traditionally fixed sectoring schemes as a fixed pattern or known mobile location problem, similar to that of the wireless local loop (WLL). To address this issue, an adaptive sectoring problem was studied in [14] as the shortest path problem based on two factors: (a) decreasing the total transmit power of mobiles and, (b) decreasing the aggregated received power of BS [15]. These approaches are similar to the modeling technique propounded in [16] which takes user's mobility into account based on the Signal to Interference plus Noise Ratio (SINR) requirements equalized overall users in each sector of the microcell system. However, the limitation of this solution is that it does not function optimally with users on high mobility due to the fact that it was originally designed for the WLL case. The success of the method in [14] is large as a result of having the foreknowledge of mobile distribution patterns. Also, the SINR-based sectoring in [17] was not so efficient in cellular systems due to the shadowing and fast fading effects observed in the SINR measurement. To increase the level of the offered SINR from the perspective of users, a simple power control (PC) algorithm is proposed in [18] which combines cell zooming with CoMP to increase energy efficiency (EE) by reducing the transmit power [19].

In some of the BS sleep strategies used in traditional systems, when a BS goes into hibernation mode, users within the sleeping area, i.e., the coverage area served by the hibernated BS, are handed over to nearest active BSs in order to maintain the users QoS requirement [20]. In periods of sparse traffic, authors in [17] used the traffic load as a criterion to determine the BSs to be hibernated under the assumption that a BS is likely to be underutilized during the hour(s) of less traffic or in idle times. Thus, a BS is selected for hibernation based on utility routine, which means, the underutilized BSs have a higher probability of being selected for hibernation. Authors in [21] proposed a distributed technique for selecting the appropriate BS for muting. In this approach, as soon as a BS is selected for deactivation, the active neighboring BSs increase their transmission power to serve the users under the coverage area of the muted BS by using the coordinated multipoint (CoMP) mechanism and the cell zooming technique [22]. A less complex power control (PC) scheme that combines the CoMP and cell zooming mechanisms has been proposed to enhance the energy efficiency in [23]. The criteria used for selecting a BS for hibernation is based on the average distance between the BS and users. In a group of neighboring BSs, one is selected for deactivation if its average distance to users is the longest. Basically, the CoMP scheme uses a complex beamforming optimization as well as a collection of other statistical inputs such as data exchanged between users and BSs, and channel state information to maintain a high capacity backhaul link. The inherent pitfalls of the BS sleep/wake scheme, especially the long-term muting approach, have been pointed out by several researches [24, 25]. It is stated that having a higher probability of failure in a highly dynamic traffic scenario due to the long operation cycle; inadequate optimization of both the traffic demand threshold and antenna slop angle values. Also, it causes high system complexity and high-power consumption due to high transmit power during cell zooming.

Moreover, the higher-order sectorization cellular scheme is considered far more efficient than the omnidirectional cellular approach, which uses only a single antenna element to serve the entire microcell in an omnidirectional fashion [26]. Moreover, in traditional cellular sectorization schemes, cells are divided into slices of equal sectors known as fixed points which are suitable for uniform traffic [27]. However, for non-uniform traffic distribution, the fixed-point strategy hardly delivers the expected system capacity and throughput since sectors with higher user density stand chances of higher outage probability. As most existing sectorization-based power saving schemes are not efficient, thus, lack the merit for deployments in future 5G networks due to their inability to adaptively follow the kind of traffic patterns that will hit the firmament of the B4G wireless networks, which requires high flexibility in the antenna spanning angle lacking in the existing cellular schemes [28].

II. CONTRIBUTION

In this paper, we have proposed entirely different approaches to BS power saving, with a focus on small cells network. In such a small cell scenarios, a BS is equipped with multiple smart/adaptive transmit antennas which partition the microcell into multiple subareas (sectors) corresponding to the number of the antenna elements, where each sector is served by a single element independent of other sectors. The smart BS can astutely de-activate or activate any of the antenna elements based on the traffic load or average SNR information of the corresponding sector. Unlike the existing schemes, which automatically activate or deactivate the entire BS system at once, based on average traffic load and/or the average distance of users from the BS. However, our proposed schemes, employ a more granulated technique that enables the BS to cautiously and smartly activate or deactivate the antenna element in an incremental fashion based on individual element's routine activity (rather than the holistic black-and-white approach of existing schemes). In our approach, the operation of every individual antenna element, which includes antenna activation/deactivation, beamforming, beam-width reconfiguration, etc., can be independently manipulated by the BS without interfering with the operations of other elements, thus, we have introduced three conditions, such as, average user density, user distribution/traffic pattern, and user channel quality indicator feedback (CQI), into our antenna activation and deactivation decision making algorithm with respect to corresponding individual antenna elements [29].

The rest of this paper is organized as follows. Section III describes the hypothesis and the kind of thought process that form the crux of the proposed schemes in this paper. Section IV presents the concept description of the paper which includes the distribution of proposed AS and AH schemes. Section V discusses the system analysis. Section VI presents numerical results and discussion. Section VII concludes the paper. In last, Section VIII discusses some limitations and possible future work.

III. HYPOTHESES

In conventional sleep/wake BS energy saving schemes, a significant amount of energy can be potentially saved if the network is strictly configured to meet the peak-hour traffic demands and then switched to sleep mode during the periods of low traffic (when no active users exist in the cellular network) [30]. However, considering the predicted dynamic nature of the traffic patterns of future wireless network, a more micronized and adaptive BS sleep/wake mode (which is entirely different from the conventional methodology where entire BS system is automatically turned off at a go during hours of low or zero traffic) is required, since it is assumed that 5G network will require 24/7 connectivity to support the enormously deployed D2D/M2M and sensors (i.e. Internet of Things) that will be constantly exchanging environmental observations with different satellites on a round-the-clock bases [31]. Another possible assumption is that in the 5G network, there will be only a period of low traffic but not a period of absolute zero traffic. Hence, to minimize the chances of outage probability (i.e., the chances of network failure) due to poorly configured or synchronized sleep/wake strategy, we have proposed alternative adaptive schemes using smart antenna systems based on the observations in the foregoing hypothesis. The proposed smart/adaptive antenna schemes were designed to overcome the issues of unforeseen network coverage holes as discussed below. In this paper, our generic base model is based on the order of 10 microcellular sectorization approaches. Consider a spatial Poisson distribution for adaptive sectoring expressed as;

$$P(i,C_i)=\frac{(\lambda C_i)^i}{i!}e^{-\lambda C} \quad (1)$$

where $P(i,C_i)$ is the probability that i users exist in a sector C_i, and λ is the intensity function linked to each antenna element used for evaluating the SNR level of users in respective sectors. Therefore, P could be rewritten as;

$$P=\sum_{j=i}^{N}p(t,i,C_i)\ , \quad (2)$$

where P is the probability that more than i users can coexist within a given sector at any instance in time t, and C_i can be substituted with $r^2\frac{\varphi}{2}$, where r denotes the radius of the microcell, and ϕ is the smart antenna's spanning angle (which is adjustable) and N represents the optimal number of concurrent users that can be supported by any sector. We will show that for a maximum BS total transmission power (TTP) efficiency, ϕ should not exceed 36^o, meaning that the optimal sectorization order should not be less than 10 sectors per microcell off radius 200 m. We assume that on average, each microcell can support up to 100 simultaneous users, which is about 10 concurrent users per sector at any given time or until λ (i.e., the received signal strength) indicates otherwise at the BS.

IV. CONCEPT DESCRIPTION

Without loss of generality, let us assume a non-uniform network scenario, where the traffic load is unequally distributed across the microcell network, such that at time *t,* the traffic normalization of the peak value is expressed as $0\le E_{bs}\le 1$, which can be modeled as a sinusoid. Suppose that a single element ($\gamma<1$) of the smart antenna system is activated at time *t*, while the other elements $(1-\gamma)$ are turned to the sleep mode, then, the expression below must be satisfied

$$E_{bs}=\left[\Pi\times\left(1+\frac{1-\gamma}{\gamma}\right)\right]^{\partial}=\left(\frac{1}{\gamma}\Pi\right)^{\partial} \quad (3)$$

where E_{bs} is the energy dissipation coefficient of a single antenna element of the BS which depends on the user density. To calculate the maximum threshold value, we derive the algorithm,

$$\Gamma_{\max}=\frac{\sum_{j=1}^{N_o}\sum_{i}^{N}RSSI_{j,i}(t)}{N_oK} \quad (4)$$

where $\Gamma_{\max}$ is the predefined threshold that determines the traffic capacity of each sector of the micro-cell network, which in order to maintain high SNR, cannot be exceeded. The maximum threshold value is determined by the user's channel quality indication (CQI) feedback, where Received Signal Strength plus Interference (RSSI) is the users received signal strength indicator, N_o is the number of trials, and *K* is the total number of users. Thus, to increase the energy efficiency as well as maintain a high SNR, ∂ must be carefully selected [32]. Let us assume at time t_1 that due to low user density in the network all uses are clustered together in one segment (which may be a combination of many sectors) of the microcell and are served by a single antenna element γ_1, then if at time t_2 the traffic load increases and approaches the threshold limit, such that $E_{bs}\le\Gamma_{\max}$, then, one or more sleeping adjacent element(s) of the smart BS antenna will be promptly and automatically activated to relieve the overloaded sector or segment of the excess traffic load. This is illustrated in Fig. 1 and according to the eq. (3), the same amount of traffic load $\frac{1-\gamma}{\gamma}$ with which the overloaded sector/segment exceeds the maximum theoretical limit is assumed to have been handed over to the adjacent sector(s). As shown in Fig. 1, all users were initially confined within the sector γ_1, see Fig. 1 (a). Note, in the event that the total number of active users that were found at any given time within a segment of the network (which may be a combination of many sectors) is less than or equal to the average traffic density of a single sector, then those multiple sectors will be merged together and served by a single antenna element using the beam-width spanning algorithm as described below,

$$K_{users}=\left(\sum_{n=1}^{N}\gamma^{i}_{E,bs,}+\ldots+\gamma_N\right)\le\Gamma_{\max} \quad (5)$$

where K_{users} is the active users distributed across $\frac{1}{2}$ the area of the microcell, $\gamma^{i}_{E,bs,}$ is the average dissipated energy of a single antenna element also called the optimal transmission power (OTP) of the antenna element.

$$\gamma^{i}_{E,bs} = \frac{1}{|A|}\sum_{i\in I_A} Z(s_i), \tag{6}$$

$$Z(s_i) = P(I_o + I_i > \varphi) \tag{7}$$

Where $|A|$ is the size of a typical sector, $Z(s_i)$ is the outage probability which can be estimated by evaluating $P(I_o + I_i > \varphi)$, where I^o is the interference between sectors, and I_i denote an in-sector interference, while φ is the maximum spanning angle of the antenna element. Since the modeling of mobiles follows a spatial Poisson process with known rate functions in each sector (assuming perfect power control), the I_i and I_o can be calculated by dividing the spatial Poisson process into n number of processes by the means of Marking theorem which will enable us to calculate the corresponding signal power of any sector of interest. These n number of processes may represent the number of mobiles within a macrocell area, which is a Poisson process with the probability that the mobile power under a given macro cell is controlled by an antenna element of interest. The computation of the outage probability based on the Poisson field has received significant attention in a growing body of literature, and we have adopted the approach in [8, 33]. We used the expression stated herein below to numerically evaluate the outage probability:

$$P(I_o + I_i > \varphi \mid I_i > 0) = \frac{e^{-x}}{1-e^{-x}}\sum_{m=1}^{\infty}\frac{x^m}{m!}Q(\bar{n}_m) \tag{8}$$

where $\bar{n}_m \equiv \frac{(\varphi - m + 1 - \chi_1)}{\sqrt{\chi_2}}$, χ_1 and χ_2 are the mean and variance Poisson process of a non-specified sector of the MC, respectively, n is the mean Poisson process of a given (specified) sector, and Q denotes the Q-function for the standard normal distribution. As shown in Fig 1 (a-d), multiple sectors can be combined and served by a single antenna element depending on user density and distribution. However, the maximum spanning angle of any single antenna element cannot 180 degrees, which is half the size of the microcell area (see Fig. 1(d)), irrespective of the traffic scarcity. These are the fundamental concept upon which we model our system. Although the actual distribution of any traffic demand is likely to vary over time due to the varying channel characteristics of different environments, however, the assumption in Eq. (1) considers only a perfect channel quality, as may be the case in small cells-based 5G networks.

A. *Adaptive Sleep Sectorization Scheme*

This section proposes an AS scheme based on 10 sectors, Fig. 1 (a). Each antenna element can be independently switched ON and OFF based on traffic distribution, user density and CQI feedback of the corresponding sector. Despite being equipped with 10 adaptive directional antenna elements, the BS is also equipped with a single omnidirectional TX antenna as shown in Fig. 1, which is to be used during periods of extremely low traffic when the total traffic load of the entire microcell network is less than or equal to the average theoretical traffic density that a single element of the microcell can support, and users are sparsely scattered around the cell area. In such a scenario, the BS uses the single omnidirectional antenna to serve the entire area of the microcell in an omnidirectional fashion, while keeping all the other antenna elements in sleep mode. In our first approach (AS), we consider a micro-cell divided into 10 equal static sectors having a half-power beam-width (HPBW) angular span of 36 degrees each, as shown in Fig. 1 (a). In this scenario, when the user density of any given sector reaches the maximum capacity defined for each sector, the TX antenna has no ability to shrink down its beam spanning angle below 36 degrees as to cut off the excess traffic load, instead, the antenna element serving the overloaded sector will increase its transmission power in order to maintain the users required SNR. In this approach, one or more dormant (sleeping) adjacent element(s) will be immediately ON, once the user distribution spills over into another sector, even though the maximum user density limit of the current sector is not yet used up. This is more of a static approach where each antenna is dedicated to serving only its corresponding sector. To find the minimum TTP of an adaptive antenna element based on the proposed AS strategy, we model the energy consumption efficiency of each single antenna as;

$$TTP_{\max} = \frac{1}{|A|}\sum_{i\in I_A} Z(s_i) + \beta\log_{10}(\varpi \times N/\varphi)^{\sigma} \tag{9}$$

where β is the transmission power level of the micro-cell BS, taken to be 10 dBm in this paper, ϖ is the number of antenna elements that are currently in hibernation (SLEEP) mode, N is the ratio of the overall partitionable capacity of the microcell relative to the number of antennas that are currently transmitting over an area of a sector φ, and σ is the energy adjustment factor.

B. *Adaptive Hybrid partitioning Scheme*

In this section, we have proposed a scheme known as AH algorithm, which combines some of the attributes of the AS scheme and another mechanism to enhance performance. Like the AS strategy, the AH mechanism also increase transmission power of the transmitting element in the event that the traffic load of a given sector exceeds the user density since the spanning angle cannot decrease below 30 degrees just like the AS given that both schemes are based on minimum partitioning limit of 10 sectors, however, the AH uses the concept of clustering and angular adjustment mechanism which gives each TX element the maximum intelligence and degree of freedom to adjust its beam-width spanning angle between 36 and 180 degrees. As shown in Fig 2 (a), the angle $\varphi = 30^o$ represents the minimum angular span of the antenna element, which, on the other hand, can be expanded up to 180^o. In other words, a single smart antenna can be used to serve up to half of the entire microcell area especially in periods of extremely sparse traffic (depending on the traffic distribution). From Fig. 2 (a-d), we can see that the HPBW (of the serving antenna element) periodically increases along the azimuth φ -direction as the user distribution continues to span across multiple sectors with low traffic density. This trend will continue provided the condition specified in Eq. 5 remains valid [34]. The hybrid scheme uses a scaling algorithm to provide the ultimate solution to the TTP problem, which can be expressed as follows:

$$TTP_{\max} = \frac{1}{|A|}\sum_{i\in I_A} Z(s_i)\left|M_j^k\right| + Q \tag{10}$$

$$M_j^k = \sum_{j=1}^{M} \frac{\theta}{360} \gamma_{C_j}^2 \times 10, \tag{11}$$

$$Q = \sum_{j=1}^{N} \frac{\beta}{KCj} \tag{12}$$

where $\gamma_{C_j}^2$ is an area of a segment/sector served by a single antenna element, which is dynamic, KC_j denotes the total number of sectors in the microcell whose corresponding elements are currently transmitting, and $\beta = \sum_{C_{j,k}}^{N} (\delta + \sigma)$ represents the power transmission coefficient of the micro-cell BS, also call the TTP where δ and σ are the two very useful optimization parameter used for normalizing the OTP of the sectored antennas, which is also called the energy adjustment parameters and are responsible for performance enhancement. The scaling algorithm enables the AH scheme to perform optimally due to the inclusion of the two energy regulating parameters (δ and σ) obtained from other schemes and were merged together to form the hybridization

V. System Analysis

We focus precisely on sectoring the up/down-link singles of a microcell-based millimeter-wave system, where users maintain a tolerable SNR level for minimum QoS requirements [35]. The smart/adaptive multi-antenna system was deployed at the BS to partition the microcell into several sectors. Each directional antenna transmits and receives signals to and from mobile stations belonging to the corresponding sector that it serves, resulting in spatially isolating the users in one sector from users in other sectors of the same microcell system. Assume that perfect directional adaptive antennas were used, then we should expect zero interference between sectors. However, users within the same sector may experience a sort of intra-sector interference, which is interference between users within the same sector. In this study, our objective is to develop efficient and robust energy-saving scheme and to find the optimal partitioning order for microcells that guarantees the lowest consumed power in future small cells network, while at the same time maintains acceptable Signal to Interference Ratio (SIR) that satisfies users' requirements [36]. In this section, we investigate through rigorous numerical processes, the performance of the proposed models for BS power consumption efficiency. For comparison purposes, we implement the different orders of sectorization, i.e., from 1 to 10 sectors. For the AS approach, all the sectors are of uniform size with fixed antenna orientation. Meanwhile, for the AH scheme, the size of each sector is dynamic and adjustable. The following parameter settings are used in our experimental design; BS transmission power β = 10 dBm, antenna element SIR requirement γ = 7dB, processing gain G=64, voice activity σ = 0.1. For the AH approach, the power adjustment interval of a sector $\delta = 10 \Big/ \left(\frac{\theta}{360} \pi^2 / 100 \right)$ is appropriated to reflect the antennas' angular accuracy, while the average e cell radius r = 200 m was considered. We compute g_P, which is the total power gained by each TX antenna in an outdoor microcell millimeter-wave networks.

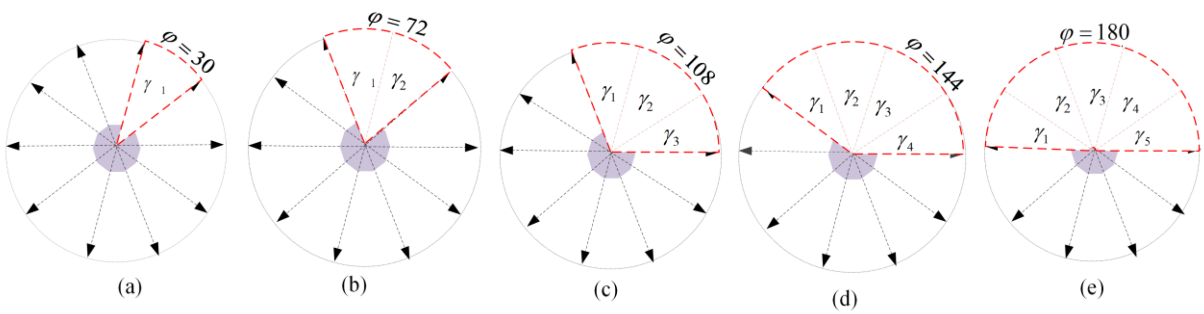

Fig. 1. Adaptive-Sleep sectorization (AS) scheme based on 10 sectors

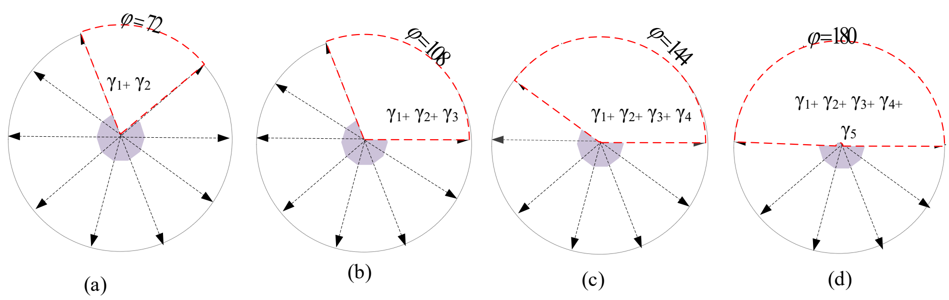

Fig. 2. Power consumption efficiency based on different order of sectors for the AH and AS strategies

VI. Results and Discussion

In this section, we investigate the performance of the proposed models, namely, the AS and AH sectorization schemes through a rigorous numerical experiment. First of all, we consider a uniform user distribution. The result contains in Table 1 shows the percentage of achievable energy by every TX antenna element. However, when all the 10 antenna elements are actively transmitting simultaneously, i.e., in the congested traffic network, it shows that up to 38.9 and 91.2% of energy can be saved by both the AS and AH schemes, respectively. Conversely, we can also observe from Table 1 that only a few percentages of energy are saved for both schemes when the BS transmits with a few numbers of antenna elements, i.e., in lower-order sectorization. The TTP performance comparison between the AH and AS strategies at a different order of sectorization, beginning from 1 to 10 in Table I reveals that the AH scheme exhibits a much better OTP and TTP performance compare to the AS scheme. In fact, the AH scheme far outperforms the AS with about more than 50% in the 9th and 10th partitions.

TABLE I.
THE TTP PERFORMANCE COMPARISON BETWEEN THE AS AND AH SCHEMES

Number of sectors	**Percentage of Power saved by AS and AH based on different orders of sectorization per sector**	
ON	**AS (%)**	**AH (%)**
1	3.49	5.2
2	9.53	15.6
3	16.32	26.55
4	20.06	37.08
5	24.28	46.75
6	27.78	56.14
7	31.11	65.1
8	34.03	73.83
9	36.46	82.46
10	38.9	91.18

From Fig. 3, it can be seen that the AH scheme exhibits much better performance compared to the AS scheme. This is because of the unique scaling algorithm employed by the AH, which contains two useful power adjustment parameters δ and σ. Generally, it can be observed in Fig. 3 that as the order of partition increases from 1 to 10, the rate of power saved for both schemes increase gradually but significantly. This proves that the proposed schemes have the ability to enhance BS's power consumption efficiency over the existing approaches. In fact, at peak hour, when the BS is transmitting with all the 10 elements simultaneously due to traffic congestion, the AH scheme can be used to save up 91% of the total BS power, compared to the AS strategy that saves only about 38% under the same circumstance. The reason is that, in AS scheme, each antenna is dedicated serving a single sector and cannot serve multiple adjacent sectors concurrently using a single antenna element, which means that the beam angle in AS is static, unlike the AH scheme which easily adjusts its beam angle to enable it to serve multiple adjacent sectors during periods of sparse traffic, thereby saving enormous transmission power for other elements.

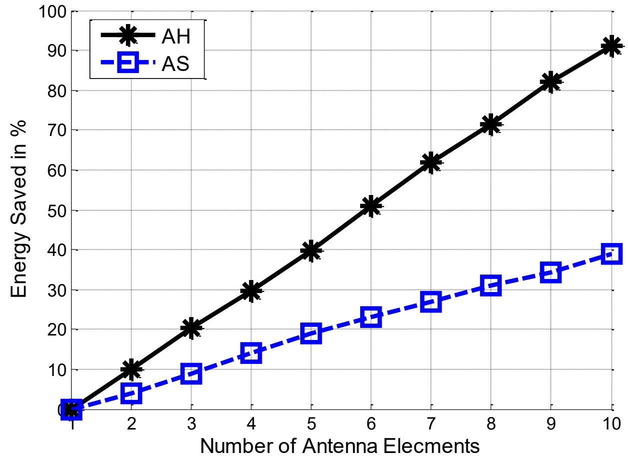

Fig. 3. Energy consumption efficiency based on a different order of sectors for the AS and AH strategies

Fig. 4 shows the impact of the energy adjustment factors δ and σ on system complexity of the AS and AH schemes. It can be seen that the energy adjustment factor of both schemes reduces with the increase in the order of sectorization (i.e., the higher the number of the sectors, the lower the system complexity relative to energy consumption efficiency). The graph further illustrates that the performances of the two schemes increase with a decrease in system complexity. Moreover, Fig. 5 shows the results obtained from the AH scheme, where the micro-cell is partitioned into 25 smaller sectors resulting in each antenna transmitting at a higher power level in the short run (when few antennas are activated) but at a very low power level in the long run.

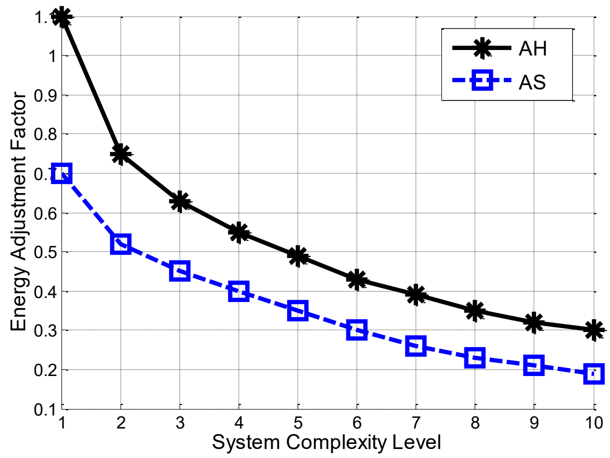

Fig. 4. The impact of the energy adjustment factors δ and σ on system complexity and performance of the AS and AH schemes

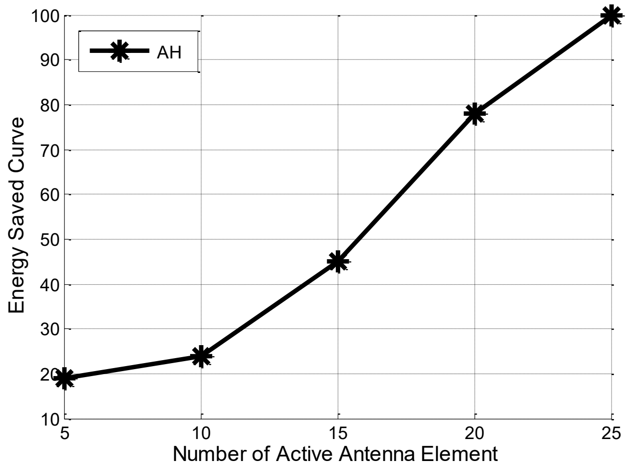

Fig. 5. Energy save curve for AH

VII. Conclusion

In this paper, we have evaluated 2 different network robust energy saving schemes, namely the adaptive sleep sectorization and adaptive hybrid partitioning. The system complexity and the BS's transmission power were optimized using the scaling algorithm and spatial Poisson process, respectively. Numerical analysis shows that the AH mechanism outperforms its AS counterpart in terms of energy consumption efficiency on the ratio of 91.2%:38.9%, respectively, at the utmost sectorization order of 10 sectors per microcell as shown in Table 1. Both the AS and AH schemes are based on 10 orders of partitioning per microcell. Both the schemes have one thing in common, they suffer a significant part loss when the BS operates at lower order, or with fewer antenna elements. This can be attributed to signal attenuation due to omnidirectional path loss, an indication that the impact of omnidirectional part loss in small networks based on millimeter-wave communication is pretty high compared to the directional case. Finally, the proposed schemes can be said to be useful in providing multi-rate services to certain user groups in a microcell network in a realistic system. Unlike the existing SLEEP/WAKE schemes, the new concept does not leave any rooms for total BS hibernation in order to save energy, which is not suitable for the kind of dynamic traffic condition that will be experienced in future wireless system, considering the fact that future applications will require 99.999% up-and-running network connectivity due to higher real-time sensitivity.

VIII. Limitations and Future work

The main objective of this study is to develop a robust, realistic and EE scheme for the future small cells mm-wave-based 5G wireless networks. Although, our proposed models have shown clear evidence of high performance, especially during periods of peak traffic, however, the proposed models have a number of limitations, which will be enhanced in future work. For instance, the inability of the AH scheme to achieve perfect beamforming (in order to save more power in periods of low user density) will be looked into in the future. Secondly, the experimented AS scheme has very little impact in the lowest order partition, in terms of power saving, therefore, as part of the future work, some enhancements will be made in order to make it a suitable candidate for the cellular communications systems with a significant power saving from the lower order.

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