Millimeter Wave Band Massive Antenna with MDMA System used in 5G Cellular System

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Abstract:
Mobile communications toward the fifth generation (5G) have been popularly new technology used in coming years.demands from 5G areboth high system capacity and high data rate. A novel multiple access schemes based on millimeter wave transmission and massive antennas at a base station (BS), named multipath division multiple access (MDMA), and is proposed in this paper to be a future 5G possible solution. MDMA is defined here as a method to use massive antennas at BS to achieve a processing gain to suppress multiple access interference (MAI) in cellular mobile radio system. The processing gain is obtained by implementing RAKE receivers at BS. The system concept is also demonstrated by computer simulations. Moreover, it has been shown through simple but crucial analysis that the system capacity and the aggregated data throughput could be boosted up to a considerable level.

IndexTerms- 5G communication, cellular system, and millimeter wave, massive antennas, system capacity.

I. Introduction

Mobile and Wireless Communication systems will allow 5G support for the expected increase in data volumes and broadening in the range of application domains. 5G systems are built upon the evolution of existing technologies complemented by new radio concepts that are designed to meet the new and challenging requirements.Essential services such as e-banking, e-learning and e-health will continue to proliferate and become handier for pocket devices. Evolutionary research has been carried out on the development of interactive television (iTV), Video on Demand (VoD) and broad wireless internet contents, which will progressively be delivered over mobile and wireless systems. These developments will lead to an avalanche of mobile and wireless traffic volume, projected to increase a thousand-fold over the next decade. Furthermore, some applications will impose additional and very diverse requirements on mobile and wireless communication systems that 5G will have to support.

Four generations of cellular communication systems have been adopted in the USA with each new mobile system generation emerging every 10 years or so since the 1980s: first generation analog FM cellular systems in 1981; second generation digital technology in 1992, 3G in 2001, and 4G LTE-A. Existing base station designs must service different bands with different cell sites, where each site has multiple base stations (one for each frequency or technology usage e.g. third generation (3G), fourth generation (4G), and Long Term Evolution-Advanced (LTE-A)[3]. To procure new spectrum, it can take a decade of legal formalities through the regulatory bodies such as International Telecommunication Union (ITU) and U.S. Federal Communications Commission (FCC). When spectrum is finally licensed, incumbent users must be moved off the spectrum, causing further delays and increasing costs.

With the IMT-Advanced (IMT-A) standards ratified by the International Telecommunications Union in November 2010 and IMT-A, i.e., the fourth generation (4G), wireless communication systems being deployed in the world, the fifth generation (5G) mobile and wireless communication technologies are emerging into research fields. Based on the Internet Protocol Architecture of 4G communication systems, unprecedented numbers of smart and heterogeneous wireless devices will be accessing future 5G mobile and wireless communication systems with a continuing growth of Internet traffic. Therefore, compared to 4G communication systems, significantly higher wireless transmission rates are expected in 5G communication systems, such as 10 Gbps peak data rates with 8~10 bps/Hz/cell. Moreover, energy efficient concepts will be fully integrated into future wireless communication systems to protect the environment. To meet the above challenges, 5G mobile and wireless communication systems will require a mix of new system concepts to boost spectral efficiency, energy efficiency and the network design, such as massive MIMO technologies, green communications, cooperative communications and heterogeneous wireless networks. We expect to explore the prospects and challenges of 5G mobile and wireless communication systems combining all of the above new designs and technologies. Thus concluding, simultaneous management of multiple technologies in the same band limited spectrum is a challenge in 5G mobile communication which supports going beyond voice for newer smart phones and advanced mobile devices. Gathered data for meeting the requirements and satisfactory constraints are highly valuable for the development of 5G cellular communications at mm bands in the coming decade.

One of the interfaces being considered for 5G mobile communications uses millimetre wave frequencies.It is estimated that bandwidths of several GHz may be required by operators to provide some of the extremely high data rates being forecast.Currently frequency below 3GHz are being used by cellular communications systems, and by the very nature, these frequencies could only offer a maximum bandwidth of 3 GHz, even if they were all clear for use which is obviously not possible. By having a 5G millimeter wave interface, much wider bandwidths are possible, and there are several candidate millimeter bands that are being considered for allocation to this type of service. The propagation characteristics of millimeter wave bands are very different to those below 3GHz. Typically distances that can be achieved are very much less and the signals do not pass through walls and other objects in buildings.Typicallymillimeter wave communication is likely to be used for outdoor coverage for dense networks - typically densely used streets and the like. Here, ranges of up to 200 or 300 meters are possible. One of the issues of using millimeter wave signals is that they can also be affected by natural changes such as rain. This can cause a considerable reduction in signal levels for the duration of the precipitation. This may result in reduced coverage for some periods. Often these 5G millimeter wave small cells may use beam forming techniques to target the required user equipment and also reduce the possibility of reflections, etc, and massive multiple-input multiple-output (massive MIMO) antennas [6]. The first approach allows different kinds of cells to co-exist and function simultaneously in the same area, which is popularly termed as small cells. The second approach resorts to utilizing the unexcavated spectrum of the millimeter wave frequency band, e.g., 20GHz-30GHz, since it not only avoidsfrequency spectrum congestion problem below 3GHz but also provides considerable bandwidth for high data ratetransmission. However, it brings out the problem of muchlarger propagation loss at much higher frequency bands. Thus, the cell size must be reduced accordingly. The third approachconsiders employing a large amount of antennas at BS side[7]–[13], usually tens to hundreds of antennas. Reference [13]has stated that the massive number of antennas provides asubstantial degree of freedom such that it can easily increasedata rate 10 times or more, improve the radiated energyefficiency, be built with inexpensive and low-powercomponents, enhance the robustness to interference etc.. However, some inherent problems need to be carefully handledsuch as pilot contamination [14]–[17] and various implementation related issues [13].

Contributions of this paper are capsuled as follows. A novel multiple access scheme for the 5G cellular systems based on millimeter wave transmission and massive antennas at BS, named multipath division multiple access (MDMA), is proposed in this paper. Different from the previous multiple access schemes (i.e., FDMA, TDMA, CDMA, and OFDMA), MDMA distinguishes its users by exploiting their distinct and rich multipath components through deploying massive antennas at BS. With MDMA as a means of implementing cellular systems, both system capacity and the aggregated data throughput could be boosted up to an appreciable extent, as we would explain in Section IV. A cellular system architecture built upon MDMA is presented, which could be served as reference system architecture for future 5G cellular systems development.

II. SYSTEM ARCHITECTURE

The proposed MDMA cellular system is exemplified in Figure 1. Every BS exploits massive antennas operating at the mmWave band, say 30 GHz, such that the size of each antenna(e.g., dipole antenna) is in the order of one centimeter, much smaller than the regular size (e.g., 30 centimeters for 1 GHz band). Thus, at BS, hundreds of antennas can be placed every other tens of wavelengths to make the received signals uncorrelated [4] across the BS antennas. For example, if we arrange 100 antennas in a two-dimensional square plane, then the total area occupied is about 10 m2, which can be easily applied to real environments. In contrast, there is only one antenna at user terminal (UT). It is customary that any two users are separated b much more than a wavelength and their multipath fading profiles are different.[2]

The cellular network architecture needs to support higher spatial reuse. Massive MIMO base stations and small-cell access points are two promising approaches for future cellular. Massive MIMO base stations allocate antenna arrays at existing macro base stations, which can accurately concentrate transmitted energy to the mobile users [24]. Small cells offload traffic from base stations by overlaying a layer of small cell access points, which actually decreases the average distance between transmitters and users, resulting in lower propagation losses and higher data rates and energy efficiency [24]. Both of these important trends are readily supported and, in fact, are enhanced by a move to mm-wave spectrum, since the tiny wavelengths allow for dozens to hundreds of antenna elements to be placed in an array on a relatively small physical platform at the base station, or access point, and the natural evolution to small cells ensures that mm-wave frequencies will overcome any attenuation due to rain.[2]

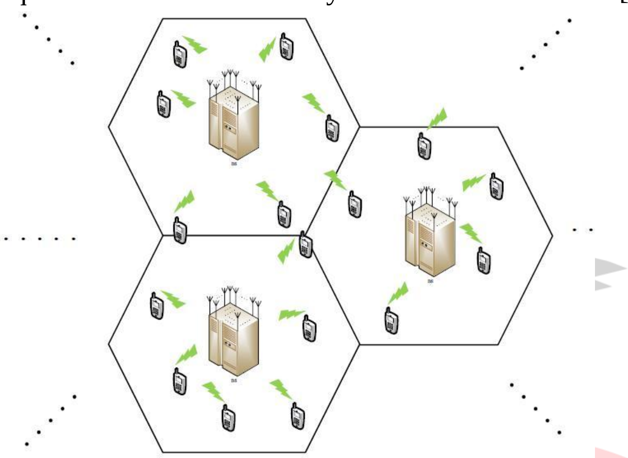


Figure 1.A cellular system with massive antennas at BS

In addition, a channel bandwidth of 200 MHz is assumed in our system at 30 GHz carrier frequency. For such a wide bandwidth used for transmission, the rich and distinct multipath components of each individual user can be resolved, which helps to distinguish all the users as compared to the traditional multiple access methods which separate users in frequency, time, and code domains.

Assume that the UL channel state information (CSI) is available at BS through channel estimation. Employing the Rake receiver [3] with massive antennas, we can equalize the received signal before data detection for desired users at BS. In brief, the equalization here is done in both *time* and *space* domains. This leads to a huge signal-to-interference plus noise ratio (SINR) gain for each user. The resultant spatial processing gain is analogous to a CDMA system's processing gain and is effective to suppress intersymbol interference (ISI), multiple access interference (MAI), and co channel interference

A. Transceiver Architecture

Figure 2 shows the block diagram of the MDMA user terminal transmitter and the base station receiver. Consider a frequency-selective multi-user scenario with K single-antenna users and an M-antenna BS in each cell. Assume binary phase shift keying (BPSK) modulation is used and ideal power control is executed in the uplink. αlkm and τlkm represent the complex gain and the path delay of the l-th resolvable path of the link between the k-th user and the m-th BS antenna, where l = 1... L, k = 1... K, and m = 1... M. $P(t)$ denotes a transmit pulse-shaping filter, and Tb is the bit time (e.g., Tb equals to 5 ns with 200 Mbps BPSK data rate). CCI stands for the cochannel interference coming from other cells. Let $nj(t)$ be the corresponding additive white Gaussian noise at the j-th BSantenna. $s_k(n)$ denotes the n-th data bit of the k-th user fortransmission. $vkj(t)$ is the received signal at the j-th BS antenna from the k-th user, and $ukj(t)$ is the result of the k-th user's Rake receiver output at the j-th BS antenna. Accordingly, we have

$$v_{kj}(t)=\sum_{l=1}^{L}\sum_{n}\alpha_{lkj}P(t-\tau_{lkj}-nT_b)s_k(n), \qquad (1)$$

and

$$u_{kj}(t) = \left(v_{kj}(t) + \sum_{\substack{q=1 \\ q \neq k}}^{K} v_{qj}(t) + \mathrm{CCI} + n_j(t) \right) \otimes \sum_{l'=1}^{L} \alpha^*_{l'kj} P^*(T_b - t - \tau_{l'kj}), \quad (2)$$

for $k = 1 \ldots K$ and $j = 1 \ldots M$, where $\otimes$ and $*$ respectively denote the linear convolution operator and the conjugation

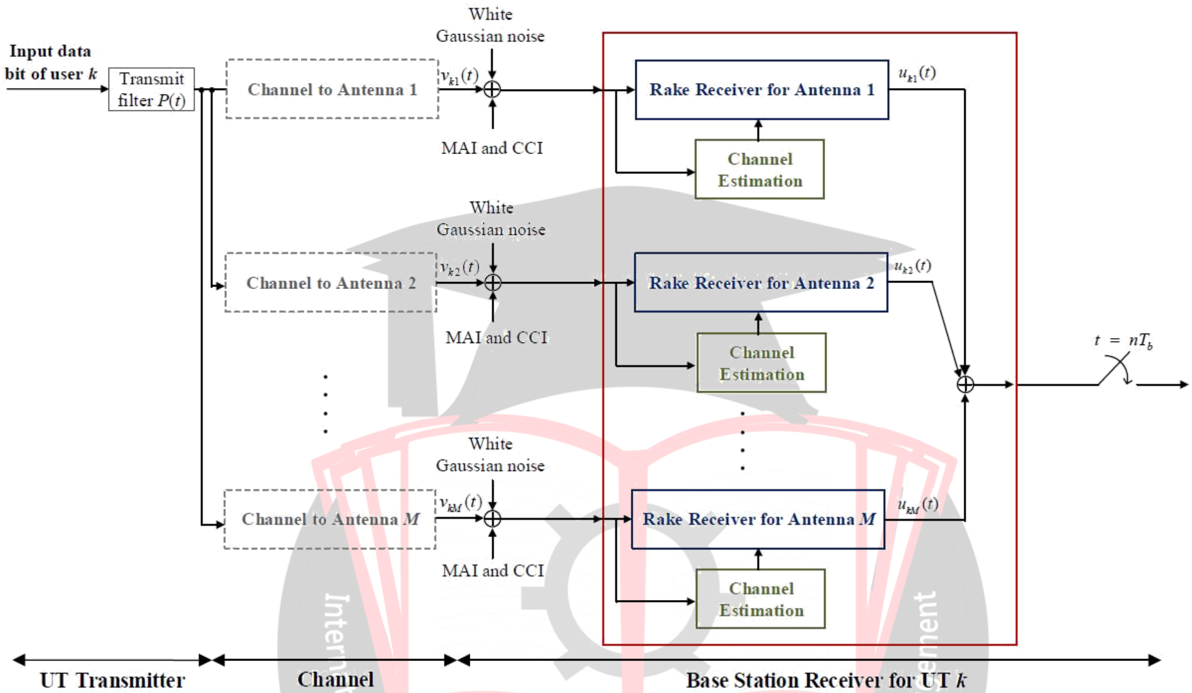


Figure 2.MDMA UT transmitter and BS receiver block diagram

B. *Simplified Analysis*

As already mentioned, the received signal at BS would be equalized for each user using the Rake receiver and then combine the results of Rake receiver outputs in a coherent manner, where a spatial processing gain is achieved for every user. This can also be verified from the above equations. If we consider user k being the desired user, then (1) corresponds to the desired signal through the channel that needs to be further processed. Inserting (1) into (2) and neglecting interference and noise terms lead to

$$u_{kj}(t) = \int_{-\infty}^{\infty} \left(\sum_{l=1}^{L} \sum_{m} \alpha_{lkj} P(\xi - \tau_{lkj} - mT_b) s_k(m) \right) \times \left(\sum_{l'=1}^{L} \alpha^*_{l'kj} P^*(T_b - t + \xi - \tau_{l'kj}) \right) d\xi. \quad (3)$$

Suppose the combination of the transmit and receive filters satisfies the Nyquist criterion for ISI-free transmission, i.e., $P_{eff}(iT_b)=\delta[i], i \in \mathbb{Z}$, where $P_{eff}(t) \equiv P(t) \otimes P^*(-t)$ and $\delta[n]$ is equal to one for n=0 and zero otherwise. Thus, sampling $u_{kj}(t)$ in (3) at $t=(n+1)T_b$, we have

$$u_{kj}((n+1)T_b)=\int_{-\infty}^{\infty}\left(\sum_{l=1}^{L}\sum_{m}\alpha_{lkj}P(\xi-\tau_{lkj}-mT_b)s_k(m)\right)\times\left(\sum_{l'=1}^{L}\alpha^{*}_{l'kj}P^{*}(-nT_b+\xi-\tau_{l'kj})\right)d\xi$$

$$=\int_{-\infty}^{\infty}\left(\sum_{l}^{L}\left|\alpha_{lkj}\right|^{2}P^{2}(\xi-\tau_{lkj}-nT_b)s_{k(n)}\right)d\xi+\text{ISI}$$

$=s_k(n)+\text{ISI}$

where the last equality holds assuming that $\int_{-\infty}^{\infty}P^{2}(t)dt=1$ and $\sum_{l=1}^{L}\left|\alpha_{lkj}\right|^{2}=1$

for normalization purposes. Summing overall M BS antennas, we can get the desired signal as $Ms_k(n)$ after sampling at time $(n+1)T_b$, whereas the interference and noise terms add *noncoherently*. In other words, the end-to-end equivalent channel of each user tends to be an ideal channel as M increases, i.e., an impulse-like channel, which is shown in Section III. Assume that data power of every user equals unity. Then, one can easily derive the average signal-to-interference power ratio (SIR) to be M / K (note that the noise is ignored for an interference-limited cellular system). Since the massive antennas are used at BS (i.e., $M >> K$), the average SIR could be boosted up to a great amount. Thus, M is the (spatial) processing gain offered by the MDMA based cellular system with massive BS antenna.

III. COMPUTER SIMULATIONS

As the proposed 5G system operates in the millimeter-wave band, the channel model used for the 5G system performance simulation should be reasonably accurate and match with the real situations. Rappaport *et al.* has conducted several real-world channel measurements for millimeter-wave frequencies [18]–[23], especially at 28 GHz. Reference [23] presented spatial channel characteristics for the 28 GHz band, including path loss statistics, cluster distributions etc. The results of [23] can be used for system-level simulations, e.g., cellular system capacity evaluation, yet improper for link-level simulations since it did not show the temporal channel characteristics such as power delay profile and the associated statistical distributions. For computer simulations in this paper, we modified the S-V channel model with the spatial parameters according to [23]. First, we set the number of clusters by the Poisson law. The arrival time of the clusters is uniformly distributed within the maximum delay spread, e.g., 404.1 ns [20]. Then, we calculate the power of each cluster using the model of [23]. Afterwards, we generate the relative arrival time of each ray within individual cluster according to the exponential distribution. Finally, we compute the power of each ray. Figure 3 shows an effective impulse response of a desired user in a single cell scenario under ideal power control in a full loading cell which serves 25 users simultaneously (The effective impulse response of a user is plotted including interference (both MAI and ISI) observed before the sampler in Figure 2 at the receiver for the user.). It is clear that as the number of BS antennas grows, the effective impulse response becomes more impulse like, i.e., the interference effect is mitigated when more antennas are deployed at BS, which agrees with the simplified analysis in section II B. Besides, Figure 4 depicts the desired user's PDF of the SIRbefore the sampler. It can be seen that the mean values arearound -14 dB, -4 dB, and 6 dB, respectively for 1, 10 and 100antennas. Again the results match well with the simplifiedanalysis that the average SIR is the number of BS antennas (M)divided by that of total users (K) in a cell. In addition, the PDFcurve turns out to be more concentrated around the mean when the number of antennas at BS increases. Therefore, the receiveSIR tends to be more deterministic for each user that guarantees better system performances, which is due to the richand distinct multipath components in the mmWave band and the law of large numbers provided by massive antennas at BS.Figure 5 plots the cumulative distribution of the receive SIR with 100 BS antennas and different number of users in a*multi-cell* scenario. The cellular system layout is composed of127 hexagonal cells corresponding to 6 tiers of cochannel cells.First, it can be seen that the average SIR is also the function ofM / K which coincides with the simplified analysis in theprevious section. Similarly, the performance gets improved asthe ratio of M over$K$ increases. Second, the average SIR is lessthan M / K by about 1.7 dB which accounts for the other cellinterference described in the next section. Third, variationsaround the mean of the receive SIR diminish as the number ofusers increases due to the law of large numbers of MAI. That is,the receive SIR converges to its mean as more users are servedin the system.[2]

Figure 3.An effective impulse response of a desired user in a single cellscenario under ideal power control in a full loading cell with 25 active users

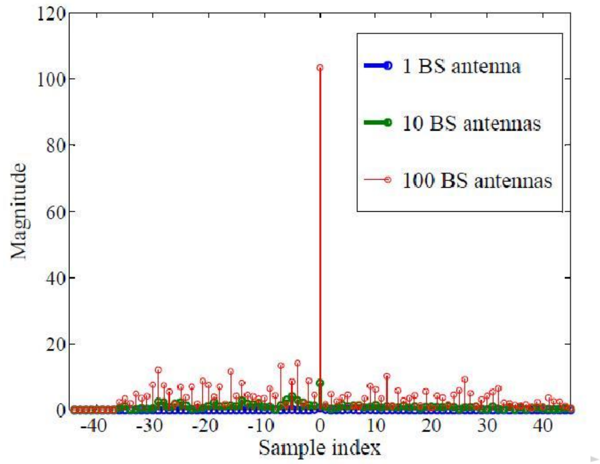
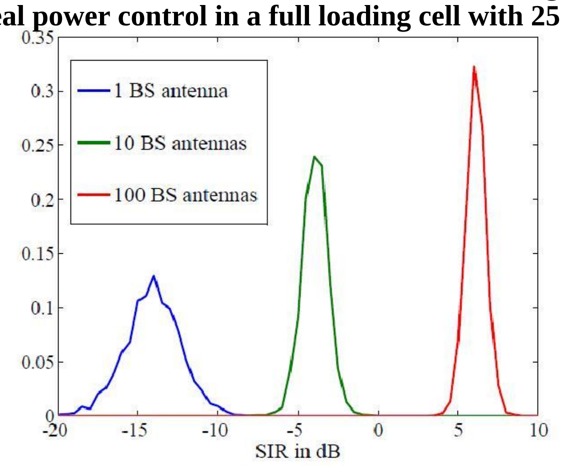


Figure 4.Adesired user's PDF of the receive SIRin a single cell scenario under ideal power control in a full loading cell with 25 active users



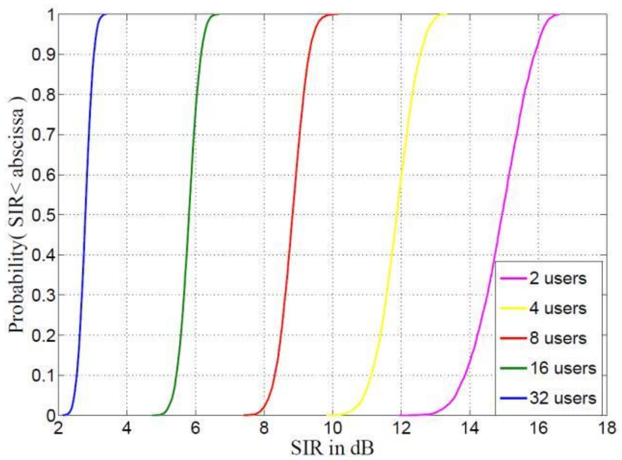


Figure 5.The cumulative distribution of the receive SIR with 100 BSantennas and different number of active users in a multi-cell scenario

IV. SYSTEM CAPACITY EVALUATION

From the preceding analysis and simulation results, a simple but crucial system capacity evaluation for the proposed MDMA cellular system is presented as follows. We set the system at the outset to operate at the carrier frequency of 30 GHz with the channel bandwidth of 200 MHz, and it works under cell reuse factor of one (i.e., a universal frequency reuse plan is adopted). Assume that the cellular system considered is interference-limited. Recall that BPSK modulation is used and the ideal power control is executed in the uplink. Additionally, the system is under full load, i.e., K users are always transmitting concurrently. Under these assumptions, the average receive SIR at each user's demodulator output is thus

$$\frac{E_b}{I_0} \cong \frac{S}{I} = \frac{M^2}{M(K-1)+M} \times \frac{1}{1+f} = \frac{M}{K1} \times \frac{1}{1+f}, \quad (5)$$

where Eb and $I0$ represent the received energy per bit and the interference power spectrum density. S and I are the average signal and interference power, respectively. $\frac{M^2}{M(K-1)+M}$ derives from the fact that the desired signal of each BS antenna adds coherently while the interference (which contains MAI and ISI) sums up noncoherently. f denotes the other-cell relative interference factor defined as the ratio of the interference power from other cell to the interference power from the home cell. It is found in [3] that f is approximately 0.5 due to the dominant 1st-tier and 2nd-tier co-channel interference, which can also be inferred from Figure 5. Rearranging (5) leads to

$$K \cong \frac{M}{E_b I_0} \times \frac{1}{1+f},$$

which gives an elegant formula for the number of users the BS can serve under the required $Eb/I0$ at each user's demodulator output.

Under the minimum required $Eb/I0$ of 6 dB (= 4 in linearscale) for data detection with the acceptable performance [3], 150 BS antennas can afford 25 full loaded users in every cell simultaneously since $\frac{150}{4} \times \frac{1}{1+0.5} = 25$. In practice, the number of users can be greatly increased if they are not full loaded. (6)

Note that the system capacity can be further increased using sector antennas. Moreover, multi-user detection techniques (e.g., successive interference cancellation or parallel interference cancellation) are capable of eliminating intra-cell interference such that the system capacity can be boosted up three times more for $f = 0.5$ since $1/(1+f)$ in (6) could be replaced by $1/f$.

Due to the fact that each user in the cell shares the whole 200 MHz bandwidth, the proposed cellular system can thus achieve the total throughput of 5Gbps (200 Mbps×25) using BPSK signaling, even without using multi-user detection and sector antennas.

V. CONCLUSIONS

Starting from the 3G and the 4G communication systems, the 5G system demands both high system capacity and high data rate. Multipath division multiple accesses (MDMA), a novel multiple access scheme based on millimeter wave transmission and massive antennas at BS, is proposed in this paper to be a future 5G possible solution. MDMA is defined here as a method to use massive antennas at BS to achieve a processing gain to suppress multiple access interference in a cellular mobile radio system. The processing gain is obtained by implementing RAKE receiver at BS Operating at millimeter wave bands provides a relatively large channel bandwidth, which benefits the high data rate transmission. the massive number of antennas provides a substantial degree of freedom such that it can easily increase data rate 10 times or more, improve the radiated energy efficiency, be built with inexpensive and low-power components, enhance the robustness to interference On the other hand, making use of massive antennas offers excess degrees of freedom, which is helpful to suppress interference so as to increase the system capacity. With MDMA as a means of implementing cellular systems, it has been shown in this paper that both system capacity and the aggregated data throughput can be boosted up to a considerable level. Users in a cellular system built upon MDMA are separated by their distinct multipath structures through deploying massive antennas at BS. Thus, a cellular system of frequency reuse factor of one can be established. In brief, MDMA could be served as an alternative to implement a 5G cellular mobile radio system.

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