MCAS: A Macrocell Channel Allocation Scheme for Broadband Wireless Access Networks

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***Abstract*— The radio spectrum of the IEEE 802.16 medium access control (MAC) protocol ranges from 2 to 66 GHz, which is one of the potential solutions for broadband wireless access (BWA) or beyond third generation (B3G)/4G networks. However, with the characteristic of radio propagation, the maximum transmission distance is proportioned inversely to the frequency which the subscriber station (SS) carries. According to this property, the base station (BS) can easily allocate appropriate channels for SSs according to the received signals which SSs transmit. Therefore, in this paper, we investigate the relationship between the signal propagation and the distance, and then we proposed a novel macrocell channel allocation scheme (MCAS) for dynamic channel allocation (DCA) in radio access networks (RAN). The MCAS enables the BS to allocate appropriate channels to SSs according to the received signal-to-noise ratio (SNR) value from the SSs. The MCAS not only increases the capacity of the system but also saves the overall power consumption of the system well. Simulation results show that the proposed MCAS increases the power saving up to 47.83% over the original IEEE 802.16 standard specifications.**

I. Introduction

In the recent years, Broadband wireless access (BWA) has received a lot of attention. [1], [2]. Working toward a specification of "beyond third generation" (B3G) or fourth generation (4G) system is an ongoing essential issue [3], [4], [5]. It has to been seen as the next-generation communications system, which may include new wireless access technologies, but in any case it will still be able to provide an acceptable broadband access in any case. The tendency can be foreseen that the demand on high bandwidth transmission will follow a large number of multimedia applications [6], [7] in wireless communications, and it will be inevitable in the near future.

Fixed BWA systems, such as the local multipoint distribution service (LMDS), provides multimedia services to a number of discrete subscriber sites with IP and offer numerous advantages over wired IP networks. This is accomplished by using base stations (BSs) to provide network access services to subscriber sites based on the IEEE 802.16 WirelessMAN® standard [8]. First published in April 2002, the IEEE 802.16 standard has recently been updated to IEEE 802.16-2004 [9] (approved in June 2004). The standard focuses on the "first-mile/last-mile" connection in wireless metropolitan area networks (WMANs). Its purpose is to facilitate the optimal use of bandwidth from 2 to 66 GHz, as well as interoperability among devices from different vendors. Typical channel bandwidth allocations are 20 or 25 MHz (United Stats) or 28 MHz (Europe) in 10 to 66 GHz, or various channel bandwidths among 1.5 to 20 MHz in 2 to 11 GHz [10]. The progress of the standard has been fostered by the keen interest of the wireless broadband industry to capture the emerging WiMAX (worldwide interoperability for microwave access) market, the next-wave wireless market that aims to provide wireless broadband Internet services. The WiMAX Forum, formed in 2003, is promoting the commercialization of IEEE 802.16 and the European Telecommunications Standard Institute's (ETSI's) high performance radio MANs (HyperMANs). It provides one of potential solutions to B3G/4G architecture [11].

With the characteristic of radio propagation, a longer distance will cause fading signal and losing path conspicuously [12], and the signal arriving the BS from the subscriber station (SS) with lower frequency will take a longer distance than the higher frequency [13]. As a result, the IEEE 802.16 [9], ranging from 10 to 66 GHz, has the maximum transmission distance around 1.6–4.8 kilometers and the maximum data rate up to 120 Mb/s. It provides a framework of the BWA backbone network based on various BSs. In IEEE 802.16a [10], the transmission distance is expended to 6–10 kilometers and the data rate is up to 75 Mb/s. It supports nonline-of-sight (NLOS) communications, thus it fits in the urban environment which may have a lot of hindrances.

The methods of frequency allocation includes a fixed channel allocation (FCA) and a dynamic channel allocation (DCA) in the IEEE 802.16 WMAN standard. FCA follows the initial characteristic of the SS (decaying, multipath, frequency enhanced ratio, and power etc.) [15] to allot each SS an exclusive channel in advance. Some performance issues for FCA are studied in [16], [17]. Comparing with FCA, DCA does not reserve an exclusive channel beforehand for SSs, but it stands on and follows the characteristics of SSs to offer proper channels [18]. Nowadays many DCA schemes are investigated and proposed in various wireless networks [19], [20], [21], [22], [23], [24], but only a small number of them are applied for the RAN correspondingly.

According to above mentions, with the wide range of spectrum (2–66 GHz), hundreds of channels will be allocated for access in the RAN if each channel has bandwidth of 200 MHz. How to organize these available channels efficiently to increase the maximum capacity of SSs becomes very important [14]. Thus, in this paper, we first point out the problem of how to distribute channels (or frequencies) to SSs according to the distance between the SS and the BS efficiently, and then we propose a novel macrocell channel allocation scheme (MCAS) based on the received signal-to-noise ratio (SNR) value of signal arriving the BS from the SS to coordinate SS's channel allocation. Based on the MCAS, we further propose a new super macrocell arrangement model for RANs. Moreover, considering the mobility of SSs in the RAN, MCAS will support SS in various velocities and movements in different directions without out of radio service. The proposed MCAS increases not only the capacity of the system and the capability of SS's mobility in the RAN but also the received strength of the signal to reduce the packet losing ratio, thus it improves the performance of BWA system. Besides, the power consumption of each SS will be minimized if it uses lower frequency to transmit data. Therefore, the MCAS also saves the battery consumption since it allocates adequate channels for SSs by considering the corresponding geographic locations.

The remainder of this paper is organized as follows. Section II takes an overview of the mechanism of the IEEE 802.16 MAC protocol. In Section III, we illustrate the relationship of the measured SNR and the maximum transmission distance in detail. Section IV introduces a new channel allocation model and the MCAS for the IEEE 802.16 networks. In Section V, we give the performance evaluations of the MCAS and show the impact of the MCAS to the IEEE 802.16 networks. Finally, some concluding remarks are discussed in Section VI.

II. The IEEE 802.16 MAC protocol

This section briefly summarizes the medium access control (MAC) protocol as standardized by the IEEE 802.16 Working Group, which provides system access, bandwidth allocation, connection establishment, and connection maintenance in detail. For a more complete and detailed presentation, refer to the IEEE 802.16 standards [9], [10]. The IEEE 802.16 physical (PHY) layer requires equally radio link control (RLC), which is the capability of the PHY to transition from one burst profile to another. RLC begins with periodic BS broadcast of the burst profiles that have been chosen for the uplink and downlink. The particular burst profiles used on a channel are chosen based on a number of factors, such as rain region and equipment capabilities [1]. For ongoing ranging and power adjustments, the BS may transmit unsolicited ranging using ranging response (RNG-RSP) messages commanding the SS to adjust its power or timing.

During initial ranging, the SS also requests to be served in the downlink via a particular burst profile by transmitting its choice of downlink interval usage code (DIUC) to the BS. The BS commands the SS to use a particular uplink burst profile simply by including the appropriate burst profile uplink interval usage code (UIUC) with the SS's grants in UL-MAP messages. After initial determination of uplink and downlink burst profiles between the BS and a particular SS, RLC continues to monitor and control the burst profiles. The SS can use the ranging request (RNG-REQ) message to request a change in downlink burst profile.

IEEE 802.16 supports a frame-based transmission, in which the frame can adopt variable lengths. The frame structure for the orthogonal frequency division multiple access (OFDMA) PHY in time division duplex (TDD) mode. Each frame consists of a DL-subframe and an UL-subframe [27]. A DL-subframe consists of DL frame prefix to specify the modulation/coding (PHY mode), length of the DL-burst-1, and the broadcast MAC control messages, i.e., and the DL and UL channel descriptor (DCD, UCD) define the characteristic of the physical channels. The DL-MAP defines the access to the DL channel, and the UL-MAP allocates access to the UL channel. The FCH is followed by one or multiple DL-bursts, which are ordered by their PHY mode. While the most robust one is transmitted first, the last burst has the highest PHY mode. Thus, the whole MAC frame is specified by the FCH and/or the DL-burst-1. The UL-subframe consists of contention intervals scheduled for initial ranging bandwidth request purposes, and one or multiple UL PHY transmission bursts, that each transmitted from a different subscriber station (SS). Each UL PHY transmission burst contains only one UL-burst and starts with a preamble. The DL-MAP defines the access to the DL channel, and the UL-MAP allocates access to the UL channel.

The investigated IEEE 802.16a PHY uses OFDM with a 256 point transform, designed for NLOS operation in the 2–11 GHz frequency bands, both licensed and license exempt. TDD and FDD variants are defined. Typical channel bandwidths vary from 1.25 to 28 MHz. There are more optional air interface specifications, e.g. based on OFDMA with a 2048-point transform or based on single-carrier modulation [25], [26]. The finalization of the IEEE's 802.16-2004 standard improves the OFDM technology, which splits a given frequency into subcarriers. This lets operators transmit more signals over a given frequency with less likelihood of interference, a key factor in opening up unlicensed spectrum. IEEE 802.11 has a 64 OFDM physical layer, while IEEE 802.16 features a 256 OFDM architecture.

However, IEEE 802.16 standard defines DL-subframe and UL-subframe that determine the downlink and uplink channel allocation, described above such as DL-MAP and UL-MAP, but it does not define how to allocate these huge channels efficiently for enhancing the maximum capacity of SS. In WMAN we will consider the whole above facts and the mobility of each handset to prevent it out of service. In the next section we will investigate how the MCAS affects network performance in the IEEE 802.16 WMAN.

III. The Signal Estimation

As we discuss in previous section, the maximum transmission distance is proportioned inversely to the frequency which the SS carries. Likewise, the BS can allocate an appropriate channel or frequency to the SS for data transmission according to the distance far from the BS if the BS knows the exactly position of the SS. The exactly position can be easily obtained by well-known global positioning system (GPS) [32]. However, this measurement scheme would not work if the environment has many obstacles and interferences such as mansions in urban scenario or other radio sources.

In order to allocate a feasible channel to a SS, we adopt the signal-to-noise ratio (SNR) value as the measurement criterion to estimate the corresponding frequency for arrangement. The power received from a transmitter at a separation distance d directly impacts the SNR, which the desired signal level is represented in received power P_r and is derived by

$$P_r = \frac{P_t G_t G_r}{\mathrm{PL}(d) L} \text{ [Valid if } d \gg 2D^2/\lambda], \quad (1)$$

where P_t is the transmitted power, G_t and G_r are the transmitter and receiver antenna gains, $\mathrm{PL}(d)$ is the path loss (PL) with distance d, L is the system loss factor ($L \geq 1$, transmission lines etc, but not due to propagation), D is the maximum dimension of transmitting antenna, and λ is the corresponding wavelength of the propagating signal [31]. The measurement unit of P_r is milliwatt (mW). The antenna gain G is equal to $4\pi A_e/\lambda^2$; A_e is the effective aperture of antenna. The length of λ can be obtained by $c/f = 3 \times 10^8/f$ in meters where f is the frequency the signal carries. Besides, the P_r can be represented in dBm units as

$$\begin{aligned} P_r[\mathrm{dBm}] &= 10\log(P_r[\mathrm{mW}]) \\ &= P_t + G_t + G_r - \mathrm{PL}(d) - L. \end{aligned} \quad (2)$$

In the free space propagation model, the propagation condition is assumed idle, and there is only one clear line-of-sight (LOS) path between the transmitter and receiver. On unobstructed LOS path between transmitter and receiver, the PL can be evaluated as

$$\mathrm{PL}(d) = \frac{(4\pi)^2 d^2}{\lambda^2} \quad (3)$$

or when powers are measured in dBm units

$$\mathrm{PL}(d) = 92.4 + 20\log(f) + 20\log(d). \quad (4)$$

From equation (3), we can get the desired T-R separation distance in meters

$$d = \frac{\lambda}{4\pi}\sqrt{\mathrm{PL}(d)} = \frac{c}{4\pi f}\sqrt{\mathrm{PL}(d)}. \quad (5)$$

However, different modulation schemes such as quadrature phase shift keying (QPSK), 16 quadrature amplitude modulation (16QAM) or 64QAM have different maximum PL values [11]. These values are 125 dB for QPSK, 120 dB for 16QAM and 115 dB for 64QAM, which leads to the distance calculations. Fig. 1, calculated from equation (4), shows the relationship of the frequency and distance between two isotropic antennas with different modulation schemes in detail.

Nevertheless, this equation can not be applied in street canyon scenario or urban environment. A general PL model

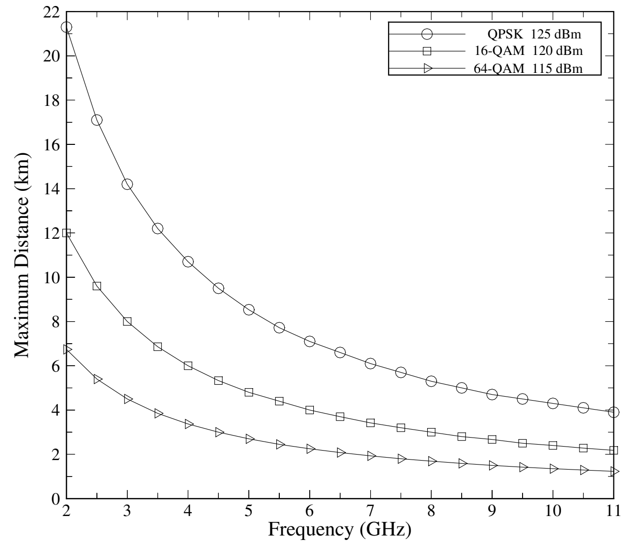

Fig. 1. Maximum transmission distance versus frequency domains from 2 GHz to 11 GHz in OFDM with different modulation schemes.

that has been demonstrated through measurements uses parameter ρ to denote the rule between distance and received power [29]. The $\mathrm{PL}(d)$ in realistic environment can be expressed as

$$\begin{aligned} \mathrm{PL}(d) = \mathrm{PL}(d_0) &+ 10\rho\log(\frac{d}{d_0}) + X_\sigma + C_f \\ &+ C_h; \quad d \geq d_0, \end{aligned} \quad (6)$$

where the term $\mathrm{PL}(d_0)$ is for the free-space PL with a known selection in reference distance d_0, which is in the far field of the transmitting antenna (typically 1 km for large urban mobile system, 100 m for microcell systems, and 1 m for indoor systems) and is measured by $\mathrm{PL}(d_0) = 20\log(4\pi d_0/\lambda)$. The term X_σ denotes a zero-mean Gaussian distributed random variable (with units of dB) which reflects the variation in average received power that naturally occurs when PL model of this type is used [28]. The ρ is the path loss exponent, $\rho = 2$ for free space, and is generally higher for wireless channels. It can be measured by $\rho = (a - bh_b + c/h_b)$, where a, b and c are constants for each terrain category. The numerical values for these constants is studied in [15] where h_b is the height of the base station between 10 m and 80 m. The term C_f is the frequency correction factor, accounts for a change in diffraction loss for different frequencies which with a simple frequency dependent correction factor C_f due to the diffraction loss, measured by $C_f = 6\log(f/1900)$ [30]. Where $C_h = -10.7\log(h/2)$, 2 m $\leq h \leq$ 8 m, which C_h is the receiver antenna height correction factor, and h is the receiver antenna height between 2 m to 8 m. This correction factor closely matches the Hata-Okumura mobile antenna height correction factor for a large city. The mostly NLOS conditions, doubling the receiver antenna height results in approximately 3.5 dB decrease in path loss.

The audio or video quality of a receiver is directly related to the SNR; the greater the SNR is, the better the reception

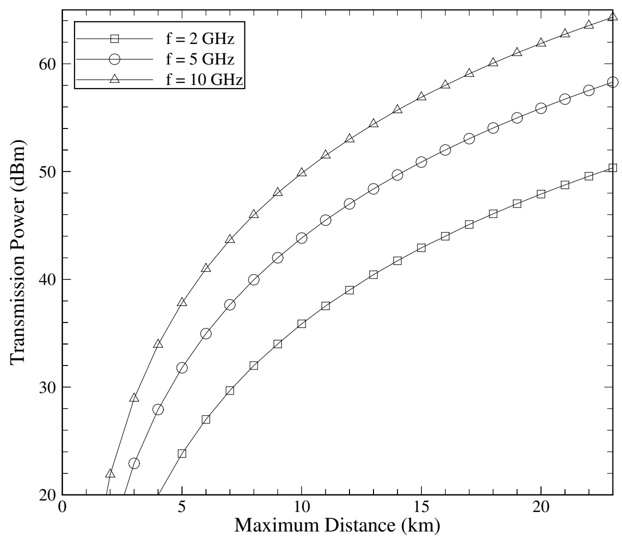

Fig. 2. Transmission power versus maximum distance when ρ = 4, B = 20 MHz, coding rate = 3/4, $\text{SNR}_{r,\min}$ = 24.4 dB, F = 7, G_t = 15, G_r = 18, L = 5 dB.

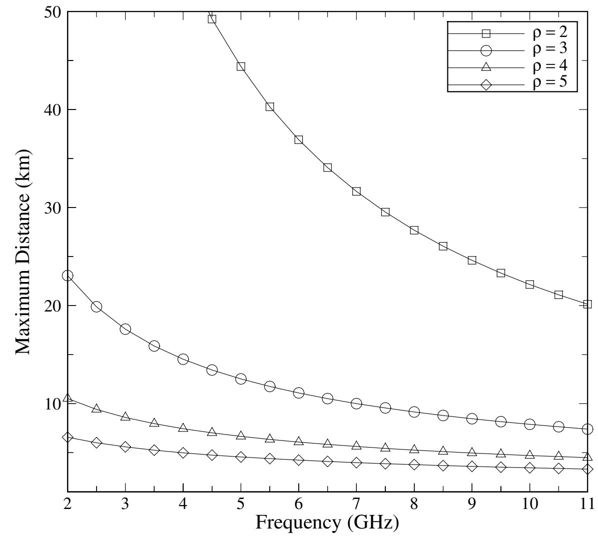

Fig. 3. Maximum transmission distance versus frequency when B = 20 MHz, coding rate = 3/4, $\text{SNR}_{r,\min}$ = 24.4 dB, F = 7, G_t = 15, G_r = 18, P_t = 15 W, L = 5 dB.

quality is. The limiting factor on a wireless link is the SNR required by the receiver for useful reception

$$\text{SNR(dB)} = P_r(\text{dBm}) - N(\text{dBm}), \tag{7}$$

where $N(\text{dBm})$ is the noise power in dBm. Assume the carrier bandwidth is B, the receiver noise figure is F, the spectral efficiency is r_b/B, and the coding gain is G_c. Then the SNR for coded modulation with data rate r_b can be obtained by

$$\text{SNR(dB)} = 10\log\left(\frac{P_r}{N}\cdot\frac{r_b}{B}\right) - G_c, \tag{8}$$

where

$$N(\text{dBm}) = -174(\text{dBm}) + 10\log B + F(\text{dB}) \tag{9}$$

and G_c is normally considered as 5 dB. The noise might consist of thermal noise generated in the receiver, co-channel or adjacent channel interference in frequency division or time division multiple access systems, or multiple access interference in code division multiple access spread spectrum systems.

IV. The Signal-Aware Dynamic Channel Allocation Scheme

Due to the fact that the maximum transmission distance is determined by which frequency its carries, each SS which has packets to transmit and must use the lowest frequency to contend the channel access right during the uplink contention period. The channel of lowest frequency is called the *contention channel*. The BS, after receiving a RNG-REQ message from the SS, calculates the estimated distance between BS and SS according to the received SNR value. Suppose the minimum required received signal power is $P_{r,\min}$, according to equations (2) and (7), we have

$$\begin{aligned} &\text{SNR}_{r,\min} = P_{r,\min} - N \\ \Rightarrow &P_{r,\min} = \text{SNR}_{r,\min} + N \\ \Rightarrow &P_t + G_t + G_r - \text{PL}(d) - L = \text{SNR}_{r,\min} + N. \end{aligned} \tag{10}$$

Substituting equation (6) into equation (10) leads to

$$\begin{aligned} &P_t + G_t + G_r - 20\log\left(\frac{4\pi d_0 f}{c}\right) - 10\rho\log\left(\frac{d}{d_0}\right) \\ &- X_\sigma - C_f - C_h - L = \text{SNR}_{r,\min} + N \\ \Rightarrow &10\rho\log\left(\frac{d}{d_0}\right) = P_t + G_t + G_r - 20\log\left(\frac{4\pi d_0 f}{c}\right) \\ &\qquad - X_\sigma - C_f - C_h - L \\ &\qquad - \text{SNR}_{r,\min} - N. \end{aligned} \tag{11}$$

Solving equation (11) for maximum transmission distance d denoted as $d_{\max}$, then we obtain

$$\begin{aligned} d_{\max} = d_0 \times 10\exp\Bigg\{\Bigg[&P_t + G_t + G_r - 20\log\left(\frac{4\pi d_0 f}{c}\right) \\ &- X_\sigma - C_f - C_h - L - \text{SNR}_{r,\min} - N\Bigg]/10\rho\Bigg\}. \end{aligned} \tag{12}$$

The BS needs a necessarily received minimum power or sensitivity $P_{r,\min}$ from each SS. In the following, for instance, we apply 64QAM modulation scheme to compare the relationships of the transmission power, the transmissive maximum distance, frequency, and $\text{SNR}_{r,\min}$, respectively. Fig. 2 shows the comparisons of the transmission power with the transmissive maximum distance in detail. We can see that the required transmission power is proportionally increasing with the maximum transmission distance. Meanwhile, a lower

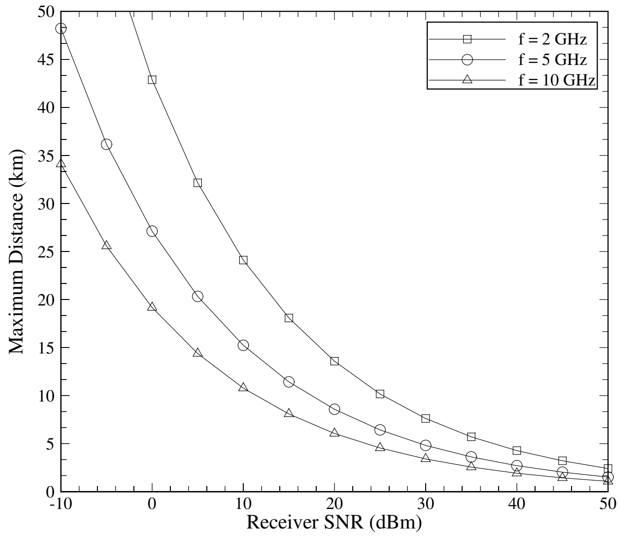

Fig. 4. Maximum distance versus receiver SNR when ρ = 4, B = 20 MHz, coding rate = 3/4, F = 7, G_t = 15, G_r = 18, P_t = 15 W, L = 5 dB.

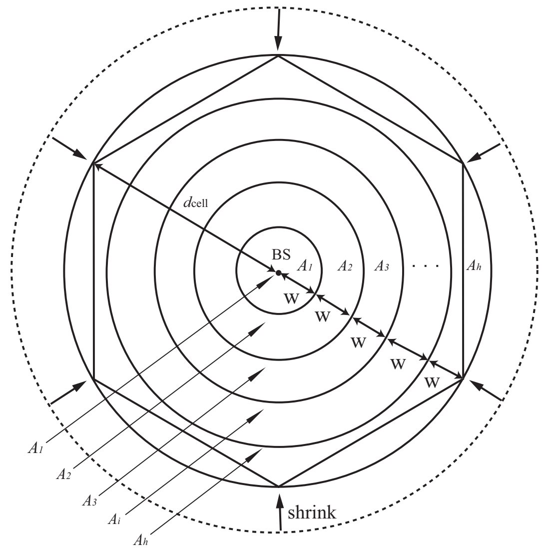

Fig. 5. An illustration of single macrocell coverage.

frequency, 2 GHz in this example, will get lower power consumption than of higher frequencies.

Fig. 3 compares the maximum transmission distance with different frequencies under different ρ when applying fixed transmission power and antenna gain. We can see that higher frequencies will lead to shorter transmission distances and vice versa. We also note that higher ρ will lead to the lower transmissive maximum distance. Fig. 4 shows the comparison of maximum distance with $\text{SNR}_{r,\min}$ of the BS. When vary the $\text{SNR}_{r,\min}$ of the receiver, the achievable maximum transmission distance will proportionally decrease with increasing the required $\text{SNR}_{r,\min}$.

A. Channel Provisioning

Assume k independent discrete spectrum sections are available in a marcocell and are represented as $S_1, S_2, \ldots, S_k$. The total available bandwidth of these spectra will be $S = S_1 + S_2 + \ldots + S_k = \sum_{i=1}^{k} S_i$. If each channel has bandwidth B, the available number of channels in each spectrum section is given by

$$N_i = \left\lfloor \frac{S_i}{B} \right\rfloor, \; i \in \{1, 2, \ldots, k\}. \tag{13}$$

Thus, we have a total number of $N = \sum_{i=1}^{k} N_i$ available channels for allocation.

Assume a number of SSs M are randomly distributed in a macrocell of the RAN, which is shown in Fig. 5. Before assigning channels to the macrocell, we have to determine how to allocate an efficient number of channels for utilization according to the fraction of related measure of area so that each area has enough number of channels for use. Assume the macrocell can be divided into h concentric circles and the width of each sections is w as shown in Fig. 5. Then the area of the i-th concentric circle D_i can be calculated as $(iw)^2\pi$. Thus the area of the i-th section denoted as A_i is given by

$$\begin{aligned} A_i &= D_i - D_{i-1} \\ &= (iw)^2\pi - [(i-1)w]^2\pi \\ &= (iw)^2\pi - \sum_{j=1}^{i-1} A_j \\ &= (2i-1)\pi w^2. \end{aligned} \tag{14}$$

For example, the area of $A_2 = (2 \times 2 - 1)\pi w^2 = 3\pi w^2$ and $A_3 = 5\pi w^2$.

From equation (14), we conclude that $A_i = (2i-1)A_1$. Since these SSs are randomly and normally distributed in the macrocell, the channel allocation can follow the ratio of A_i to A_1 and the number of channels in each A_i is denoted as $C_i = (2i-1)C_1$. According to the characteristic of transmission distance increasing proportionally with decreasing frequency, we allocate available channels in accordance with highest to lowest frequency channels from the inner to the outer side of the macrocell. Then we have $C_1, C_2, \ldots, C_h$ and $C_2 = 3C_1$, $C_3 = 5C_1$ and so forth as shown in Fig. 6. However, SSs in the outer side of the macrocell will interfere with or interrupt other SSs in the outer side of neighboring macrocell if we allocate same frequencies in the A_h. To tackle this problem, we reserve three quanta of C_h to allocate to different neighboring macrocells so that neighboring A_h will have different frequencies for transmission as shown in Fig. 7. Deducting the contention channel ($C_0 = 1$) from N, the allocated channels satisfy

$$C_1 + C_2 + \ldots + C_{h-1} + 3C_h \leq N - 1 \tag{15}$$

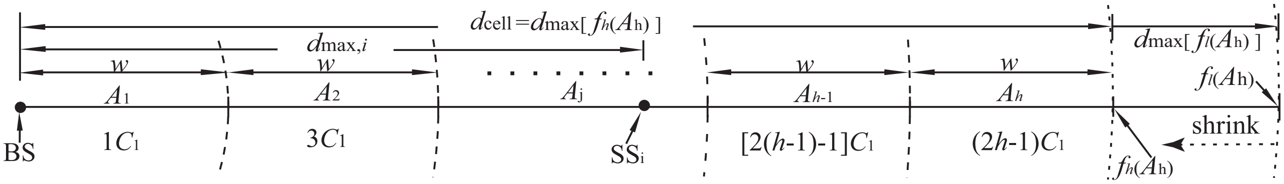

Fig. 6. An illustration of channel arrangement within the macrocell. The channel allocation is from highest frequency to lowest frequency and is started from the inner side of the marcocell (the left side of the figure).

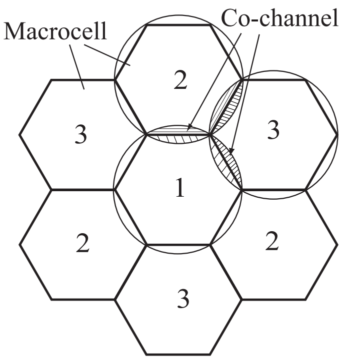

Fig. 7. The demonstration of a super macrocell arrangement. The number of each macrocell is denoted as a different identification of C_h, which is reserved to avoid interference and co-channel effect with each other.

To solve equation (15) for h, we have

$$\begin{aligned}
&\sum_{i=1}^{h} C_i + 2C_h = \Big\{\sum_{i=1}^{h}(2i-1) + 2(2h-1)\Big\}C_1 \le N-1 \\
&\Rightarrow \Big\{\frac{[1+(2h-1)]h}{2} + 2(2h-1)\Big\}C_1 \le N-1 \\
&\Rightarrow (h^2+4h-2)C_1 \le N-1 \\
&\Rightarrow h \le \sqrt{\frac{N-1}{C_1}+6} - 2, \qquad (16)
\end{aligned}$$

and the upper bound of h is equal to

$$h = \left\lfloor \sqrt{\frac{N-1}{C_1}+6} - 2 \right\rfloor. \qquad (17)$$

Now we have to determine the radius of a macrocell denoted as d_{cell}. The channels of the boundary area A_h are ranging from $\sum_{i=1}^{h-1} C_i C_1$ to $\sum_{i=1}^{h} C_i C_1$ (or from $(h-1)^2 C_1$ to $h^2 C_1$) if the channel allocation is started from the inner side of the macrocell. The highest frequency of A_h, denoted as $f_h(A_h)$, is equal to

$$f_h(A_h) = f_{\text{high}} - [(h-1)^2 C_1 + 1]B, \qquad (18)$$

where f_{high} is the highest available frequency of the system as shown in Fig. 6. According to equation (12), the boundary of the macrocell d_{cell} will be

$$\begin{aligned}
d_{\text{cell}} = d_0 \times 10 \exp\Bigg\{\bigg[&P_t + G_t + G_r \\
&- 20\log\left[\frac{4\pi d_0\big(f_{\text{high}} - ((h-1)^2 C_1 + 1)B\big)}{c}\right] \\
&- X_\sigma - C_f - C_h - L - \text{SNR}_{r,\min} - N\bigg]/10\rho\Bigg\}.
\end{aligned} \qquad (19)$$

According to equation (19), the width of each section w will be

$$w = \frac{d_{\text{cell}}}{h}. \qquad (20)$$

Assume a SS_i has a packet to transmit and the SS_i sends a RNG-REQ message to the BS with transmission power P_t. The BS receives the request message and measured $\text{SNR}_{r,\min}$ and estimates the distance $d_{\max,i}$ according to equation (12). The SS is determined to allocated in the j-th area by the following equation:

$$j = \left\lceil \frac{d_{\max,i}}{w} \right\rceil. \qquad (21)$$

From equation (21), the BS can easily allocate channel for SSs by measured SNR. This implies that the MCAS can be implemented easily and provides a more efficient way to assign an adequate channel for access.

According to Fig. 2 we defined the channel allocation rule of MCAS is form low to high frequency in the some area. In j-th area there will be $2j-1C_1$ channels between $f_{\text{high}} - [(j-1)^2 C_1 + 1]B$ to $f_{\text{high}} - (h^2 C_1)B$. BS will follow our rule to select a suitable channel to allocated the SS i. Therefore SS i may use this allocated channel including uplink and downlink to communicate with BS.

V. Simulation Model and Results

A. Simulation Model

In this section, in order to evaluated the performance of MCAS, we design a detailed simulation model as described following. We adopt IEEE 802.16a MAC protocol as the data link layer protocol and the 64QAM modulation model with 3/4 coding rate. Each channel's bandwidth is considered as 5 MHz and is operating in TDD mode. Each OFDM symbol time is evaluated a cyclic prefix of 1/4 of the useful time T_b and is chosen to deal with delay spread values for NLOS operation in suburban areas.We assume the initial BS's transmission power

TABLE I
SYSTEM PARAMETERS IN SIMULATIONS

Parameters	Value
Frame length	20 ms
Bandwidth (B)	5 MHz
F_s/B	7/6
$F_s = 7/6 \cdot 20$	5.833 MHz
(T_g/T_b)	1/4
$T_b = 256/F_s$	43.89 μs
OFDM symbol time,	
$T_{sym} = T_g + T_b$	54.86 μs
Modulation/code rate	64QAM 3/4
$Carriers N_{FFT}$	256
Bit rate	16 Mb/s
SNR$_{r,\min}$	24.4 dB
Tx antenna gain (G_t)	16 dB
Rx antenna gain (G_r)	18 dB
The system loss factor (L)	5 dB
Receiver noise figure (F)	7 dB

of the BS is 300 mW. The maximum transmission power is limited to 450 mW. Other simulations parameters can be found in Table I.

There are 1800 channels are ranged in the spectrum from 2 to 11 GHz. The size of macrocell is fixed and has a 6 km radius, which is calculated from $P_t = 300$ mW, $B = 5$ MHz, $C_1 = 1$, $f_h(A_h) = 3.39$ GHz and the path loss exponent is 4. The width of each section is 150 m. All MSSs are randomly distributed in the macrocell through all simulations. The frame arrival rate of each MSS is a constant value and is set 2 frames/second. If a MSS is allowed to entry the system, the BS also has 2 frames/second data frames for the MSS. That is, each allowed MSS will occupy total 3 Mb/s bandwidth including the uplink and downlink bandwidth. Each MAC frame, MAC protocol data units (MPDUs), consists of a 6-byte MAC header, a 32-bit cyclic redundancy check (CRC), and a fixed 1875-byte length of MAC service data unit (MSDU) and equals to 20 ms. The MAC frame consists of four initial maintenance opportunities (UIUC=2) slots, 10 request contention opps (UIUC=1) slots. The transmit to receive (T_x/R_x) transition gap (TTG) and the R_x/T_x transition gap (RTG) are both 5.14 μs.

B. Simulation Results

To compare with MCAS, a random dynamic channel allocation (RDCA) scheme is used for comparison. Fig. 8 shows the average transmission power of SSs by varying the number of SSs M in MCAS and RDCA, respectively. From Fig. 8, we can see that the RDCA consumes higher transmission power than of our proposed MCAS. This is because that MCAS allocates appropriate channels for SSs according to their geographic locations in the macrocell, that is, MCAS considers the property of radio propagation and chooses an adequate channel for SS so that the total battery consumption will be minimized. On the other hand, the RDCA adopts random fashion to allocate channel for SSs and may choose a higher frequency for the SS. This misarrangement will lead to the SS to use a higher power to communicate with the BS.

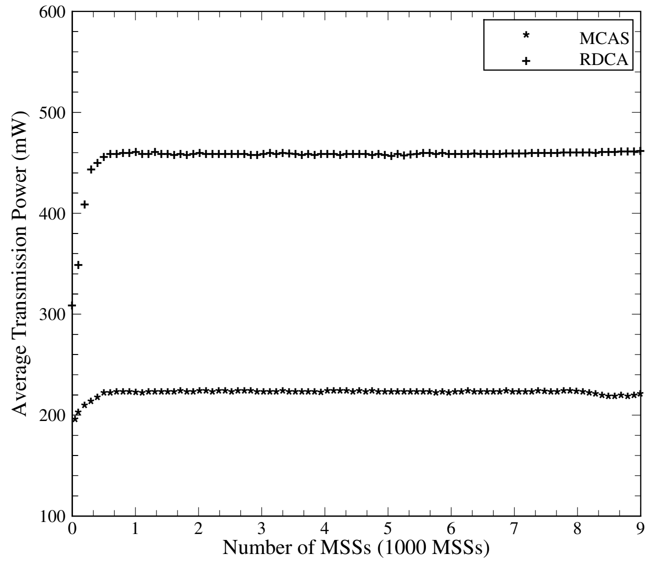

Fig. 8. The average transmission power versus the number of SSs (M) when ρ = 4, B = 5 MHz, coding rate = 3/4, SNR$_{r,\min}$ = 24.4 dB, F = 7, G_t = 16 dB, G_r = 18 dB, L = 5 dB.

We also note that the curve of MCAS is increased proportionally with increasing M. However, the curve decreases when $M = 8300$ since the channel is saturated and the reserved channel (lower frequencies) will be used to allocate. Thus the average power consumption will degrade. As a matter of fact, the MCAS is even higher in saving power than the RDCA by 47.83%.

Fig. 9 shows the throughput in each channel by using MCAS and RDCA, respectively. We can see that both the throughput of the MCAS and RDCA increase with increasing the number of SSs. The throughput of MCAS reaches 15 Mb/s per channel (approximate $15/16.9 \times 100\% = 89\%$ throughput deducting the physical and MAC header) when $M = 9000$. Therefore, each SS in the macrocell will be equally distributed and then get the higher throughput. Nevertheless, the RDCA only reaches 6 Mb/s per channel throughput when $M = 4000$, since it does not allocate channels according to positions. This will lead to higher call blocking ratio due to the limitation of maximum transmission power and may allocate many SSs in one channel.

VI. CONCLUSION

In this paper, we propose a novel macrocell channel allocation scheme (MCAS) to improve the channel utilization as well as to reduce the probability of out-of-service for the IEEE 802.16 networks. The relationship between the signal-to-noise ratio (SNR) by different modulation schemes and the maximum transmission distance is also introduced in this paper. According to received SNR value from the SS, the BS can determine an adequate channel for allocation so that the channel is used more efficiently. Moreover, by adopting the MCAS, the power consumptions of the BS and SSs are saved further since it allocates adequate channels for

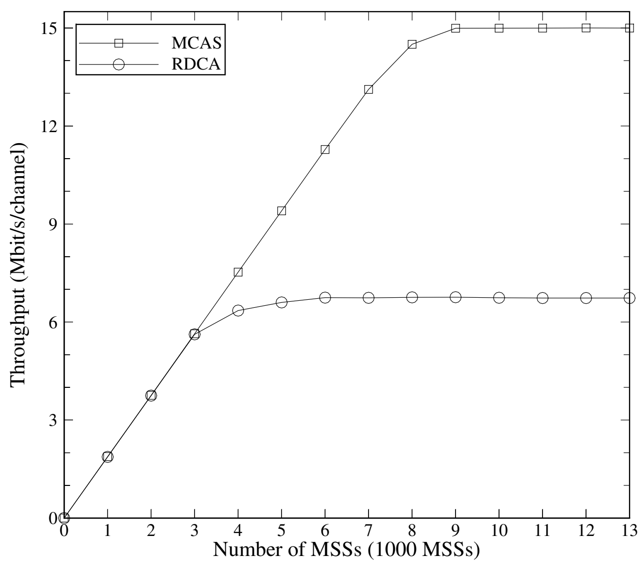

Fig. 9. The comparison of throughput versus number of SSs.

SSs by considering the corresponding geographic locations. Simulation results show that the average transmission power can be saving power up to 47.83% over the original IEEE 802.16 standard specifications. Without a doubt, the MCAS is suitable for channel allocation in IEEE 802.16 networks. This result encourages us to apply this mechanism to increasing the capacity of the BWA system.

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