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LETTER

Geographic Channel Assignment Framework for Broadband Wireless Access Networks*

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SUMMARY This letter proposes a novel geographic channel assignment (GCA) framework for dynamic channel allocation (DCA) in broadband wireless access networks (BWANs). The proposed GCA scheme is based on the characteristics of radio propagation, which focuses on the relationship between transmission distances and communication parameters, e.g., signal-to-noise ratio (SNR) etc., and uses a signal-aware distance estimation scheme to determinate an appropriate channel for communication. This method significantly increases the capacity of the BWA system. Simulation results show that the GCA framework can yield approximate two times throughput of the IEEE 802.16 standard specifications as well as obtain significantly lower call blocking probability compared with classical channel assignment methods.
key words: *broadband, DCA, MAC, spectrum, wireless*

1. Introduction

Radio spectrum is an open, unique, and ubiquitous natural resource shared by various types of services [6]. Unlike other natural resources, it can be repeatedly reused. The IEEE 802.16 [7] and 802.16a [8] wireless metropolitan area network (WMAN) standards (also known as WiMAX), ranging from 2–66 GHz, have maximum transmission distance around 36–48 kilometers and maximum data rate up to 120 Mbps. It provides a framework of the broadband wireless access (BWA) backbone network based on various base stations (BSs). With the characteristics of radio propagation, a longer distance will cause a fading signal and losing path conspicuously [11]. This effect will lead to the signal arriving the BS from the subscriber station (SS) with higher frequency to take a shorter distance than that of lower frequencies [2].

It is important to plan the basic access cell of the BWA system with the above mentioned characteristics. Therefore, considering the communication parameters such as the signal-to-noise ratio (SNR), the distance between the SS and the BS, and the transmission power, we propose a new geographical channel assignment (GCA) framework for spatial frequency reuse and cochannel interference management in the BWA networks (BWANs). Each cell can be organized as a new *macrocell* and divided by several small *microcells*. Based on the new designed framework, the capacity of the BWA system can be improved further as well as reduced the blocking probability of each call even in highly competing circumstance.

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2. Distances versus Frequencies

The power received from a transmitter at separation distance d will directly impact the received SNR. The desired signal level is represented in received power P_r in milliwatt (mW) and is given by

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

where P_t is the transmitted power, G_t and G_r are the transmitter and receiver antenna gains, 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 [9]. 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, P_r can be represented in dBm units as

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

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 (T-R). On unobstructed LOS path between T-R, PL(d) can be evaluated as $(4\pi)^2 d^2/\lambda^2$ or when powers are measured in dBm units as $92.4 + 20\log(f) + 20\log(d)$. We can get the desired T-R separation distance in meters

$$d = \frac{\lambda}{4\pi}\sqrt{\text{PL}(d)} = \frac{c}{4\pi f}\sqrt{\text{PL}(d)}. \tag{3}$$

However, in street canyon scenario or urban environment, the PL model can be demonstrated through measurements using parameter σ to denote the rule between distance and received power [1] and be expressed as

$$\mathrm{PL}(d) = \mathrm{PL}(d_0) + 10\rho \log\left(\frac{d}{d_0}\right) + X_\sigma + C_f + C_H, \quad (4)$$

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 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 in dB) that reflects the variation in an average received power, which naturally occurs when PL model of this type is used [4]. The ρ is the path loss exponent, where $\rho = 2$ for free space, and is generally higher for wireless channels. It can be measured as $\rho = (a - bH_b + c/H_b)$, where a, b and c are constants for each terrain category. The numerical values for these constants is studied in [5] where H_b is the height of the base station and is $10\,\mathrm{m} \le H_b \le 80\,\mathrm{m}$. The term C_f is the frequency correction factor, accounts for a change in diffraction loss for different frequencies which a simple frequency dependent correction factor C_f due to the diffraction loss, and measured by $C_f = 6 \log(f/1900)$ [3]. The C_H is the receiver antenna height correction factor and H is the receiver antenna height. The $C_H = -10.7 \log(H/2)$ when $2\,\mathrm{m} \le H \le 8$ m. This correction factor closely matches the Hata-Okumura mobile antenna height correction factor for a large city [6].

As we know that the audio or video quality of a receiver is directly related to the SNR. The limiting factor on a wireless link is the SNR required by the receiver for useful reception

$$\mathrm{SNR}\,[\mathrm{dB}] = P_r\,[\mathrm{dBm}] - N_0\,[\mathrm{dBm}], \quad (5)$$

where N_0 [dBm] is the noise power in dBm. Assuming 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

$$\mathrm{SNR}\,(\mathrm{dB}) = 10 \log\left(\frac{P_r}{N_0} \cdot \frac{r_b}{B}\right) - G_c, \quad (6)$$

where $N_0\,(\mathrm{dBm}) = -174\,(\mathrm{dBm}) + 10 \log B + F\,(\mathrm{dB})$. To obtain a criterion measurement of the received SNR, we force each SS to use the lowest frequency to contend the channel with a pre-defined transmission power. The BS, after receiving a RNG-REQ message from the SS, calculates the estimated distance between BS and SS according to the received SNR. Assume the BS needs a minimum receiving power or sensitivity $P_{r,\min}$, which corresponds to a minimum required SNR denoted as $\mathrm{SNR}_{\min}$, from each SS to successfully receive the signal. According to (2) and (5), we have

$$\begin{aligned} \mathrm{SNR}_{\min} &= P_{r,\min} - N_0 \\ &= P_t + G_t + G_r - \mathrm{PL}(d) - L - N_0. \end{aligned} \quad (7)$$

Substituting (4) into (7) leads to

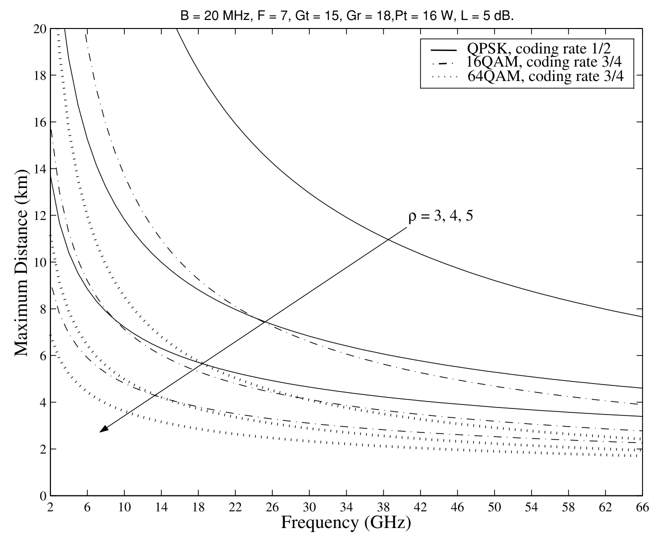

Fig. 1 Maximum transmission distance vs. frequency domains from 2 to 66 GHz in OFDM with different modulation schemes.

$$\begin{aligned} \mathrm{SNR}_{\min} = {} & P_t + G_t + G_r - 20 \log\left(\frac{4\pi d_0 f}{c}\right) - 10\rho \log\left(\frac{d}{d_0}\right) \\ & - X_\sigma - C_f - C_H - L - N_0. \end{aligned} \quad (8)$$

Solving (8) for maximum transmission distance d denoted as $d_{\max}$, then we obtain

$$\begin{aligned} d_{\max} = d_0 \times 10 \exp\Bigg\{ \Bigg[& P_t + G_t + G_r - 20 \log\left(\frac{4\pi d_0 f}{c}\right) \\ & - X_\sigma - C_f - C_H - L - \mathrm{SNR}_{\min} - N_0 \Bigg] / 10\rho \Bigg\}. \end{aligned} \quad (9)$$

Figure 1, derived from (9), shows the relation of the frequency and the distance between two isotropic antennas with different modulation schemes when QPSK, $\mathrm{SNR}_{\min} = 9.4$ dB; 16-QAM, $\mathrm{SNR}_{\min} = 18.2$ dB; 64-QAM, $\mathrm{SNR}_{\min} = 22.4$ dB, and ρ in detail.

3. The GCA Framework

We consider the channel reuse of BWANs to improve the system capacity. The GCA framework is composed of many hexagonal macrocells and each macrocell is divided into six equal parts denoted as $A_0, A_1, \ldots, A_5$ and h concentric hexagonal cells with equal width w inside. Each sector in part A_i denoted as A_{ij} where $i \in \{0, 1, \ldots, 5\}$ and $j \in \{0, 1, \ldots, h-1\}$ is divided by several regular triangles called microcells. Figure 2 shows an example of four-level concentric hexagonal macrocell of the GCA framework. Assuming the range of available spectrum is S and every channel has equal bandwidth B. Thus, there will be $N_C = S/B$ number of channels for usage in a macrocell.

In a wireless environment, the channel usage of neighboring nodes may interfere with each other as they use the same channel (frequency) and can hear with each other. This

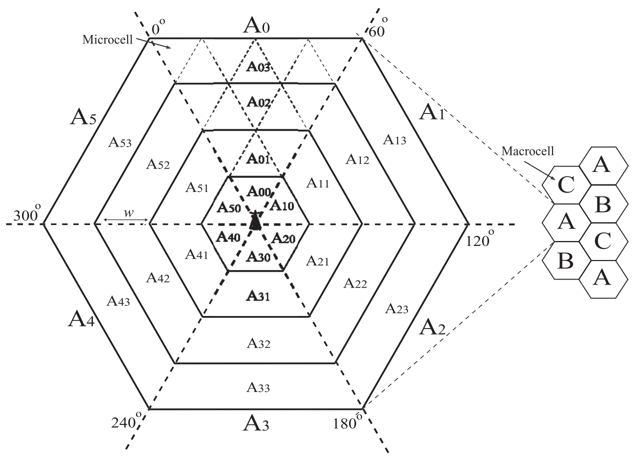

Fig. 2 An example of four-level GCA framework.

problem can be considered in two cases: the intracell and intercell interferences. In the former case, we consider that a macrocell is operated by a BS and under consideration with 6 directional antennas (from 0° to 360° divided by 60°). For channel reusing, we allocate double the same channels in a macrocell. Areas $\{A_0, A_1, A_2\}$ and $\{A_3, A_4, A_5\}$ use same channels. Channels allocated in area A_i are denoted as C_i where $C_0 = C_3$, $C_1 = C_4$, $C_2 = C_5$, and $C_0 \neq C_1 \neq C_2$. The number of channels in C_0 is represented as $|C_0|$ and we have

$$|C_0| + |C_1| + |C_2| + |C_x| + 3 = N_C \tag{10}$$

where C_x represents the isolated channels for neighboring macrocells and 3 is for number of control channels.

According to the division of sections, we have $|A_{ij}| = (2j+1)|A_{00}|$ where $|A_{00}|$ represents the area of a basic microcell. Assuming SSs are randomly distributed in the macrocell, then the channel allocation can follow the ratio of $|A_{ij}|/|A_{00}|$ accordingly. Based on the characteristic of carried frequency to transmission distance, we allocate available channels according to the ratio of areas and the highest to lowest frequencies from the inner to outer side of the macrocell. Hence, the number of channels in A_{ij} denoted as $|C_{ij}|$ will be $(2j + 1)|C_{00}|$ and $|C_i| = \sum_{j=0}^{h-1} |C_{ij}|, \forall\, i = \{0, \ldots, 5\}$.

Rewrite (10), we have

$$3|C_0| = N_C - |C_x| - 3. \tag{11}$$

Replacing $|C_0|$ with $\sum_{j=0}^{h-1} |C_{ij}|$ in (11), we get

$$\sum_{j=0}^{h-1} |C_{ij}| = \frac{N_C - |C_x| - 3}{3}. \tag{12}$$

Solving (12) for h, we have

$$|C_{00}| + 3|C_{00}| + \ldots + (2h-1)|C_{00}| = \frac{N_C - |C_x| - 3}{3}. \tag{13}$$

Substituting $|C_x| = \sum_{i=0}^{2} |C_{i(h-1)}| = 3(2h - 1)|C_{00}|$ for (13) will be

$$(h + 1)^2 = \frac{N_C - 3}{3|C_{00}|} + 2. \tag{14}$$

Since h is an integer, then we use the floor function

$$h = \left\lfloor \sqrt{\frac{N_C - 3}{3|C_{00}|} + 2} - 1 \right\rfloor. \tag{15}$$

As we discussed earlier, a lower frequency can achieve a longer distance. We use the highest frequency allocated in $A_{i(h-1)}$ denoted as $f^*_{i(h-1)}$ to determine the macrocell's boundary denoted as d_{cell}. We note that the lowest frequency channel's transmission distance is not used to be the boundary of the macrocell because we have to ensure all frequencies allocated in the section that can be operated well. The highest frequency channel of $A_{i(h-1)}$ is equal to $\mathcal{F}_\text{H} - \left[3(h-1)^2|C_{00}| + 1\right]B$, where $\mathcal{F}_\text{H}$ is the highest frequency of the system. According to (9), the d_{cell} can be obtained by

$$\begin{aligned} d_{\text{cell}} = d_0 \times 10 \exp\Bigg\{ \Bigg[& P_t + G_t + G_r \\ & - 20 \log \left[\frac{4\pi d_0 \left(\mathcal{F}_\text{H} - (3(h-1)^2|C_{00}| + 1)B \right)}{c} \right] \\ & - X_\sigma - C_f - C_H - L - \text{SNR}_{r,\min} - N_0 \Bigg] / 10\rho \Bigg\}. \end{aligned} \tag{16}$$

4. Comparison and Discussions

To compare with GCA, the random channel allocation (RCA) scheme [7] and measured channel allocation (MCA) scheme [10] are simulated. The spectrum of the WiMAX is considered as 2.5–2.725 GHz. There are totally 45 channels divided by $B = 5$ MHz for bandwidth allocation where $P_t = 300$ mW, $|C_{00}| = 1$, $|C_x| = 15$, $f^*_{i(h-1)} = 2.66$ GHz, $h = 3$, $G_t = 16$, $G_r = 18$, $\rho = 4$, $L = 0$, and the size of macrocell is 6855 meters long. Each simulation runs least over 100,000 frame time (2000 seconds), and each data point represents an average of at least one hundred runs with identical traffic models, but in different randomly generated scenarios. The bandwidth of each channel is 15.75 Mbps, and the frame arrival rate of each SS follows the Poisson distribution with a mean Λ, which consists of a upload $\lambda_u = 50$ frames/sec (0.75 Mbps) and a download $\lambda_d = 50$ frames/sec. Each frame length is an exponential distribution with a mean of 1885 bytes ($\approx$ 20 ms). The maximum transmission power $P_{t,\max}$ of the SS is limited to 300 mW. If the required power exceeds $P_{t,\max}$ in the allocated frequency, the SS will not reach the BS and lead to call blocking.

Figure 3 shows the throughput (Mbps per channel) by using GCA, MCA, and RCA. As shown in the figure, the maximum throughput of GCA reaches 23.7 Mbps per channel (approximately 23.7/15.75 = 150.48% channel utilization deducting the physical and MAC headers) when M reaches 700. The reason why GCA outperforms MCA and RCA is that GCA considers the spatial reusing way by dividing a macrocell into two opposite areas $\{A_0, A_1, A_2\}$ and

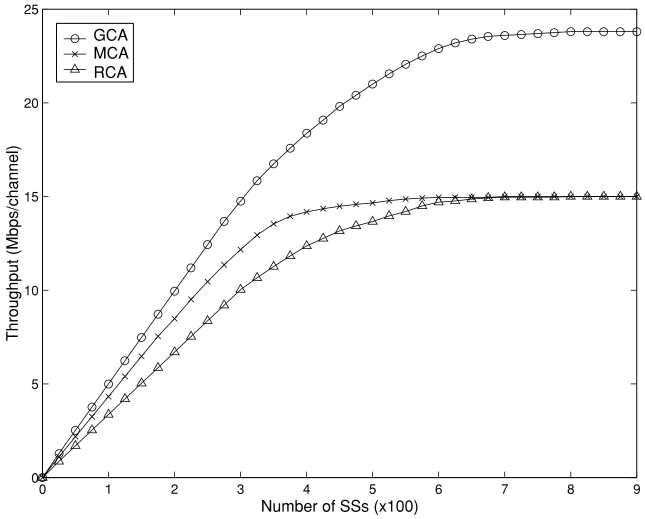

Fig. 3 The comparison of channel throughput derived by GCA, MCA, and RCA under different M.

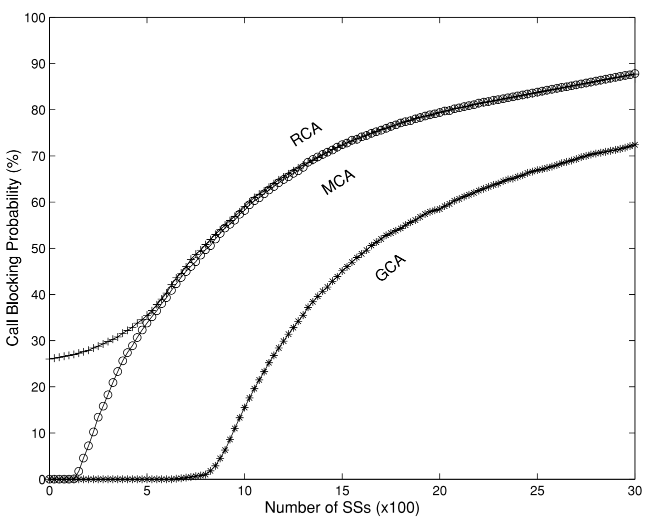

Fig. 4 Call blocking probability vs. M.

$\{A_3, A_4, A_5\}$, and it allocates the same frequencies of channels (channel reuse) in the two areas. As a result, GCA will accommodate more SSs and thus get more throughput as the number of SSs increases. On the contrary, MCA and RCA only reach their maximum throughput at 15 Mbps due to their lack of channel reuse. In addition, GCA still outperforms MCA as $M \leq 350$ (smaller number of SSs) due to the effect of the appropriate channel allocation strategy in accordance with the relationship between the achievable distances and its corresponding operating frequencies. This scheme will avoid misarranging SSs into inadequate channels and thus get higher throughput.

In the second experiment, we investigate the call blocking probability (CBP) of the system. The CBP is defined as the average number of blocked new calls over the number of total calls. To begin with, Fig. 4 shows that RCA gets higher CBP than MCA and GCA since it uses the random channel allocation scheme. On the contrary, GCA achieves zero CBP when $M \leq 650$ due to the appropriate channel allocation scheme and channel reusing mechanism. Please note that MCA obtains zero CBP as well as GCA when $M \leq 180$ since there are enough number of channels for allocation. However, when M is increasing, the effect of signal-aware distance estimation scheme is revealed that GCA will appropriately allocate channels for SSs so that it will lead to lower CBP than other schemes. This result also explains why GCA obtains higher throughput than MCA and RCA when M increases as shown in Fig. 3.

5. Conclusions

In this paper, we presented the relationship between the maximum transmission distance and the corresponding frequency it carries. A novel geographic channel assignment (GCA) framework is proposed to improve the system capacity of BWANs. The GCA framework divides the macrocell into several microcells and assigns appropriate frequencies for channel allocation. Simulation results show that GCA increases the throughput of the BWA system as well as lowers the CBP of SSs efficiently even in highly competitive circumstance. Moreover, by considering the mobility of SSs, the GCA framework can be investigated further for supporting handover among macrocells.

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