Research on Capacity Calculation of TD-CDMA High Altitude Platform System

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***Abstract* - A capacity calculation method of high altitude platform (HAP) system in which TD-CDMA multiple access schemes are applied is proposed. With the influence of both power limit and bandwidth limit on capacity integrated, the paper derives the equations by which the capacity of TD-CDMA systems can be calculated, and performs calculation on a real system. This calculation method is quite simple and effective with a comparatively small error, which is essential to the designing and research on HAPS.**

I. INTRODUCTION

In the passed years, stratosphere communication system which uses High Altitude Platforms (HAP) to provide communication facilities has been viewed as a novel approach of wireless communication. Building a series of relatively stable wireless communication platforms, HAPs can support a diversity of service with multiple users and aims. Compared with satellite communication, HAP system has a shorter round-trip time delay, and the free space loss is obviously much lower, which are quite favorable in the miniaturization of broad band mobile terminals, and also in the implementation of time division duplex access. Furthermore, HAP system has longer transmission distance and larger coverage than land cellular system, with less severer channel fading condition, which can greatly decrease the costs for ground infrastructure, and the radiation contamination in the neighborhood of base station [1]. With the unique flexibility, HAPs can be applied in some emergencies where rapid deployment is needed, such as rescues, disasters and military operations. Meanwhile, as a promising communication approach, HAPs can also work as a complement to current satellite systems and cellular systems in the third generation communication system [2].

At the present time, the research on HAP is still in the testing phase. Considering the similarities lying in channel division and link budget between HAP system and satellite system, many hybrid multiple access technologies in satellite communication network are also adopted in HAP system. The application of hybrid multiple access fully utilizes system resources and increases the number of available channels, while brings more complexity to the system capacity estimation. This paper derives a capacity calculation method of HAP system under TD-CDMA scheme, which integrates influences caused by both bandwidth limit and power limit. Using this method, the designer of HAP can figure out the system capacity rapidly and effectively with known key parameters, in order to make necessary adjustments and modifications, and to give estimation about the overall performance of the system [3]. That is of great significance to the studies on TD-CDMA systems, and can also help in capacity estimation work for systems which apply other multiple access schemes.

The remaining sections of the paper are organized as follows: Section 1 deduces the capacity calculation equations for TD-CDMA HAP system only when the bandwidth is limited, Section 2 takes power limit into account and presents the complete system capacity calculation method influenced by both power limit and bandwidth limit, Section 3 applies the equations in a practical system, Section 4 concludes the paper and highlights the advantages of this method that merit attention in the future development of HAP.

II. CAPACITY CALCULATION OF BAND LIMIT SYSTEM

The TD-CDMA access scheme actually enlarges the system capacity on the base of CDMA. There are multiple quasi-orthogonal CDMA carriers which are used at the same frequency, but the access time can be further divided into frames and time slots, as illustrated in Figure 1. Therefore, the TD-CDMA scheme could be viewed as a special CDMA scheme with time division when the system capacity calculation is being done, and total number of channels under the bandwidth limit condition can be figured out by multiplying CDMA carriers and TDMA channels.

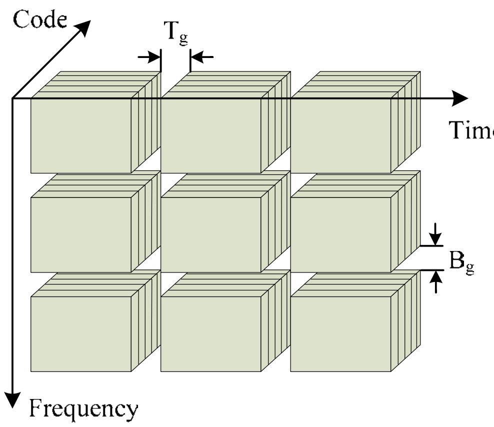

Fig. 1 Channel division of the TD-CDMA scheme.

Key parameters of TD-CDMA HAP system involved in this section are as follows: the bit data rate of a voice signal per channel R_b, the chip rate of spread spectrum code in CDMA R_c, processing gain G, the frame duration T_f, a guard

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time of T_g, the number of bits per time slot n, and bits of frame header F.

To find the number of channels in TD-CDMA system, we first start with the influence of time division. In a common TDMA system, if the bit data rate of a single TDMA carrier is R_c, then the number of half duplex channels in a TDMA frame with a header of F bits is

$$N_{\text{hd}} = \frac{R_c T_f - F}{n + R_c T_g} \tag{1}$$

The number of full duplex channels is

$$N = N_{\text{hd}} / 2 = \frac{1}{2} \frac{R_c T_f - F}{n + R_c T_g} \tag{2}$$

Considering the processing gain in a TD-CDMA system, $R_c = GR_b$. Then (2) becomes

$$N_{\text{TDMA}} = \frac{1}{2} \frac{GR_b T_f - F}{n + GR_b T_g} \tag{3}$$

The equation above gives the number of channels that each CDMA carrier can support simultaneously when the access time is divided into slots.

The capacity of a CDMA system mainly depends on the interference from other channels. According to the typical capacity calculation method of CDMA cellular communication system [9], if there are N users using the same frequency in a CDMA system, then the mean value of the power spectral density of the total inference from other channels without power control, $\overline{I_i}$, is

$$\overline{I_i} = \alpha (N-1) \frac{E_b}{G} \tag{4}$$

Where α denotes the voice activity factor, representing the expected voice activity state of the channel. Then the mean total noise power spectral density is sum of the inference noise and the thermal noise,

$$I_{\text{tot}} = \overline{I_i} + N_0 = \alpha (N-1) \frac{E_b}{G} + N_0 \tag{5}$$

Then the number of CDMA channels can be calculated by

$$N = 1 + \frac{G}{\alpha} \left[\left(\frac{E_b}{I_{\text{tot}}} \right)^{-1} - \left(\frac{E_b}{N_0} \right)^{-1} \right] \tag{6}$$

Because of the quasi-orthogonality between CDMA codes, every single CDMA carrier ocupies the whole bandwidth of a transponder, B_T, therefore

$$G = \frac{B_T}{R_b} \tag{7}$$

Combining (6) and (7), we obtain the maximum value of channels which can be supported at the same frequency:

$$N = 1 + \frac{B_T}{R_b} \frac{1}{\alpha} \left[\left(\frac{E_b}{I_{\text{tot}}} \right)^{-1} - \left(\frac{E_b}{N_0} \right)^{-1} \right] \tag{8}$$

In MF-CDMA scheme, the whole bandwidth is further divided into multiple sub-frequencies. Therefore, the total bandwidth required to support T CDMA carriers can be denoted as

$$B_{HAP} = T(GR_b + B_g) \tag{9}$$

The total number of CDMA channels in a bandwidth of B can be obtained by adopting (8) and (9):

$$N_B = TN = T + \frac{B_{HAP} - TB_g}{R_b} \frac{1}{\alpha} \left[\left(\frac{E_b}{I_{\text{tot}}} \right)^{-1} - \left(\frac{E_b}{N_0} \right)^{-1} \right] \tag{10}$$

An HAP system typically concentrates its transmission power in multiple spot beams. The usage of spot beams improves bandwidth efficiency by reusing frequency bands and bringing space isolation between spot beams. In a multiple spot beam system, the users are interfered not only by channels in the same cell, but also by users from other cells. Therefore the total inference is the sum of both:

$$\overline{I_i'} = I_{\text{own}} + I_{\text{other}} \tag{11}$$

Due to the complexity of calculation about inference caused by other cells, we introduce the inference factor f here to indicate the relation between inference inside and outside the cell:

$$f = \frac{I_{\text{other}}}{I_{\text{own}}} \tag{12}$$

Then (4) can be written as

$$\overline{I_i'} = \alpha (1+f)(N-1) \frac{E_b}{G} \tag{13}$$

The number of CDMA channels within one spot beam of a HAP system can be obtained by the equations above:

$$N_{\text{CDMA}} = T + \frac{B_{\text{HAP}} - TB_g}{R_b} \frac{1}{\alpha(1+f)} \left[\left(\frac{E_b}{I_{\text{tot}}} \right)^{-1} - \left(\frac{E_b}{N_0} \right)^{-1} \right] \tag{14}$$

Consequently, the total number of channels supported within a single spot beam in TD-CDMA access scheme is

$$\begin{aligned} N_c &= N_{\text{CDMA}} N_{\text{TDMA}} \\ &= \frac{T}{2} \frac{GR_b T_f - F}{n + GR_b T_g} + \frac{GR_b T_f - F}{n + GR_b T_g} \frac{B_{\text{HAP}} - TB_g}{2R_b} \\ &\quad \cdot \frac{1}{\alpha(1+f)} \left[\left(\frac{E_b}{I_{\text{tot}}} \right)^{-1} - \left(\frac{E_b}{N_0} \right)^{-1} \right] \end{aligned} \tag{15}$$

The total number of channels in an HAP system using Z spot beams is

$$N_{\mathrm{HAP}} = ZN_{\mathrm{c}} \tag{16}$$

By now, the basic capacity calculation method of bandwidth limit TD-CDMA HAP systems using multiple spot beams has been obtained.

III. TD-CDMA HAP SYSTEM CAPACITY CALCULATION CONSTRAINED BY BOTH POWER LIMIT AND BANDWIDTH LIMIT

The system capacity of HAP communication network is constrained by not only the given frequency resource, but also the limited transmission power on board. Gains and losses caused by a large diversity of factors along the signal transmission path decrease the available data rate in one way or another, which leads to a shrinkage of the system capacity. In the previous discussions on system capacity, influences caused by bandwidth limit and power limit were often considered separately, while the practice always calls for an integration of both aspects. Next, we will discuss the capacity calculation of TD-CDMA HAP system when integrating factors involved with both power and bandwidth.

Similar with satellite link budget, the forward link budget equation is known as

$$\frac{C}{N_0}(\mathrm{dBHz}) = EIRP + G_{\mathrm{r}} - L_{\mathrm{tot}} - k - T_{\mathrm{S}} - margin \tag{17}$$

or

$$\frac{E_{\mathrm{b}}}{N_0}(\mathrm{dBs}^{-1}) = EIRP + G_{\mathrm{r}} - L_{\mathrm{tot}} - R_{\mathrm{b}} - k - T_{\mathrm{S}} - margin \tag{18}$$

where *EIRP* represents Effective Isotropic Radiated Power, G_{r} is the antenna gain of receiver, L_{tot} is the total link losses, T_{S} denotes noise temperature of the system, and *margin* is known as the extra budget compensating the losses caused by multipath fading and shadowing.

Assuming P_{cell} is the transmission power of a spot beam, the power of each CDMA carrier in TD-CDMA scheme is

$$P_{\mathrm{CDMA}} = \frac{P_{\mathrm{cell}}}{N_{\mathrm{c}}} \tag{19}$$

Substitute for *EIRP* in (18) with P_{CDMA} in (19), we obtain

$$\frac{E_{\mathrm{b}}}{N_0}(\mathrm{dBs}^{-1}) = \frac{P_{\mathrm{cell}}}{N_{\mathrm{c}}} + G_{\mathrm{t}} + G_{\mathrm{r}} - L_{\mathrm{tot}} - R_{\mathrm{b}} - k - T_{\mathrm{S}} - margin \tag{20}$$

or

$$\frac{E_{\mathrm{b}}}{N_0} = \frac{P_{\mathrm{cell}} G_{\mathrm{t}} G_{\mathrm{r}}}{N_{\mathrm{c}} k T_{\mathrm{S}} L_{\mathrm{tot}} R_{\mathrm{b}} \cdot margin} \tag{21}$$

Combining (15) and (21), the total number of channels in one spot beam is derived as

$$N_{\mathrm{c}} = \frac{T + \dfrac{B_{\mathrm{HAP}} - TB_{\mathrm{g}}}{R_{\mathrm{b}}} \dfrac{1}{\alpha(1+f)} \dfrac{I_{\mathrm{tot}}}{E_{\mathrm{b}}}}{\dfrac{2(n + GR_{\mathrm{b}}T_{\mathrm{g}})}{GR_{\mathrm{b}}T_{\mathrm{f}} - F} + \dfrac{B_{\mathrm{HAP}} - TB_{\mathrm{g}}}{R_{\mathrm{b}}} \dfrac{1}{\alpha(1+f)} \dfrac{kT_{\mathrm{S}}R_{\mathrm{b}}L_{\mathrm{tot}} \cdot margin}{P_{\mathrm{cell}}G_{\mathrm{t}}G_{\mathrm{r}}}} \tag{22}$$

Therefore, the number of channels that an HAP with Z spot beams will simultaneously support is

$$N_{\mathrm{HAPt}} = ZN_{\mathrm{c}} = Z \frac{T + \dfrac{B_{\mathrm{HAP}} - TB_{\mathrm{g}}}{R_{\mathrm{b}}} \dfrac{1}{\alpha(1+f)} \dfrac{I_{\mathrm{tot}}}{E_{\mathrm{b}}}}{\dfrac{2(n + GR_{\mathrm{b}}T_{\mathrm{g}})}{GR_{\mathrm{b}}T_{\mathrm{f}} - F} + \dfrac{B_{\mathrm{HAP}} - TB_{\mathrm{g}}}{R_{\mathrm{b}}} \dfrac{1}{\alpha(1+f)} \dfrac{kT_{\mathrm{S}}R_{\mathrm{b}}L_{\mathrm{tot}} \cdot margin}{P_{\mathrm{cell}}G_{\mathrm{t}}G_{\mathrm{r}}}} \tag{23}$$

Fig. 2 and Fig. 3 illustrate the relation among N_{c}, R_{b}, and P_{cell}. Here $\alpha = 0.35$, which is the typical value in practice, and the link margin is assumed to be 12dB. As indicated by the curves, when the transmission power is constant, system capacity will be reduced with the bit data rate increasing. The reduction can be explained by the consumption of bandwidth resource when the data rate increases. The curves also infer that the system capacity is more sensitive to the fluctuation of transmission power per cell when the data rate is smaller.

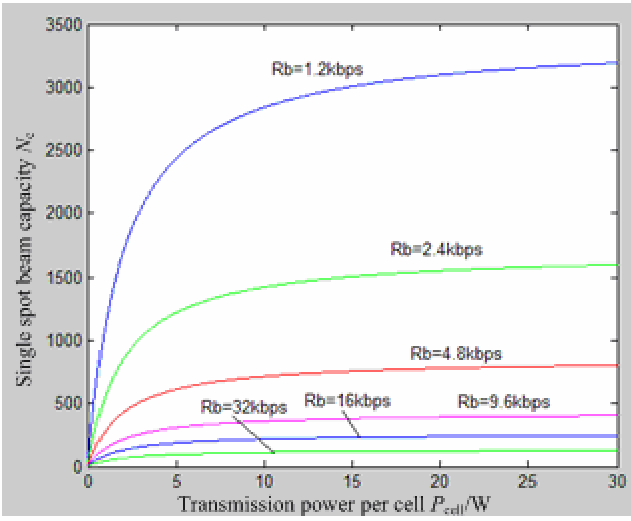

Fig. 2 Relation between system capacity and transmission power in TD-CDMA scheme.

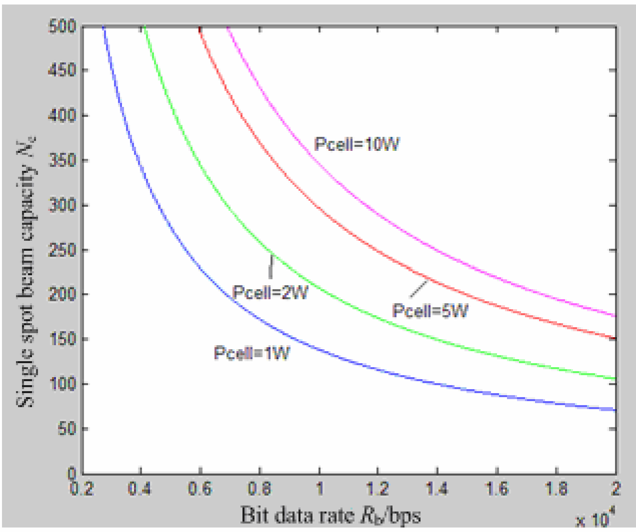

Fig. 3 Relation between system capacity and bit data rate in TD-CDMA scheme

IV. APPLICATION OVER AN EXISTING SYSTEM

Key parameters of an HAP system are shown in Table 1. The system works at the frequency of 2GHz, and the voice data rate is 1.2kbps, which becomes 6kbps after the channel coding. It adopts the TD-CDMA access scheme, the frequency bands are shared by both uplink and downlink, and the time slots are allocated according to the state of resource utility.

TABLE I
KEY PARAMETERS OF AN HAP SYSTEM

Carrier Frequency	2GHz
Total Bandwidth	3.84MHz
Bit Data Rate R_b (bps)	6000
Modulation Scheme	QPSK
Number of Time Slots per Frame	16
Frame Length (ms)	16
Time Slot Length (ms)	1
Number of Spot Beam	33
BER	10^{-5}
E_b/N_0 (dB/Hz)	9.6

TABLE II
LINK BUDGET FACTORS IN AN HAP SYSTEM

Transmitter Gain (dB)	10.4
Transmission Power per Spot Beam P_{cell} (W)	2
G/T (dB/K)	-30
Free Space Loss (dB)	125.3
Antenna Tracing Loss and Atmosphere absorption Loss (dB)	1
Noise Bandwidth (dBHz)	63
Link Margin (dB)	10
HAP Noise Temparature (K)	300

The factors used in link budget are given in Table 2. Other minority losses are ignored here. Then the total losses of the link $L_{tot} \approx 125.3 + 1 = 126.3\text{dB}$.

In order to simplify the calculation, we rewrite equation (22) as

$$N_c = \frac{1 + p\dfrac{I_{tot}}{E_b}}{q + pr} \tag{24}$$

where

$$p = \frac{B_T}{R_b}\frac{1}{\alpha(1+f)} = \frac{3.84\times10^6}{6\times10^3}\times\frac{1}{0.35\times(1+1.36)} = 774.82 \tag{25}$$

$$q = \frac{2(n + GR_bT_g)}{GR_bT_f - F} = \frac{1}{N_{TDMA}} = \frac{1}{16/2} = \frac{1}{8} \tag{26}$$

$$r = \frac{kT_sR_bL_{tot}\cdot margin}{P_{cell}G_tG_r} = \frac{1.38\times10^{-23}\times6000\times10^{12.63}\times10}{2\times10^{1.04}\times10^{-3}} \tag{27}$$

$$= 1.6121\times10^{-4}$$

Substituting the data to (24), the number of channels supported by each spot beam of the HAP system can be obtained:

$$N_c = \frac{1 + p\dfrac{I_{tot}}{E_b}}{q + pr} = \frac{1 + 774.82\times10^{-0.96}}{\dfrac{1}{8} + 774.82\times1.6121\times10^{-4}} \approx 344 \tag{28}$$

Then the total capacity of an HAP with 33 spot beams is

$$N_{HAP} = ZN_c = 33\times20 = 11352 \tag{29}$$

It should be noted that the numbers of channels supported by different cells are usually assumed same, which would not be thoroughly verified in practical system. Because the edge cell usually has different capacity with the centre one. a certain amount of error shall exist in the capacity calculation by directly multiplying single cell capacity and the number of cells.

V. CONCLUSION

This paper provides a basic capacity calculation method over HAP systems using TD-CDMA hybrid access technology. The major advantages of this method lie in its simplicity. With the key designing parameters known, the system designer can easily estimate the number of channels that a TD-CDMA system constrained by both power limit and bandwidth limit can support simultaneously by adopting equation (23). The calculation program based on this approach can be used as a tool on the level of HAP system research, and also provide a firm theory foundation for related strategies of capacity control and resource allocation. However, limited by the existing beam forming conditions, a certain discrepancy still exists in this method, which is waiting to be improved in the future of HAP study.

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