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ORIGINAL ARTICLE

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# Downlink power control in multi-code CDMA for mobile medicine

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**Abstract** In this paper, we propose a downlink power-control mechanism to be applied in a multi-code code division multiple access (CDMA) mobile medicine system. The mobile medicine system can provide (i) measured blood pressure and body temperature, (ii) medical signals measured by the electrocardiogram (ECG) device, (iii) mobile patient's history, (iv) G.729 audio signals, (v) Joint Photographic Experts Group 2000 Medical images and Moving Picture Experts Group 4 charge-coupled device sensor video signals. By utilizing a multi-code CDMA spread spectrum communication system with downlink power-control strategy, it is possible for this system to meet the quality of service requirements of a mobile medicine network. In addition, such a system can maximize the resource utilization. For different messages to be sent, the power is controlled according to the requisite bit error rate (BER). Higher transmission power is given to the media with lower BER requirement. Numerical analysis shows that the ratios of transmission power for voice, video, and data virtual channels is approximately 1:2:13 when the BERs for voice, video, and data are 10^(− 3), 10^(− 4), and 10^(− 7), respectively. This power ratio is similar to the ratio of signal-to-noise plus interference power ratio for voice, video, and data during transmission. For the purpose of verifying the proposed argument, a simulation has been done and the results match the derivation very well.

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## 1 Introduction

In a modern society, it is useful to take advantage of advanced wireless communication technologies to support and help doctors who rely on Telemedicine or Home Tele-Care Systems. Thus, the development of a mobile medicine platform has become an important issue. Murakami et al. [15] adopted the INMARSAT-B to deliver mobile medicine services for interactive medical treatments. The media that were transmitted may include a color image, an audio signal, a three-channel electrocardiogram (ECG) medical signal, and measured blood pressure, etc. Along with the rapidly developed wireless communication-transmission platform, the transmission speed has become higher and higher. In the present day, there are many platforms that can be used for mobile medicine including satellite communication systems, cellular mobile communication systems, Bluetooth systems, or wireless local area networks [2, 8, 9, 14–16, 19, 22].

A system that uses wideband code division multiple access (CDMA) technologies will be a major cellular communication system in the future. Since a CDMA system is interference-limited, less multi-channel interference can result in large system capacity. Early studies on power-control technologies for a spread spectrum communication system were mainly to eliminate the near–far effect [4, 6]. Recently, different quality of service (QoS) requirements for different media in multimedia communications has been widely studied. Dynamic power control for a CDMA communication system makes it possible for media transmission in a mobile medicine system to meet the required QoS. By using different power levels for different media, maximum resource utilization can be achieved. Power-control mechanisms for orthogonal variable spreading factor

CDMA systems for QoS control have been investigated by Wu et al. [23], Kim et al. [10], and Gurbuz et al. [7]. For maximum uplink capacity, a power-control criterion has been proposed for multi-code CDMA systems by Liu et al. [13]. But the issue of QoS was still not addressed. Moreover, equal bit error rate (BER) for all different media is considered therein. In this paper, we consider a multi-code CDMA mobile medicine system with unequal downlink BER by utilizing different power levels for different media.

A multi-code CDMA is one of the various multiple access techniques for beyond third-generation systems. One advantage of such a system is that it can easily be used to support high data rates. The number of codes can be assigned according to the requirement of data rates. In this system, the strength of transmitting power used in a virtual channel will directly affect communication quality of the system. In other words, a virtual channel with smaller transmitting power will experience larger BER. If a wireless medical communication requires high data rates and, in the mean time can tolerate higher BER for some media, then a multi-code system with unequal power is a candidate. For example, voice and video transmissions necessitate high throughput as well as real time. On the other hand, data may require less bandwidth but stringent BER. In this paper, we assume that the voice BER is limited to 10^(− 3), video BER is limited to 10^(− 4), and data BER is limited to 10^(− 7), based on the literature [8]. For this multi-code CDMA spread spectrum mobile medicine system, we discuss transmission power-control strategies among virtual channels with different requirements of transmission BER. The base station may assign different transmission-power levels to voice, video, and data to meet the requirement of different BER. With the above BER settings, the ratio of transmission power for voice, video, and data are approximately 1:2:13. This power ratio is derived based on the ratio of signal-to-noise plus interference power ratio (SNIR) for voice, video, and data during transmission. We have also verified the mathematical model via a simulation test with various medical signals.

## 2 Method

In a multi-code spread spectrum multimedia communication system, every virtual channel uses spread spectrum code with same spreading factor. For media that demand larger transmission rates, several virtual channels are used in parallel. In this way, media can be transmitted with any transmission rate. At the time of creation of medicine information, a patient uses a model to specify temporal constraints among various data objects, which must be transmitted. A model, which is called Object-Composition Petri-Net (OCPN) [21], is able to describe the temporal relationships for the various components of medicine information including type, size, throughput requirements, the duration of its presentation. This information chain can then be delivered by a communication system. In this paper, we consider a multi-code CDMA mobile medicine system as shown in Fig. 1. For practical application, one OCPN model is used to describe the measured blood pressure, body temperature, and ECG signal. The blood pressure, body temperature, and ECG signal are integrated to data bit streams. The 64-kbps microphone audio signal is compressed by G.729 to 8-kbps audio bit streams. The 600-kbps charge-coupled device (CCD) sensor video signal is compressed by Moving Picture Experts Group 4 (MPEG-4) to become a 64-kbps video bit stream. The 3,340-kbits X-ray medical image signal is compressed by Joint Photographic Experts Group 2000 (JPEG2000) to form a 128-kbits image bit stream. The image, video, audio, and data bit streams are inserted to the OCPN model. There are three kinds of channels in our multi-code CDMA mobile medicine system to transmit audio, video, and data bit streams. The channel number of whole audio, video, and data channels can be easily represented by OCPN models. In our system, the length of Walsh code $c(t)$ is 1,024 and is concatenated with a 2^(42) − 1 PN code $d(t)$ to form the spreading codes. The transmitted medical signals contain outputs of ECG detector, blood pressure, and body temperature. Patients can interact with doctors through microphones and CCD sensors of the mobile medical platform in interactive ways. For our system, each patient uses two multi-code data virtual channels to transmit medical history, blood pressure, body temperature, and ECG outputs. The transmission data rate of every virtual channel in our design is 8 kbps. A multi-code voice virtual channel is used to deliver G.729 voice signals and nine multi-code video virtual channels are used to deliver MPEG-4 CCD sensor video signals as well as JPEG2000 medical images. Our BER restriction for data channel is 10^(− 7), smaller than that of a general data channel. This is because the data is a medical message. The BER restriction for audio channel is 10^(− 3) and the BER restriction for video channel is 10^(− 4). To achieve the requirement of these QoS, we consider power-control policies for different media. Let the transmission power weightings be denoted by $\mu_a$, $\mu_v$, and $\mu_d$. Base station assigns different transmission powers to all virtual channels according to the type of the media to be transmitted, such as audio, video, and data. In the following, we will derive the relation between the transmission power and the specified requirement on the BER. Assume that there are $K$ users in our system, and the $k$th user has $N_k$ virtual channels. The transmitting signal $s_{km}$ $(t)$ of the $m$th data stream (virtual channel) belonging to the $k$th user is expressed as

$$\begin{aligned} s_{km}(t) &= \sqrt{2P_{km}} a_{km}(t) b_{km}(t) \cos(w_c t + \theta_{km}) \\ &= \sqrt{2\mu_{km} P} a_{km}(t) b_{km}(t) \cos(w_c t + \theta_{km}) \\ & \quad 1 \le m \le N_c, 1 \le k \le K, 0 < u_{km} \le 1 \end{aligned} \tag{1}$$

In Eq. 1, $u_{km}$ is the weighting factor of the $m$th virtual channel belonging to the $k$th user. This factor is

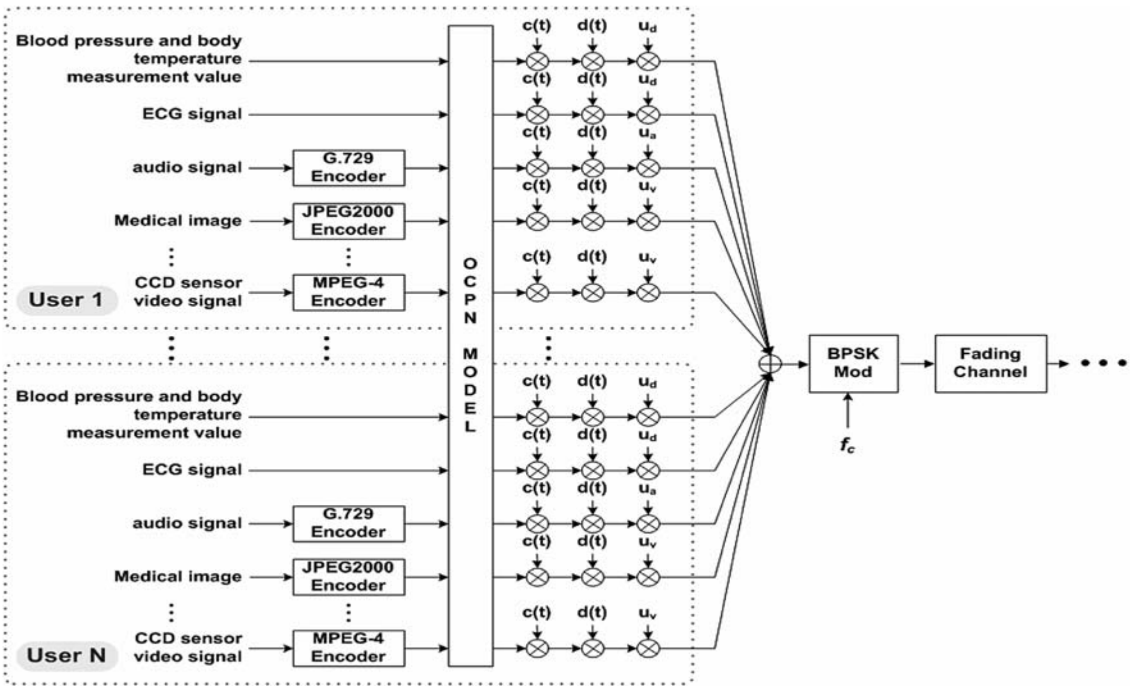


**Fig. 1** A multi-code code division multiple access mobile medicine system with downlink power-control mechanisms

dynamically assigned according to our power-control mechanism to achieve maximum resource utilization with acceptable quality of multimedia presentation services. The constant $P$ is the reference transmission power of the base station; $\theta_{km}$ is the random phase angle uniformly distributed between 0 and $2\pi$, and $b_{km}$ $(t)$ is the data signal consisting of a sequence of rectangular pulses of duration $T$. The concatenated spreading-code sequence $a_{km}$ $(t)$ is equal to the product of a Walsh-code sequence $c_m \in \{1, -1\}$ assigned to the $m$th virtual channel and a PN sequence $d_k \in \{1, -1\}$ used by the $k$th user. Thus, the received signal at the input to the matched filter in the mobile receiver is given by

$$
\begin{aligned}
r(t) & \\
&= \mathrm{Re}\left\{ \int_{-\infty}^{\infty} h_{km}(\tau)\bar{s}_{km}(t-\tau)\,\exp(\mathrm{j}w_c t)\,\mathrm{d}\tau \right\} + n(t) \\
&= \sum_{k=1}^{K}\sum_{m=1}^{N_k}\sum_{l=1}^{L_{km}} \sqrt{2\mu_{kmP}}\,\beta_{lkm} a_{km}(t-\tau_{lkm}) b_{km}(t-\tau_{lkm}) \\
&\times \cos(w_c t + \varphi_{lkm}) + n(t)\varphi_{lkm} = -w_c\tau_{lkm} + \phi_{lkm} + \theta_{lkm}
\end{aligned}
\quad (2)
$$

where $\tilde{s}(t)$ is the complex envelope of $s(t)$, $\mathrm{Re}\{\cdot\}$ denotes the real part of complex number, $n(t)$ is the white Gaussian noise process with two-side power spectral density $N_o/2$. For the purpose of mathematical simplification, the first virtual channel of the first user is chosen as the reference for calculating the probability of bit error of the data symbol $b_{11}$. The receiver can coherently recover the carrier phase $\varphi_{lkm}$ and $\tau_{lkm}$ locking to the $l$th path as a reference path between the transmitter and its corresponding receiver. All other paths are considered as interference. That is, we assume without loss of generality that $\varphi_{l11} = 0$ and $\tau_{l11} = 0$. Moreover, since all the signals including the desired signal and the interfering signals caused by other virtual channels relative to the reference virtual channel (virtual channel 1 of user 1) are transmitted to the first mobile receiver from the same base station (downlink) and are experiencing identical propagation environments between the base station and the receiver for reference virtual channel, it can be shown that $\bar{\beta}_{lkm} = \bar{\beta}_l$. The envelope of the matched-filter output at the $j$th sampling time instant $(t = jT)$, which is denoted by $Y^{(j)}{}_{11}$, can be expressed as

$$
\begin{aligned}
Y_{11}^{(j)} &= \int_{(j-1)T}^{jT} r(t)a_{11}(t)\,\cos(w_c t)\,\mathrm{d}t \\
&= \beta_{l11}\sqrt{\frac{\mu_{11}PT^2}{2}} b_{11}^{(j)} + \mathrm{Int}_1 + \mathrm{Int}_2 + \mathrm{Int}_3 + v
\end{aligned}
\quad (3)
$$

where $v = \int_{(j-1)T}^{jT} n(t)a_{11}(t)\,\cos(w_c t)\,\mathrm{d}t$, $\mathrm{Int}_1$ is the intra multi-user interference (self-interference) introduced by other virtual channels of the reference user; $\mathrm{Int}_2$ is the intra multi-path interference; $\mathrm{Int}_3$ denotes inter multi-user interference. All these interferences are represented in the following:

$$\mathrm{Int}_1 = \sum_{m=2}^{N_1} \sqrt{\frac{u_{1m}P}{2}} \beta_l b_{1m}^{(j)} \tilde{R}_{1m,11}\left(n_1', 0\right)$$

$$\mathrm{Int}_2 = \sum_{m=1}^{N_1} \sum_{\substack{lq=1 \\ q \neq 1}}^{L} \sqrt{\frac{u_{1m}P}{2}} \{\beta_l \cos(\varphi_l) \times \left[b_{1m}^{(j-1)} R_{1m,11}\left(n_1', n', \tau\right) + b_{1m}^{(j)} \hat{R}_{1m,11}\left(n_1', n_1', \tau\right)\right]$$

$$\mathrm{Int}_3 = \sum_{k=2}^{K} \sum_{m=1}^{N_k} \sum_{q=1}^{L} \sqrt{\frac{u_{km}P}{2}} \{\beta_l \cos(\varphi_l) \times \left[b_{km}^{(j-1)} R_{km,11}\left(n_k', n_1', \tau\right) + b_{km}^{(j)} \hat{R}_{km,11}\left(n_k', n_1', \tau\right)\right] \quad (4)$$

In Eq. 4, $\tilde{R}_{1m,11}\left(n_1', \tau\right), R_{km,11}\left(n_k', n_1', \tau\right)$, and $\hat{R}_{km,11}\left(n_k', n_1', \tau\right)$ are the well-known continuous period cross-correlation, partial cross-correlation, and auto-correlations of the regenerated code and a delayed version of the interfering codes [5], respectively. They are defined as

$$\tilde{R}_{1m,11}\left(n_1', \tau\right) = \int_{(j-1)T}^{jT} a_{1m}\left(t + n_1' T_c - \tau\right) a_{11}\left(t + n_1' T_C\right) \times \mathrm{d}t \hat{R}_{km,11}\left(n_1', \tau\right) = \int_{\tau}^{jT} a_{km}\left(t + n_1' T_c - \tau\right) a_{11}\left(t + n_1' T_C\right) \mathrm{d}t \quad (5)$$

where $n'_k$ is the initial phase of the PN sequence used by the $k$th user. Fong et al. [5] have shown that $\hat{R}_{km,11}\left(n_1', 0\right)$ is always equal to 0 when $a_{1m}$ $(t)$ and $a_{11}$ $(t)$ are the concatenated spreading codes. This is because var$\{\mathrm{Int}_1\}$ is 0 due to the orthogonality of the concatenated spreading codes. Since the interference terms in Eq. 4 are all mutually conditionally independent, the total variance becomes $\sigma^2$ = var $\{v\}$ + var $\{\mathrm{Int}_1\}$ + var $\{\mathrm{Int}_2\}$ + var $\{\mathrm{Int}_3\}$, with

$$\mathrm{var}\{\mathrm{Int}_1\} = 0$$

$$\mathrm{var}\{v\} = \frac{N_o T}{4}$$

$$\mathrm{var}\{\mathrm{Int}_2\} = \frac{T^2 \kappa^2}{4} \times \left\{ \sum_{m=2}^{N_1} \sum_{\substack{lq=1 \\ q \neq l}}^{L} \mu_{1m} P \bar{\beta}_{q1}^2 \right\} \quad (6)$$

$$\mathrm{var}\{\mathrm{Int}_3\} = \frac{T^2 \kappa^2}{4} \times \left\{ \sum_{k=2}^{K} \sum_{m=2}^{N_k} \sum_{\substack{lq=1 \\ q \neq l}}^{L} u_{km} P \bar{\beta}_{qk}^2 \right\}$$

From the above discussion, the variance of the total interfering signals can be described by

$$\mathrm{var}\{\mathrm{Int}_2\} + \mathrm{var}\{\mathrm{Int}_3\} = \left\{ \frac{T^2 \kappa^2}{4} \times \sum_{k=1}^{K} \sum_{m=2}^{N_k} \sum_{q=1}^{L} u_{km} P \bar{\beta}_q^2 - \sum_{m=2}^{N_1} \mu_{1m} P \bar{\beta}_l^2 \right\} \quad (7)$$

Let $\bar{E}_{\mathrm{b}} = \left(\beta_l^2 PT\right)$ represent the received energy per information bit via the $l$th path (reference path). Further let $N_{\mathrm{a}}$, $N_{\mathrm{v}}$, and $N_{\mathrm{d}}$ be the number of virtual channels for transmitting audio, video, and data media in the multi-code mobile medicine system, respectively. Parameters $\mu_{\mathrm{a}}$, $\mu_{\mathrm{v}}$, and $\mu_{\mathrm{d}}$ are the weighting factors denoting transmission power $\upsilon = \sum_{q=1}^{L} \left(\bar{\beta}_q^2 / \bar{\beta}_l^2\right)$ Thus, the total variance can be obtained by weighting the audio, video, and data media, as

$$\mathrm{var}(\mathrm{Int}_2\} + \mathrm{var}\{\mathrm{Int}_3\} = \frac{\bar{E}_{\mathrm{b}} T^2 \kappa^2}{4} \times \{(N_{\mathrm{a}} u_{\mathrm{a}} + N_{\mathrm{v}} u_{\mathrm{v}} + N_{\mathrm{d}} u_{\mathrm{d}}) \times \upsilon - N_1\} \times \bar{\beta}_l^2$$

The received signal power is found to be $\frac{\mu_{11} P T^2 \bar{\beta}_l^2}{2} \left(= \frac{\mu_{11} T \bar{E}_{\mathrm{b}}}{2}\right)$. The mean of the SNIR is defined as

$$\bar{\gamma}_{\mathrm{b}} = \frac{\frac{T \bar{E}_{\mathrm{b}} \mu_{11}}{2}}{\frac{T \bar{E}_{\mathrm{b}} \kappa^2}{4} \times \left[(N_{\mathrm{a}} u_{\mathrm{a}} + N_{\mathrm{v}} u_{\mathrm{v}} + N_{\mathrm{d}} u_{\mathrm{d}}) \upsilon - N_1\right] + \frac{N_o T}{4}} \quad (8)$$

Pursley et al. [18] showed that $\kappa^2$ is a constant with value $\frac{2}{3} N_C$. Thus, the SNIR for audio, video, and data are given by

$$\bar{\gamma}_{\mathrm{b}}, \text{audio} \approx \left[ \frac{(N_{\mathrm{a}} u_{\mathrm{a}} + N_{\mathrm{v}} u_{\mathrm{v}} + N_{\mathrm{d}} u_{\mathrm{d}}) \upsilon}{3 N_c u_{\mathrm{a}}} + \frac{N_o}{2 \mu_{\mathrm{a}}} \bar{E}_{\mathrm{b}} \right]^{-1}$$

$$\bar{\gamma}_{\mathrm{b,video}} \approx \left[ \frac{(N_{\mathrm{a}} u_{\mathrm{a}} + N_{\mathrm{v}} u_{\mathrm{v}} + N_{\mathrm{d}} u_{\mathrm{d}}) \upsilon}{3 N_c u_{\mathrm{v}}} + \frac{N_o}{2 \mu_{\mathrm{v}} \bar{E}_{\mathrm{b}}} \right]^{-1} \quad (9)$$

$$\bar{\gamma}_{\mathrm{b,data}} \approx \left[ \frac{(N_{\mathrm{a}} u_{\mathrm{a}} + N_{\mathrm{v}} u_{\mathrm{v}} + N_{\mathrm{d}} u_{\mathrm{d}}) \upsilon}{3 N_c u_{\mathrm{d}}} + \frac{N_o}{2 \mu_{\mathrm{d}} \bar{E}_{\mathrm{b}}} \right]^{-1}$$

Proakis et al. [17] showed that the BER for both the non-diversity coherent receiver and a receiver with maximal ratio combining of order $L$ can be expressed in terms of $\bar{\gamma}_{\mathrm{b}}$, as

$$p_e = p_e(\bar{\gamma}_{\mathrm{b}}) = \left(\frac{1-\lambda}{2}\right)^L \times \sum_{s=0}^{L-1} \binom{L-1+s}{s} \left(\frac{1+\lambda}{2}\right)^s \quad (10)$$

In Eq. 10, $\lambda = \sqrt{\frac{\bar{\gamma}_{\mathrm{b}}}{1+\bar{\gamma}_{\mathrm{b}}}}$ and the quality $\bar{\gamma}_{\mathrm{b}}$ represents the average SNIR per combined path. Let $\eta_{\mathrm{a}}$, $\eta_{\mathrm{v}}$, and $\eta_{\mathrm{d}}$ denote the minimum SNIR required to meet the specified BER. The next goal is to derive the set of power-weighting factors for which minimum requirement of the SNIR can be satisfied. These weighting factors $\mu_{\mathrm{a}}$, $\mu_{\mathrm{v}}$ and $\mu_{\mathrm{d}}$ can be obtained by

$$\mu_{\mathrm{d}} = \frac{\frac{N_o}{2E_{\mathrm{b}}} \frac{3N_c}{\alpha L \eta_{\mathrm{a}}}}{-\frac{N_{\mathrm{d}}}{\eta_{\mathrm{a}}} - \frac{N_{\mathrm{a}}}{\eta_{\mathrm{d}}} + \frac{3N_C}{\alpha L \eta_{\mathrm{a}} \eta_{\mathrm{d}}} - \frac{\eta_{\mathrm{v}}}{\eta_{\mathrm{a}}} \frac{N_{\mathrm{a}}}{\eta_{\mathrm{d}}}}$$

$$\mu_{\mathrm{a}} = \frac{-\frac{N_o}{2E_{\mathrm{b}}} \frac{3N_C}{\alpha L} - N_{\mathrm{d}} u_{\mathrm{d}}}{N_{\mathrm{a}} - N_{\mathrm{v}} \frac{\eta_{\mathrm{v}}}{\eta_{\mathrm{a}}} - \frac{1}{\eta_{\mathrm{a}}} \frac{3N_c}{\alpha L}} \quad (11)$$

$$\mu_{\mathrm{v}} = \frac{\eta_{\mathrm{v}}}{\eta_{\mathrm{a}}} \mu_{\mathrm{a}}$$

## 3 Numerical results

In the above multi-code CDMA system, an $m$-sequence with period 2^(42) − 1 and the Walsh code with a period of 1,024 are chosen as the PN and orthogonal spreading sequences, respectively. The CDMA receiver has a maximum ratio combiner of order $L = 4$. The BER requirements for voice, video, and data are set to 10^(− 3), 10^(− 4), and 10^(− 7), respectively. Thus, the thresholds of the SNIR for audio, video, and data media are 4, 7, and 15 dB in our multi-code CDMA mobile medicine system. The used multimedia presentation activity factor $\alpha$ is 0.75. Transmission power of each virtual channel is calculated using our power-control mechanism derived above. Based on the requirements of BER for different media and the signal to white Gaussian noise and multi-channel interference in per bit duration, the transmission power of each virtual channel can be adjusted accordingly. Figure 2 shows weighting factors for audio, video and data as a function of the signal to white Gaussian noise. The three signs (○), (△), and (□) denote the transmission-power weighting for data, video, and audio virtual channel $\mu_{\mathrm{d}}$, $\mu_{\mathrm{v}}$, and $\mu_{\mathrm{a}}$, respectively. The power ratio is obtained from a system with 100 video, 100 audio, and 10 data virtual channels.

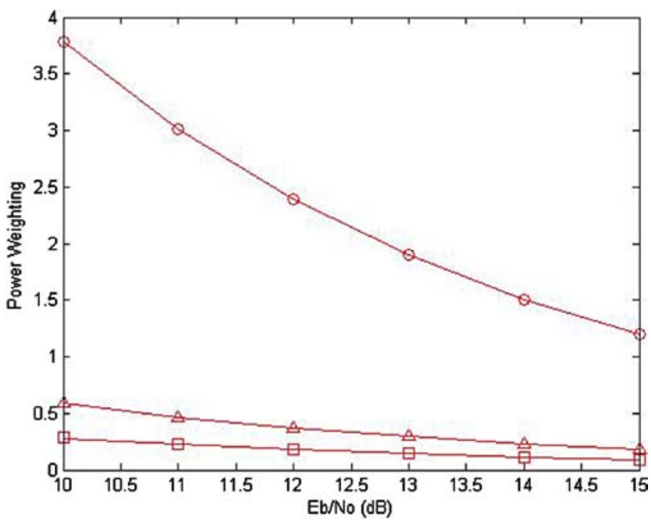


**Fig. 2** Power weighting for the three different media as a function of the signal to white Gaussian noise (*open circle* data virtual channel, *open triangle* video virtual channel, *open square* audio virtual channel)

The signal to white Gaussian noise lies in the range 10– 15 dB. The multi-path gains are (1 0.5 0.25 0.125). From Fig. 3, it can be seen that for 100 video and 100 audio virtual channels, the transmission-power weighting increases as a function of the number of data virtual channels, as the signal to white Gaussian noise is 13 dB. Moreover, the transmission-power weightings for audio, video, and data virtual channels increase as the number of data virtual channel increases. The purpose of the power control is to keep the BER at 10^(− 7) for each data virtual channel at any channel condition and with any number of virtual channels. Numerical analysis shows that the ratio among these three powers is 1:2:13. This ratio of the transmission power is found to be similar as the ratio of SNIR.

A property of this system is that the power level is a function of the BER. So for media that can tolerate higher BER, less power is assigned. The consequence is that more channels of this kind of media can be supported without causing too much interference. This is good for video or audio media that demand real-time transmission. Thus, we can trade BER for transmission capacity in such a system. That is, the system can support a lot of channels with high BER, while still maintaining channels with very low BER. As a result, more channels can be used for media with less-stringent BER. In the following example, we compare the performance of the new system with that of a system with equal power [3]. For this, an average BER is defined first. In the case of equal power system, the number of channel is bounded by the given BER, which is the same for all the virtual channels. But in the case of unequal power system, the BER is different for virtual channels. Therefore, for the purpose of comparison, an average BER is defined for the equal power case. The average BER is a weighted sum of all the BERs for an unequal power system. Starting with the known numbers of transmission channels, for example, $N_{\mathrm{a}} = 125$, $N_{\mathrm{v}} = 125$, and $N_{\mathrm{d}} = 12$, as shown in Table 1, we define

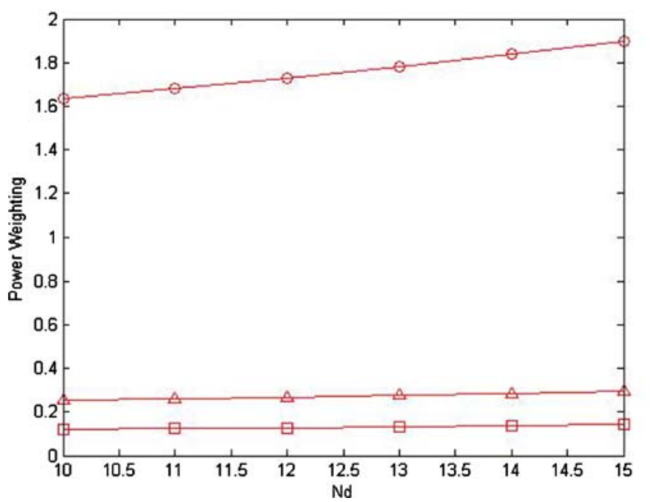


**Fig. 3** Virtual channel transmission power as a function of the number of data channels (*open circle* data virtual channel, *open triangle* video virtual channel, *open square* audio virtual channel)

the average BER for the equal power multi-code CDMA system [3] as

$$\frac{125}{262} \times 10^{\wedge}(-3) + \frac{125}{262} \times 10^{\wedge}(-4) + \frac{12}{262} \times 10^{\wedge}(-7) = 5.24 \times 10^{\wedge}(-4)$$

Then, we use the average BER to calculate the corresponding SNIR. From this SNIR, the maximum number of channels that can be used in an equal power system can be derived based on the following equation

$$\bar{\gamma}_{\mathrm{b}} \approx \left[\frac{N_{\mathrm{ref}}\upsilon}{3N_C}\alpha + \frac{N_o}{2\bar{E}_{\mathrm{b}}}\right]^{-1} \approx \left[\frac{N_{\mathrm{ref}}\upsilon}{3N_C}\alpha\right]^{-1}. \quad (12)$$

In this example, the maximum number of channel is $N_{\mathrm{ref}} = 226$. Consequently, the capacity decreases from 262 to 226 channels for equal power system. This increase of capacity is obtained at the expense of higher BER for some channels. The increase of the channel capacity for the unequal power control strategy can be calculated as

$$\frac{N_{\mathrm{a}} + N_{\mathrm{v}} + N_{\mathrm{t}} - N_{\mathrm{ref}}}{N_{\mathrm{a}} + N_{\mathrm{v}} + N_{\mathrm{t}}} \times 100\% = 14.91\%.$$

Furthermore, the decrease of the transmission power with unequal power-control strategy can be calculated as

$$\frac{N_{\mathrm{a}}u_{\mathrm{a}} + N_{\mathrm{v}}u_{\mathrm{v}} + N_{\mathrm{t}}u_{\mathrm{t}} - N_{\mathrm{ref}} \times 1}{N_{\mathrm{ref}} \times 1} \times 100\% = 69.59\%$$

where $N_{\mathrm{ref}}$ is the number of channels for the system with equal power control [3] for which the BER is equal to the average BER in the system with dynamic power control. Table 1 also presents several cases for comparing channel capacity and transmission power between the two power-control strategies. From this table, we can see that use of dynamic power-control mechanism can increase the system capacity and decrease the transmission power, as compared to a system with equal power multi-code.

## 4 Discussion

Based on the above analysis, it can be seen that when the channel number is 226, the average SNIR is 5.3 dB and the BER is 5.24 × 10^(− 4) for the equal power system. So, it is impossible to achieve BER at 10^(− 7). Only by using a downlink power control for audio, video, and data power weighting with $u_{\mathrm{a}} = 0.1491$, $u_{\mathrm{v}} = 0.2976$, and $u_{\mathrm{d}} = 1.9887$ can the required BER of 10^(− 7) be met. To illustrate the advantage of such an approach, we have carried out a simulation with real data. In this system, each patient uses two multi-code data virtual channels. One is used to transmit medical history, blood pressure, and body temperature. The other one is used to transmit results from ECG outputs. The transmission-data rate of every virtual channel in our design is 8 kbps. In this design, a multi-code voice virtual channel is used to deliver G.729 voice signal, eight multi-code video virtual channels are used to deliver MPEG-4 CCD sensor video signal and another video channel is used to transmit JPEG2000 X-ray medical image. The image channel is different from the video channel in that the former is repeated every 16 s to deliver the 128-kbits compressed data. We assume that there are many other patients such that the total number of channels is 262 with 125 video channels, 125 audio channels, and 12 data channels.

Simulation results show that, when transmission-power weighting for audio, video, and data are respectively, 0.1491, 0.2976, and 1.9887, the corresponding BER is 0.00096, 9.63 × 10^(− 5), and 9.51 × 10^(− 8), respectively. These are close to the required values 10^(− 3), 10^ (− 4), and 10^ (− 7). Figure 4 shows the results of the ECG signals received in the multi-code CDMA mobile medicine system with downlink power control. The mean square error between the received and the original ECG signals is 0.00805. Figure 5 shows the results of the ECG signal received in the multi-code CDMA mobile medicine system without downlink power control using 262 channels. The BER is $5.29 \times 10^{-4}$. It can be seen that the BER is too high so that the signal is corrupted severely. This indicates that power control is necessary in such a system, which serves error-prone signals for real-time transmission, to ensure a high-quality channel as well as to maintain sufficient number of channels.

Figure 6 shows the original audio test signal. Figure 7 shows the received and decoded G.729 audio signals in a multi-code CDMA mobile medicine system

**Table 1** Several cases for comparing channel capacity and transmission power between unequal power-control and equal power-control strategies

| Unequal power assignment | | | | | | | Equal power assignment | | Performance comparison | |
|---|---|---|---|---|---|---|---|---|---|---|
| $u_{\mathrm{a}}$ | $u_{\mathrm{v}}$ | $u_{\mathrm{d}}$ | $N_{\mathrm{a}}$ $10^{-3}$ | $N_{\mathrm{v}}$ $10^{-4}$ | $N_{\mathrm{d}}$ $10^{-7}$ | Power consumption | $N_{\mathrm{ref}}$ [3] | Average BER | Increase capacity (%) | Descend power (%) |
| 0.1491 | 0.2974 | 1.9877 | 165 | 165 | 3 | 79.635 | 229 | 5.45×10−4 | 45.41 | 76.09 |
| 0.1472 | 0.2937 | 1.9629 | 150 | 150 | 6 | 78.0912 | 228 | 5.39×10−4 | 34.21 | 74.22 |
| 0.1476 | 0.2945 | 1.9682 | 137 | 137 | 9 | 79.059 | 227 | 5.32×10−1 | 24.12 | 72.06 |
| 0.1491 | 0.2976 | 1.9887 | 125 | 125 | 12 | 79.664 | 226 | 5.24×10−4 | 14.91 | 69.59 |


**Fig. 4** Results of the electrocardiogram signals tested in the multi-code code division multiple access mobile medicine system with downlink power control (MSE = 0.00805)

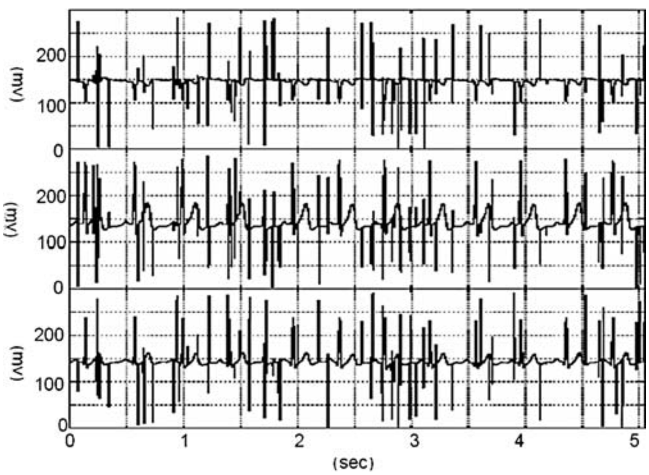


**Fig. 5** Results of the electrocardiogram signals tested in the multi-code code division multiple access mobile medicine system without downlink power control

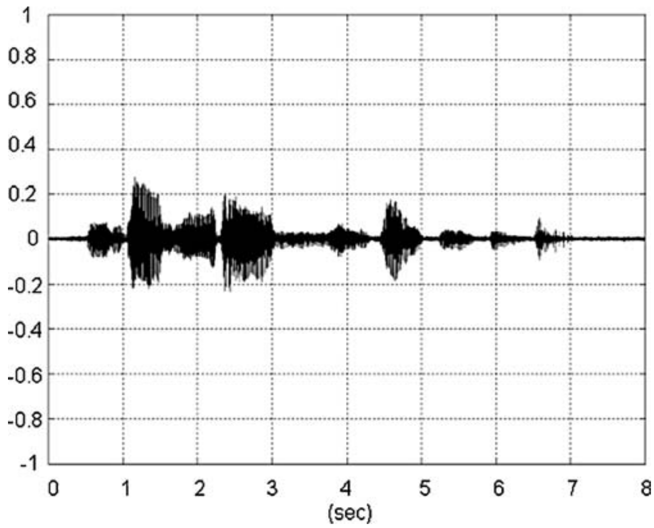


**Fig. 6** Original audio test signals

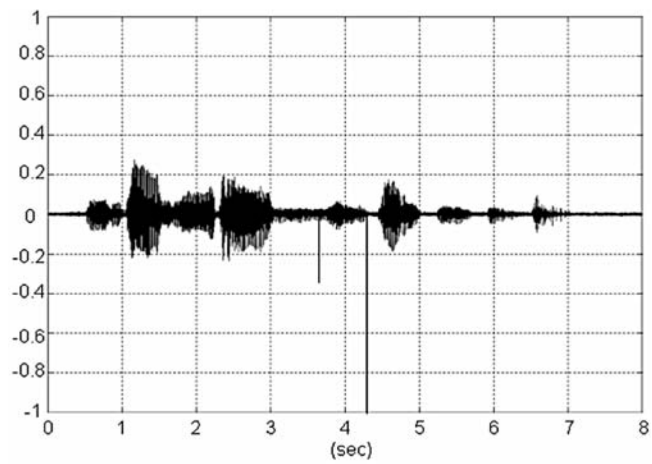


**Fig. 7** Received and decoded G.729 audio signals simulation tested in the multi-code code division multiple access mobile medicine system with downlink power control [MSE = 3.1861 × 10^(− 4)]

with downlink power control. The mean square error of the original and the received audio signal is 3.1861 × 10^(− 4). Figure 8 shows the received and decoded JPEG2000 medical image. The peak signal-to-noise ratio (PSNR) value of this JPEG2000 medical image is 39.11 dB. Figure 9 shows the received MPEG-4 CCD sensor video signals. The average PSNR value of the MPEG-4 CCD sensor video signal is 38.31 dB. From these simulations, it can be seen that by using power control not only the system capacity can be increased but also the required QoS for a mobile medicine system can be achieved.

## 5 Conclusion

In this paper, we have proposed a mobile medicine system using multi-code CDMA spread spectrum techniques. A downlink power-control mechanism is presented to combat channel fading and multi-channel interference, so that transmission quality to meet the BER requirements for different media can be maintained. A simulation is done to demonstrate the capability of transmitting ECG signal, blood pressure measured by sphygmomanometer and clinical thermometer, body temperature, microphone voice signals, and MPEG-4 CCD sensor video signals. Numerical analysis and simulation results have shown that use of multi-code CDMA with downlink power-control mechanism can result in larger system capacity and smaller transmission-power consumption as compared with an equal power system. The ratio of transmission power is found to be similar to the ratio of SNIR.

**Fig. 8** Transmission results of image signals simulation tested in the multi-code code division multiple access mobile medicine system with downlink power control (peak signal-to-noise ratio = 39.11 dB)

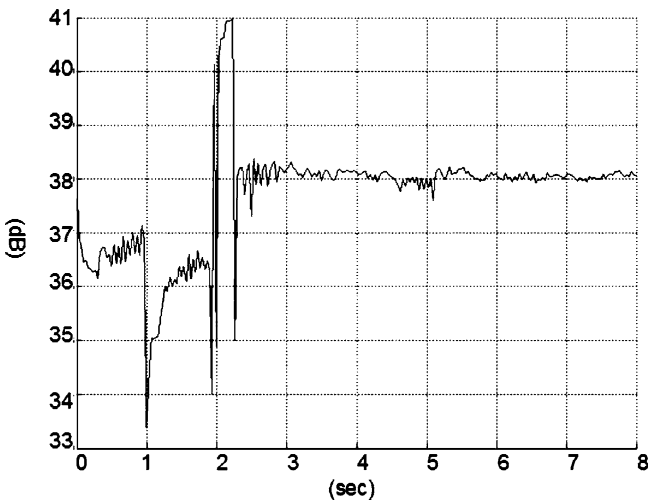


**Fig. 9** Received peak signal-to-noise ratio values of medical images and moving picture experts group 4 charge-coupled device sensor video signals tested in the multi-code code division multiple access mobile medicine system with downlink power control

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