CDMA2000 1X CAPACITY DECREASE BY POWER CONTROL ERROR IN HIGH SPEED TRAIN ENVIRONMENT

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Abstract: CDMA2000 1X capacity was analysed in the high speed train environment. We calculated the power control error by Doppler shift and simulated bit error rate (BER) at the base station. We made the interference model and calculated the BER from lower bound of power control error variance. The reverse link BER was increased by high velocity although there was no coverage reduction. Capacity decrease was negligible in the pedestrian (5 km/h), urban vehicular(40 km/h), highway and railroad(100 km/h) environment. However, capacity was severely reduced in high speed train condition(300 km/h and 350 km/h). Cell-planning considering capacity as well as coverage is essential for successful cellular service in high speed train.

1 INTRODUCTION

Cellular mobile telephone and data communication services are very popular. Cellular service is usable in anywhere, even though tunnel, sea, and underground places. Railroads and highways are main service area of cellular service because many people move through them. Many countries adopts the high speed train for transportation capability and convenience for example TGV in France, ICE in Deutschland. Korea also constructs the Korea Train Express (KTX) between Seoul and Pusan. KTX travels by 300 km/h speed and will be upgraded by 350 km/h speed.

High speed mobility can damage pilot acquisition, steady-state demodulation, code tracking, and power control. We experimented the CDMA2000 1X service quality using channel simulator in Test-bed network. There was no quality degradation such as MOS(mean of score), data throughput, call drop, and call fail. We got the same results in the KTX. Call origination, response, data download, and data upload was successful in the train with 300 km/h velocity. Received power, transmitted power, and pilot chip energy to interference ratio (Ec/Io) of mobile station were not correlated with the mobile velocity. We could serve successfully the CDMA2000 1X in the KTX by existing cellular network.

Experimental results confirm that coverage is not reduced by speed mobility. However, a few base station and frequency assignment (FA) is established in rural area. It makes the capacity shortage. One KTX train is composed of 20 cars and one car seats 64 persons. It means more than 2000 calls can connect one base station when two opposite trains are in coverage of same base station. In the dense urban area, heavy traffic cell is split for dividing traffic. This method cannot be used for KTX because traffic cannot be split in one train. We must increase the FA for capacity improvement. Adjacent cell uses same FA for smooth handoff. If one cell increases the FA number, adjacent cells also increase the FA number. Therefore we have to estimate the capacity of one FA for efficient network investment.

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Velocity does not influence the coverage, but it does not mean that capacity is not varied by velocity. Network performance can be changed with user number because CDMA is the system limited by interference. CDMA performance is influenced by multi-user interference. CDMA capacity is limited by Walsh code on the forward link and by cell loading on the reverse link. Cell loading is the received power increase by mobile station at the base station receiver. High cell loading increases the noise level at the base station receiver and it degrades the bit energy to noise ratio (Eb/Nt). Low Eb/Nt increases the transmitted power of mobile station by power control and high transmitted power degrades Eb/Nt repeatedly. CDMA2000 1X uses the fast power control for corresponding to variable radio channel. High velocity of mobile causes the power control error due to Doppler shift and fast radio channel environment variation. This paper analysed the capacity decrease by power control error. Section 2 will derive the calculation of power control error and Section 3 will show the simulation results.

2 POWER CONTROL ERROR SIMULATION

2.1 Interference Model

We starts making interference model by followed assumption.

- User *o* who is analysis target has the appropriate received signal strength 0 dB.
- There are K+*1* users including target user *o.*
- *K+1* users are served in same cell.
- *K+1* users are riding the KTX.
- There is no other user who is not riding KTX in the analysed cell. That is to say, all of users in the analysed cell are riding KTX.
- Other cell user *K* interference is assumed in-cell user *gK.*
- There is no error in the power control procedure of the other cell user.

Received signal in base station from interference user *i* is as follows:

$$S_i = m_i^{+}\varepsilon_i \quad \text{(dB)} \qquad 2.1$$

m_i is the signal strength without power control error. ε_i is the random variable due to power control error and has log-normal distribution with 0 dB expected value and σ_i^2 dB variance. Expected value and variance of random variable S_i measured by Watt-unit are as follows.

$$E[S_i] = e^{\beta m_i + \frac{1}{2}\beta^2\sigma_i^2} \qquad 2.2$$

$$Var(S_i) = e^{2\beta m_i + \beta^2\sigma_i^2}\left(e^{\beta^2\sigma_i^2} - 1\right) \qquad 2.3$$

β is (ln10)/10 in equation 2.2 and 2.3. Received signal strength of user *o* is as equation 2.4.

$$S_o = \varepsilon_o \quad \text{(dB)} \qquad 2.4$$

In equation 2.4, it is assumed ε_o has a log-normal distribution with variance σ_e^2 (dB).

Received power from other cell users must be considered to analyse multi-cell environment. Interference from other cell is represented by in-cell interference. If there are *K* users in the each cell and average propagation loss ratio of in-cell and other cell is *g*, other cell interference is *gK*. Standard deviation of received signal is the control function of base station transmitted power because of fading. Total interference considering both in-cell and other cell interference is as equation 2.5

$$I = \sum_{i=1}^{K} S_{ei} + \sum_{i=1}^{gK} S_{oi} \qquad 2.5$$

S_{ei} is signal power of in-cell user *i* with standard deviation σ_{ei}. S_{oi} is signal power of other cell user *i* with standard deviation σ_{oi}. Therefore, expected value and variance of *I* is as follows

$$E[I] = \sum_{i=1}^{K} E[S_{ei}] + \sum_{i=1}^{gK} E[S_{oi}] \qquad 2.6$$

$$Var(I) = \sum_{i=1}^{K} Var(S_{ei}) + \sum_{i=1}^{gK} Var(S_{oi}) \qquad 2.7$$

Probability density function (PDF) of *I* can be approximated by log-normal random variable ξ, because *I* is sum of independent log-normal random variables. Expected value and variance of ξ is as follows

$$E[\xi] = e^{m_K + \frac{1}{2}\sigma_K^2} \qquad 2.8$$

$$Var(\xi) = e^{2m_K + \sigma_K^2}\left(e^{\sigma_K^2} - 1\right) \qquad 2.9$$

It is assumed power control error variance of in-cell users and other cell is σ_e^2 and σ_o^2, respectively. Expected value and variance of *I* is defined with expected value and variance of ξ using Wilkinson's Method.

$$Ke^{\beta m+\frac{1}{2}\beta^2\sigma_e^2}+gKe^{\beta m+\frac{1}{2}\beta^2\sigma_o^2}=e^{m_K+\frac{1}{2}\sigma_K^2} \tag{2.10}$$

$$Ke^{2\beta m+\beta^2\sigma_e^2}\left(e^{\beta^2\sigma_e^2}-1\right)+gKe^{2\beta m+\beta^2\sigma_o^2}\left(e^{\beta^2\sigma_o^2}-1\right)=e^{2m_K+\sigma_K^2}\left(e^{\sigma_K^2}-1\right) \tag{2.11}$$

We get m_k and σ_k from equation 2.10 and 2.11.

$$\sigma_K^2=\ln\left[\frac{e^{\beta^2\sigma_e^2}\left(e^{\beta^2\sigma_e^2}-1\right)+ge^{\beta^2\sigma_o^2}\left(e^{\beta^2\sigma_o^2}-1\right)}{K\left(e^{\frac{1}{2}\beta^2\sigma_e^2}+ge^{\frac{1}{2}\beta^2\sigma_o^2}\right)^2}+1\right] \tag{2.12}$$

$$m_K=\ln K+\ln\left(e^{\frac{1}{2}\beta^2\sigma_e^2}+ge^{\frac{1}{2}\beta^2\sigma_o^2}\right)-\frac{1}{2}\sigma_K^2 \tag{2.13}$$

2.2 Mean BER Calculation

Bit energy to interference ratio of BPSK having bandwidth W is given by equation 2.14.

$$\frac{E_b}{N_0+I_0}=\frac{S_{eo}/R_b}{N_0+\frac{1}{W}\left(\sum_{i=1}^{K}S_{ei}+\sum_{i=1}^{gK}S_{oi}\right)} \tag{2.14}$$

N_o is the power spectral density of background noise and R_b is the bit rate. BER of BPSK is given by

$$P_e=Q\left(\sqrt{2\frac{E_b}{N_0+I_0}}\right) \tag{2.15}$$

The received signal is log-normal random variable due to imperfect power control and BER is given by

$$P_e=Q\left(e^{\gamma}\right) \tag{2.16}$$

γ is the Gaussian random variable and its mean and variance is given by

$$m_\gamma=\frac{1}{2}\left(\ln 2\frac{W}{R_b}-m_K\right) \tag{2.17}$$

$$\sigma_\gamma^2=\frac{1}{4}\left(\beta^2\sigma_e^2+\sigma_K^2\right) \tag{2.18}$$

With mean γ, mean BER is calculated by

$$\overline{P}_e=\int_0^\infty Q\left(e^{\gamma}\right)g(\gamma)d\gamma \tag{2.19}$$

Equation 2.19 is approximated to equation 2.20 using the expansion of central difference.

$$\overline{P}_e\approx\frac{2}{3}Q\left(e^{m_\gamma}\right)+\frac{1}{6}Q\left(e^{m_\gamma+\sqrt{3}\sigma_\gamma}\right)+\frac{1}{6}Q\left(e^{m_\gamma-\sqrt{3}\sigma_\gamma}\right) \tag{2.20}$$

2.3 Variance of Power Control Error

Each base station controls the received power from mobile station in cellular CDMA network. There is four main error factor when tracking the received power. They are the quantum(σ_q), decoding(σ_d), measurement(σ_m), and propagation delay(σ_p) error. Generally, σ_m and σ_p is much larger than σ_q and σ_d. If error factor is statistically independent,

$$\sigma_e^2=\sigma_m^2+\sigma_p^2+\sigma_q^2+\sigma_d^2 \tag{2.21}$$

v is the maximum velocity of mobile. f_c is the carrier frequency. c is the light velocity. We assume the bandwidth is narrow enough to neglect bandwidth. Maximum Doppler shift is

$$f_d=f_c v/c \tag{2.22}$$

Propagation delay is $2d/c$ for closed loop power control. d is the distance between mobile and base station. Therefore, processing delay is

$$T_p<\frac{\alpha}{f_d}-\frac{2d}{c} \tag{2.23}$$

We define the p_m is measured received power in dB scale. p_0 is the received power in linear scale and p_m is $10\log p_0$. If σ_{m1}^2 is variance of natural logarithm($\ln p_0$) of p_0

$$\sigma_m^2=(10\log e)^2\sigma_{m1}^2 \tag{2.24}$$

It is assumed that fluctuation of received power can be neglected during measurement time T_m. Measurement period T_m is the main factor of processing delay T_p. Power control error is due to multi-user interference and white Gaussian noise. We assume the power control makes received power from any mobile to be almost same. It enables us to

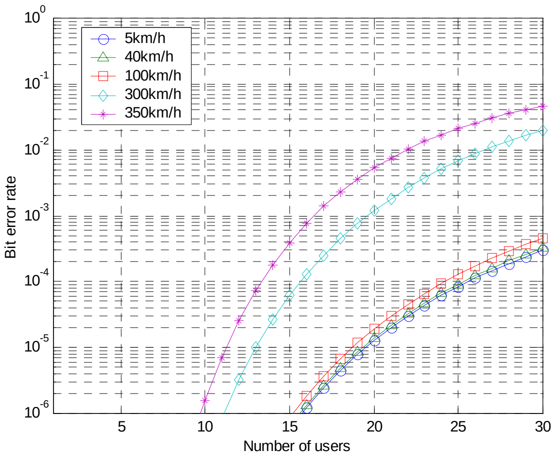

Figure 1(a): $g = 0.3$ and $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 0.5(\text{dB})^2$

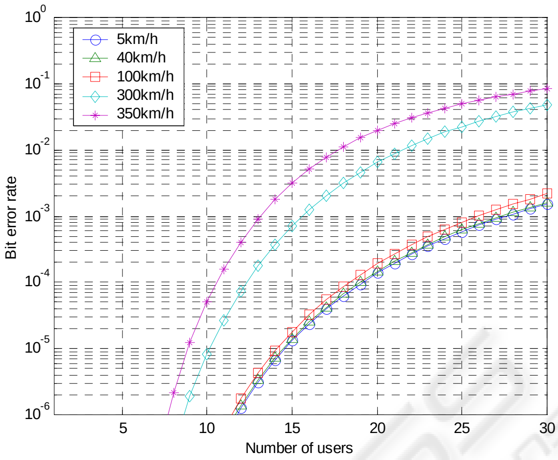

Figure 2(a): $g = 0.634$ and $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 0.5(\text{dB})^2$

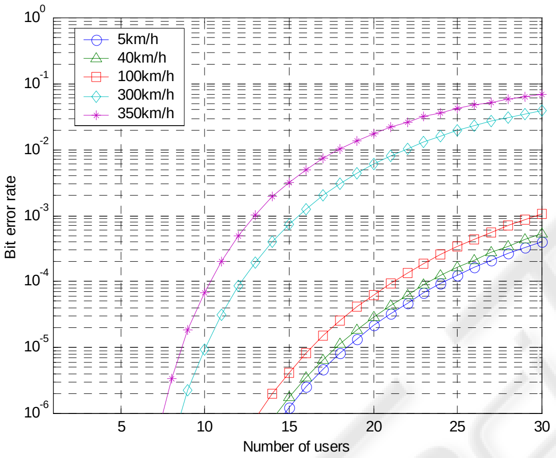

Figure 1(b): $g = 0.3$ and $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 1.5(\text{dB})^2$

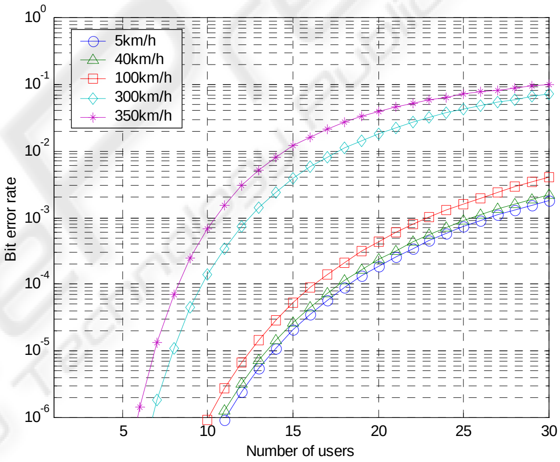

Figure 2(b): $g = 0.634$ and $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 1.5(\text{dB})^2$

determine the lower bound. Multi-user interference is modelled Gaussian process that increases one-sided power spectral density N_o to N_t.

$$N_t = N_0 + \frac{p_0}{W}K(1+g) \qquad 2.25$$

p_o is *K-1* interference signal power. *W* is the receiver bandwidth. g is the interference constant that represents other cell interference. Received signal is $\sqrt{p_0}\,s(t)$.

$$\sqrt{p_0}\,s(t) = \exp\left(\frac{y}{2}\right)s(t) \qquad 2.26$$

y is lnp_o in equation 2.26. Cramer-Rao bound provides lower bound of lnp_o variance. Equation 2.27 is obtained from this lower bound and equation 2.26.

$$\sigma_{m1}^2 \ge \left\{\frac{2}{N_t}\int_0^{T_m}\left[\frac{\partial}{\partial y}e^{y/2}s(t)\right]^2 dt\right\}^{-1} \qquad 2.27$$

using equation 2.24 and 2.25

$$\sigma_m^2 \ge \frac{200(\log e)^2}{T_m}\left[\frac{N_0}{p_0}+\frac{K(1+g)}{W}\right] \qquad 2.28$$

If we define $T_1 = T_p - T_m$ and use equation 2.23, we obtain equation 2.29 from 2.21

$$\sigma_{low}^2 \underline{\underline{\Delta}} 200(\log e)^2 \left(\frac{\alpha}{f_d} - \frac{2d}{c} - T_1 \right)^{-1} \left[\frac{N_0}{p_0} + \frac{K(1+g)}{W} \right] + \sigma_p^2 + \sigma_q^2 + \sigma_d^2 \tag{2.29}$$

3 SIMULATION RESULTS

We simulated the BER of received signal at base station when user number was 5 ~ 30 persons. Simulation circumstance was assumed to be pedestrian(5 km/h), urban vehicle(40 km/h), highway and railroad(100 km/h), KTX(300 km/h), and upgraded KTX(350 km/h).

BER was calculated from equation 2.20. m_r and σ_r of equation 2.20 was calculated from equation 2.17 and 2.18. m_k and σ_k was calculated from equation 2.12 and 2.13. We used the lower bound of equation 2.28 when calculating equation 2.12 and 2.13. Figure 1 and 2 shows user number and BER when mobile speed is 5 km/h, 40 km/h, 100 km/h, 300 km/h, and 350 km/h. We assumed R_b = 4.8 kbps, W = 1.2288 MHz, d = 4 km, α = 0.1, T_1 = 100 us, N_o/p_o = 5 us, σ_o^2 = 3.9 (dB)^2. Figure 1 and 2 shows increase of mobile speed degrades the BER of received signal. This means the reverse link capacity decreases to maintain the quality of service. Figure 1 and 2 shows the result when interference constant g is 0.3 and 0.634, respectively. Larger interference constant increases the receiver sensitivity with user number. (a) and (b) of each Figure shows the results in the case of $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 0.5(\text{dB})^2$ and $\sigma_p^2 + \sigma_q^2 + \sigma_d^2 = 1.5(\text{dB})^2$. High speed enlarges the Doppler shift in equation 2.22. Doppler shift increases the lower bound of error variance in equation 2.29. This increases the BER and degrades the quality of service.

In urban vehicular (40 km/h) condition, BER increase by Doppler shift was negligible. BER degradation was not severe even though highway and railroad (100 km/h) condition. We could plan the cellular network assuming constant capacity with mobile speed before KTX service. However, BER was dramatically increased in KTX circumstance. User number in KTX was limited to 17 ~ 26 persons to maintain BER lower than 1 %.

4 CONCLUSION

We measured the coverage of CDMA2000 1X network experimentally and simulated the capacity in KTX condition. Although coverage was not decreased, capacity was reduced severely in high mobile speed of 300 km/h. We don't have to consider the mobile velocity in cell-planning because capacity reduction is negligible in highway and railroad. However, capacity is severely reduced in KTX for its high velocity. We must consider the number of passenger carried by KTX when opposite train is met. Cell-planning without considering capacity can make the burst error in high traffic intensity. It causes not only quality degrade but also call drop. We must consider capacity as well as coverage for cellular network planning.

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