System-Level Simulator for the W-CDMA Low Chip Rate TDD System †

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Abstract— **A system-level simulator for the W-CDMA Low Chip Rate TDD system is developed. This simulator considers multi-cell and multi-user environmets and SIR-based power control. For accurate and reliable results, inner-cell and outer-cell interference is modeled by chip-level spreading and an SIR estimation scheme is used. From this simulator, system-level performance is evaluated in terms of the received SIR distributions for downlink and uplink. The degradation probability is also introduced as a QoS indicator in system-level.**

I. INTRODUCTION

The Time Division Duplex(TDD) mode has been specified in 3GPP. The TDD mode consists of two options, one is the wideband-TDD(WB-TDD) of 3.84Mcps, and another is the W-CDMA Low Chip Rate TDD system of 1.28Mcps which is also called the narrowband-TDD(NB-TDD). Future mobile systems require multimedia and asymmetric services and TDD systems may be a candidate solution for meeting user demands. The NB-TDD system is an improved technology based on the WCDMA-TDD system. The NB-TDD system can provide more flexible and advanced resource management schemes with DCA(Dynamic Channel Allocation) and smart antenna technologies. Hence, performance evaluations are needed for the NB-TDD system.

In this paper, the system-level performance of the NB-TDD system is evaluated through simplifications by using link-level performance results and simulations are performed by OPNET(Optimum Network Performance). Inner-cell and outer-cell interference is modeled by chip-level spreading. An SIR estimation scheme is used to obtain SIR distributions. As a performance measure, the received SIR distributions which indicate the QoS of each frame are collected in multi-cell(1-tier model) and multi-user environments. The received SIR distribution is a good indication for monitoring system-level states. From these received SIR distributions, power control performance, system degradation, and system capacity can be evaluated. The NB-TDD system performance is evaluated qualitatively and quantitatively from the received SIR distribution. In addition, the degradation probability derived from the received SIR distribution is shown as a example.

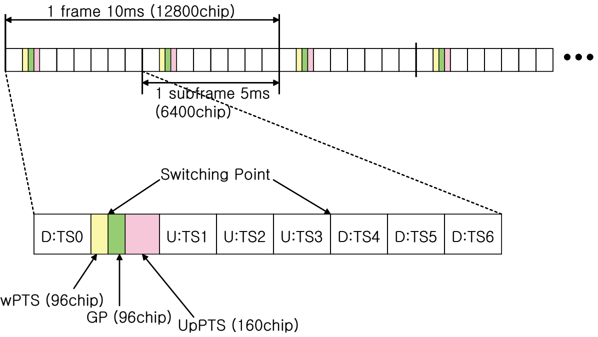

Fig. 1. Radio frame structure for NB-TDD

The outline of this paper is as follows: First, The NB-TDD system is briefly described in Section 2, and a system-level simulator of the NB-TDD system is implemented in Section 3. Performance measures of the system-level simulator are described in Section 4 and simulation results are shown in Section 5. Finally, conclusions are presented in Section 6.

II. NB-TDD SYSTEM

The NB-TDD system supported by China and Siemens is based on the WCDMA-TDD system. In Layers 2 and 3, services and functions of the NB-TDD system are almost similar to the WCDMA-TDD[1]. In Layer 1, the NB-TDD system has similar channel, frame, and channel multiplexing structures to the WCDMA-TDD. However, the NB-TDD system includes advanced technologies such as joint detection and smart antenna. For adapting to these key technologies, the NB-TDD is modified in frame structures and burst types[1][2].

In the NB-TDD, the frame length is 10ms and each frame is divided into 2 sub-frames of 5ms. The frame structure for each sub-frame in the 10ms length is the same with the WCDMA-TDD system[1]. The frame structure for each sub-frame is shown in Fig.1. The total number of timeslots for data traffic is seven. Timeslot 0 which includes control channels is always used for downlink. The other six timeslots are used for uplink and downlink data channels. The number of uplink and downlink timeslots can be configured according to traffic balance between uplink and downlink. In each sub-frame of 5ms, there are two switching points for adjusting the number of uplink and downlink timeslots.

A burst structure for timeslots is introduced. The NB-TDD system has only one data burst type, compared with three data burst types in the WCDMA-TDD. The data burst type of the NB-TDD includes two data symbol fields of 352 chips, a midamble field of 144 chips, and a guard field of 16 chips. The midamble is used for training sequences. The

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† This work was supported in part by Korea Advanced Institute of Science and Technology (KAIST) and Samsung Electronics Co., LTD

midamble which is cyclically shifted version of a single basic midamble code is used to identify each UE in the same cell and the same timeslot[1].

The NB-TDD system has open-loop and closed-loop power control. The maximum frequency of the closed-loop power control is 200 cycle/sec, which corresponds to the sub-frame length of 5ms. The open-loop power control is performed only for uplink due to similarities between downlink and uplink channel characteristics. The closed-loop power control is based on the periodical measurements of received SIRs. If the measured SIR is smaller than the target SIR of a receiver, the transmitter sends a power-up command. On the other hand, a transmitter sends a power-down command in the reverse situation.

Each connection has a different combination of code and timeslot in a cell. Multi-code and multi-timeslot can be allocated for high rate data connection. Spreading with an allocated channelization code and scrambling with a scrambling code are performed for each connection, which is the same as the WCDMA-TDD[3][4].

III. SYSTEM MODELING

The objective of this study is to evaluate system-level performance of the NB-TDD system in multi-cell/multi-user environments. In system modeling, channel coding is excluded for simplification, but spreading and scrambling are included for accurately modeling inner-cell and outer-cell interference. The operating range of the system-level simulation is determined by link-level performance of the required target SIR. In addition, an SIR measurement scheme is included for SIR-based power control.

Fig.2 shows the multi-cell structure of the NB-TDD system-level simulator. Six neighboring hexagonal cells are located around an inner hexagonal cell. Each cell has multiple UEs and each UE is located at a fixed position. Handoff is not considered, but a constant mobile speed is assumed during a call for generating fast fading. Two receiver antennas for each Node B and one receiver antenna for each UE are assumed. The traffic type for evaluating system-level performance is 12.2kbps voice traffic. In case of uplink for 12.2kbps voice, each connection has one orthogonal code channel within one timeslot and the spreading factor is 8. In case of downlink for 12.2kbps voice, each connection has two orthogonal code channels within one timeslot and the spreading factor is 16 [5]. If the system has three timeslots for both uplink and downlink, the maximum number of active UEs in a 7-cell structure is 147.

A radio channel consists of three components: propagation loss, shadow fading, and fast fading. Propagation loss is determined by distance between a transmitter and a receiver. Shadow fading is represented by a log-normal shadowing and time-invariant because of the fixed location of UEs. Fast fading is time-variant due to varying mobile speeds and modeled by Jakes' fading. In case of uplink, two independent fast fading channels are assumed due to two receiver antennas and in case of downlink, one fast fading channel is assumed due to one receiver antenna.

Fig.3 shows the overall procedure of the NB-TDD system-level simulator for each connection. A transmitter(Tx) consists of Tx symbol generation, data modulation, spreading, and Tx power calculation. A receiver consists of despreading, SIR measurement, and power control bit generation. In order to obtain reliable results, data are collected after the time of Γ.

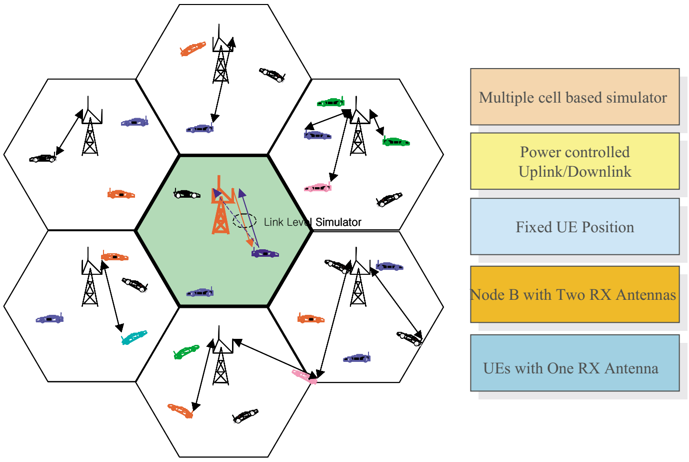

Fig. 2. Cell Structure for NB-TDD System-Level Simulator

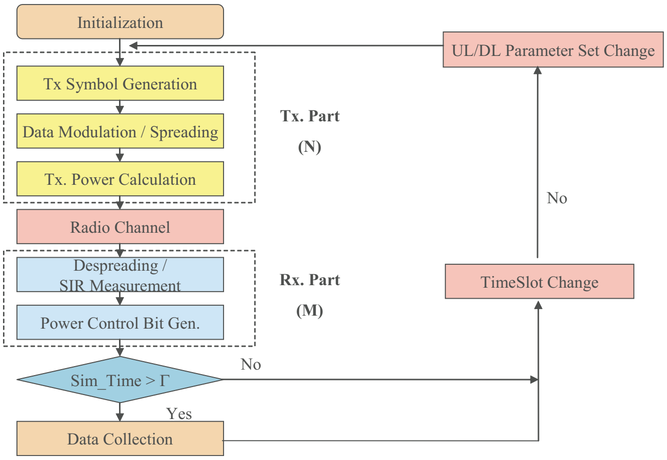

Fig. 3. Procedure of data transmission and receiption

A. Initialization

In the initialization phase of Fig.3, UEs are uniformly distributed within 7 cells. For data communication, each UE selects its own cell. In the NB-TDD system-level simulator, both propagation losses and shadow fadings are considered for the cell selection. UEs perform the cell selection by finding a cell with a minimum path loss from UEs. After the cell selection, radio resources considering of both codeword and timeslot are allocated to active UEs. For 12.2kbps voice traffic, two orthogonal codewords of spreading factor 16 and one timeslot are allocated per downlink connection and one orthogonal codeword of spreading factor 8 and one timeslot are allocated per uplink connection[5].

B. Symbol Generation, Data Modulation, and Spreading

Transmitted symbols are randomly generated for a Dedicated Physical Data Channel(DPDCH). There is no channel coding and 176 data symbols are generated for adapting the physical channel structure. Both downlink and uplink have a QPSK data modulation scheme. In the NB-TDD system-level simulator, each transmitter spreads the modulated-symbols in order to model inner-cell and outer-cell interference. All transmitters send the spreaded-symbols to all receivers. Then, the receivers despread the combined spreaded-symbols from all transmitters with their own orthogonal codewords and scrambling codes.

C. Radio Channel

The propagation delay is not considered in simulation. The propagation loss is mainly due to the geographical distance between a transmitter and a receiver. Eqn(1) models the propagation loss under the assumption that attenuation constant μ is 4.

$$P_r = P_t \cdot r^{-\mu} \tag{1}$$

Shadow fading is modeled as a log-normal distribution and time-invariant for a fixed location of UEs. In the initialization phase, shadow fading per UE from seven Node B's is generated. This shadow fading exhibits some correlation because shadow fading depends on geographical environments. When shadow fading is given by $x_1, x_2, .., and\ x_{m-1}$, the distribution of shadow fading x_m with a correlation coefficient of 0.5 is recursively calculated by

$$\begin{aligned} f(x_m) \mid_{x_1,..,x_{m-1}} &= \frac{f(x_1,\ldots,x_m)}{f(x_1,\ldots,x_{m-1})} \\ &\sim N\left(\frac{x_1+\ldots+x_{m-1}}{m}, \frac{m+1}{2m}\sigma^2\right), \end{aligned} \tag{2}$$

where σ is the standard deviation of 10dB and m=2,3. . .n.

The Jakes' fading model is used symbol by symbol.

D. SIR Measurement

For the closed-loop power control based on received SIR values, an optimized SIR estimation scheme is needed. In the NB-TDD system-level simulator, the mean-squre/variance method is used. The key idea is that a direct current(DC) component is a desired signal and a varying component corresponds to interference. For whole data symbols which are modulated by QPSK, the estimated SIR is derived as follows[6].

$$Estimated\ Rx.\ SIR = \frac{E_s}{I_0} \approx \frac{\mu^2}{2\sigma^2}, \tag{3}$$

where

$$\mu = \frac{1}{N}\sum_{i=1}^{N} \mid x_i \mid, and\ \sigma^2 = \frac{1}{N}\sum_{i=1}^{N} \mid x_i \mid^2 - \mu^2$$

E. Transmission Power Control

Power control is crucial in minimizing interference in CDMA systems. In the NB-TDD system-level simulator, the closed-loop power control is based on comparison of the received estimated-SIR with the target SIR. The dynamic range of power control is limited to ±15dB and ±10dB from the initial transmitted power in downlink and uplink, respectively[5][7].

TABLE 1

SIMULATION PARAMETERS

Environment	Value or Method
Cell radius	1 km
Shadow fading standard deviation	10 dB
Attenuation constant	4
UE speed	3 km/h
Carrier frequencey	2GHz
Fast fading	Jakes' 1 path fading
Dynamic range of closed-loop power control	Downlink : ± 15 dB Uplink : ± 10 dB
Power control step size	± 1 dB

TABLE 2

LINK-LEVEL PERFORMANCE FOR BLER OF 10^{-2}

1-path	Downlink	Uplink
Received E_s/I_o	6.07 dB	5.5 dB

IV. PERFORMANCE MEASURES FOR SYSTEM-LEVEL SIMULATOR

The collected data from the NB-TDD system-level simulator is the received SIR distribution. The received SIR distribution is a strict measure for monitoring system states. The received SIR of each data burst varies with fast fading and transmitted powers of other users. All of the changes are reflected to the received SIR distribution. From the received SIR distribution, various approaches are available for estimating system-level performance. The degradation probability, which does not meet the target SIR, can be derived from the received SIR distribution. The degradation probability is briefly defined as follows:

- *Degradation Probability*: The degradation probability is defined as the accumulated probability below a specific received SIR

$$P_D = Pr\{Rx.\ SIR \leqq Target\ SIR - \alpha\}, \tag{4}$$

where α is the margin for meeting a QoS.

It is certain that the degradation probability is an important measure for evaluating performance in a power-limited system such as CDMA system. If the relationship between degradation and outage probabilities is given, the outage probability can be derived from the received SIR distribution. In this paper, we show the degradation probability from the received SIR distribution.

V. SIMULATION RESULTS

A. Simulation Environments and Parameters

Table 1 shows system and the environment parameters used for simulation. In the frame structure, Timeslots 1,2, and 3 are used for uplink and Timeslots 4,5, and 6 are used for downlink.

Table 2 shows the link-level performance of the NB-TDD system. The E_s/I_o values of Table 2 are the required SIRs for meeting BLER of 10^{-2}. The operating range of the system-level simulator is determined through link-level performance.

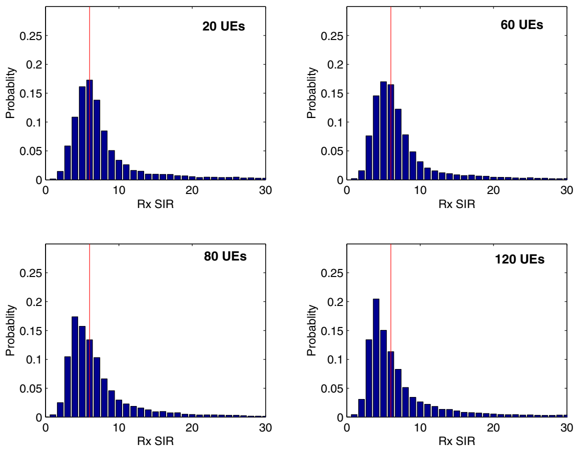

Fig. 4. The received SIR distributions for downlink with 20,60,80, and 120 UEs when the target SIR is 6 dB.

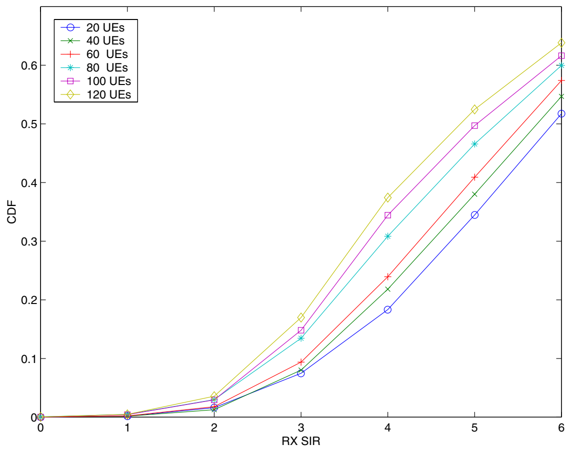

Fig. 5. The CDF of the received SIR distributions for downlink with 20, 40, 60, 80, 100, and 120 UEs when the target SIR is 6 dB.

B. Simulation Results

For a given environment of Table 1, simulations are performed through 20 seeds and 1,000 samples are collected per seed. The simulator collects received SIR samples only in the inner cell. In this subsection, downlink and uplink performance is independently analyzed under the assumption that there is no correlation between downlink and uplink.

B.1 Downlink Performance

In case of downlink, simulations are performed without considering diversity effect. The results under a target SIR of 6 dB are shown in this section.

Fig.4 shows the received SIR distributions for downlink when the target SIR is 6 dB. The bars in each figure represent the received SIR distribution and the vertical line set at 6dB indicates the target SIR. The probability that the SIR is over 10 dB is observed due to large fluctuations of the received SIR. An increase in the number of UEs causes to shift the position of the received SIR with the maximum probability to the left. Since an increase in the number of UEs yields an increase in interference, the average received SIR decreases. An increase in the number of UEs yields a performance degradation because the probability below a specific received SIR increases.

In case of 80 UEs and 120 UEs of Fig.4, the received SIR with maximum probability is below the target SIR of 6dB. It means that power control is not effective under the given number of UEs. Reducing the number of UEs is inevitable for stable communication. In this way, system capacity can be estimated from the received SIR distributions.

In order to evaluate the system performance quantitatively, the received SIR distribution is expressed by CDF, as shown in Fig.5. Fig.5 is focused on the range from 0 dB to 6 dB because the performance degradation depends on what is the probability below the target SIR. CDF values from 0.1 to 0.2 are shown at a received SIR of 3 dB. As predicted in qualitative analyses from Fig.4, an increase in the number of UEs yields worse performance and the degradation probability P_D increases.

B.2 Uplink Performance

In case of uplink, there is a diversity effect from two receiver antennas. The receiver diversity gain is approximately 2∼3 dB in a fading environment. The effect of asynchronous transmission is not considered. Fig.6 shows the received SIR distribution for uplink when the target SIR is 6 dB. In Fig.6, the received SIR with maximum probability shifts only a little to the left as the number of UEs increases. There is little degradation even for 120 UEs. However, if there are no diversity gain and no synchronous transmission, degradation can be worse.

Fig.7 shows the CDF of the received SIR for uplink when the target SIR is 6 dB. From Eqn (4), the degradation probability increases as the number of UEs increases.

Fig.8 shows the CDF of the received SIR for uplink when the target SIR is 5 dB. The smaller target SIR means that services demand a lower QoS level under the assumption of identical link level performance. System capacity can be improved in terms of the number of UEs. Therefore, compared with Fig.7, the lower degradation probabilities are shown in Fig.8 and the variation of CDF decreases at the same number of UEs.

B.3 Overall Performance

The figures for uplink show similar characteristics to those for downlink. However, compared with Fig.4, the variation of the received SIR distribution for uplink is smaller than for downlink. The reason can be explained by the central limit theorem. In case of uplink, more transmitters make a gaussian-like shape of the received SIR distribution. Another reason is receiver antenna diversity. For uplink, there are two receiver antennas, while there is only one receiver antenna for downlink. The diversity gain increases the received SIR value and supports more capacity in power-limited environments. Through comparison between Figs.7 and 8, it is verified that the lower target SIR is required, the more capacity can be supported. This trend can be observed in Table 3.

Table 3 derived from the CDF of the recieved SIR shows the relationship among the degradation probability, the num-

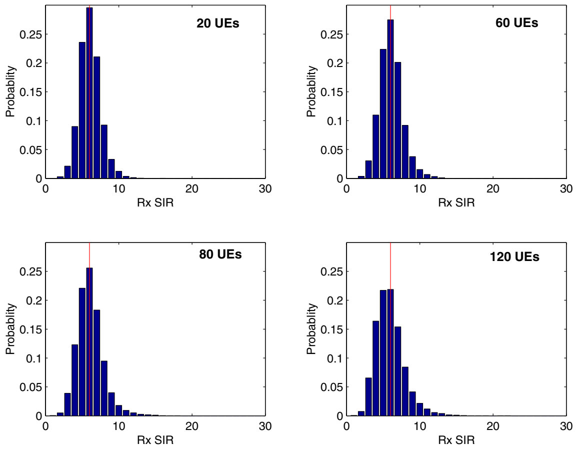

Fig. 6. The received SIR distributions for uplink with 20,60,80, and 120 UEs when the target SIR is 6 dB.

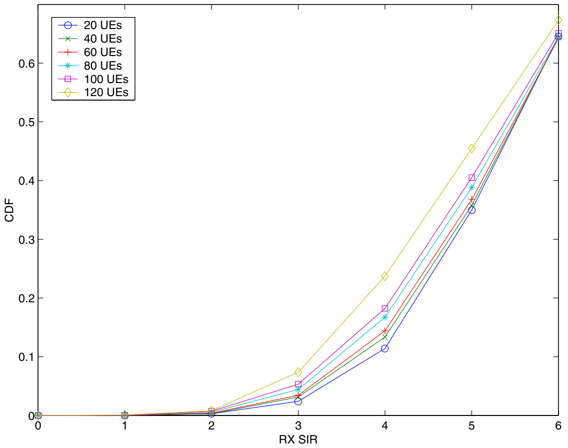

Fig. 7. The CDF of the received SIR distributions for uplink with 20, 40, 60, 80, 100, and 120 UEs when the target SIR is 6 dB.

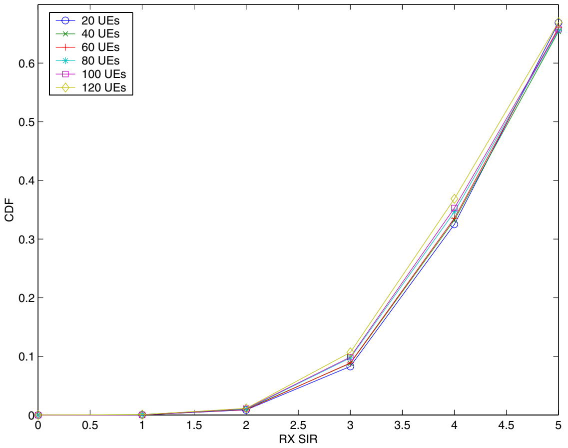

Fig. 8. The CDF of the received SIR distributions for uplink with 20, 40, 60, 80, 100, and 120 UEs when the target SIR is 5 dB.

TABLE 3

DEGRADATION PROBABILITY WHEN α IS 3DB

Number of UEs	DL (5dB)	UL (5dB)	DL (6dB)	UL (6dB)	DL (7dB)	UL (7dB)
20	0.022	0.009	0.075	0.024	0.104	0.039
40	0.023	0.010	0.080	0.031	0.167	0.064
60	0.028	0.009	0.094	0.034	0.212	0.080
80	0.038	0.010	0.135	0.044	0.290	0.113
100	0.042	0.011	0.148	0.053	0.320	0.180
120	0.042	0.011	0.170	0.074	0.366	0.212

ber of UEs, and the target SIR. In Eqn (4), the degradation probabilities P_D are obtained under the condition that α is 3 dB. For supporting an appropriate number of UEs, the system is set at a low target SIR. However, as the compensation for the low target SIR, the system requires a powerful channel coding and open-loop/outer-loop power control scheme.

From the results of Table 3, a small decrease in the target SIR provides a large capacity for the NB-TDD system. Thus, it is possible to achieve a large capacity for downlink, if multi-path fading and other diversity effects are considered.

VI. CONCLUSIONS

A system-level simulator of the NB-TDD system is developed. This system-level simulation is performed using a link-level simulation result. Inner-cell and inter-cell interference is modeled by chip-level spreading. An estimation method for the received SIR is used. The performance of the NB-TDD system is evaluated using the received SIR distribution for downlink and uplink. The various approaches for evaluating the system-level performance are available from the received SIR distribution and the degradation probabilities are shown as an example. For further study, this simulator will be used for analyzing the interference and power control schemes of the NB-TDD system in multi-cell and multi-user environments.

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