Transmission Power Control for Downlinks in CDMA/Shared–TDD Cellular Packet Systems

Kazuo MORI†, Takehiko KOBAYASHI†, Takaya YAMAZATO‡, and Akira OGAWA‡
† YRP Key Tech Labs
YRP Center 1st Bldg. 6F, 3-4 Hikari-no-oka, Yokosuka, 239-0847 Japan
Phone: +81 468 47 5303 Fax: +81 468 47 5305 E-mail: kmori@m.ieice.org
‡ Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan

Abstract— **This paper proposes a transmission power control scheme for downlinks in CDMA/shared–TDD cellular packet systems that experience inter-cell interference between uplinks and downlinks. The proposed scheme increases the downlink transmission power for re-transmission packets and thus improves the signal-to-interference ratio for the packets. Simulation results show that the proposed scheme improves downlink throughput without sacrificing the uplink throughput.**

Keywords— **asymmetric communication system, time division duplexing, CDMA, packet communication, transmission power control**

I. Introduction

Future mobile communication systems will be called upon to provide various multimedia services besides voice communication. Current mobile communication systems have a symmetric structure whose uplinks (mobile to base station) and downlinks (base to mobile station) occupy the same bandwidth, which is suitable for voice communication. However, data and video communication services generally have asymmetric traffic between the links. In these services, a large amount of traffic may be transferred in one direction, while a small amount of traffic may be transferred in the other. Time division duplexing (TDD) is more flexible than frequency division duplexing (FDD) from the viewpoint of accommodating asymmetric traffic because TDD systems can adaptively allocate time slots to uplinks and downlinks according to the balance of traffic [1]. A shared–TDD scheme that allows uplink and downlink traffic to share a common channel (bandwidth) has been proposed for low-delay high-quality wireless voice communications [2]. This shared–TDD scheme can also be applied to accommodate asymmetric traffic; and its application to time division multiple access (TDMA) cellular systems based on a circuit-switched architecture has been investigated [3]. In contrast, the application of the shared–TDD scheme to code division multiple access (CDMA) systems has been studied only in single-cell environments [4].

Since CDMA cellular systems use the same frequency band for all cells, the shared–TDD scheme may cause inter-cell interference between uplinks and downlinks (hereafter called "inter-link interference") when it is applied to CDMA packet communication systems in cellular environments. CDMA/shared–TDD cellular packet systems experience two additional types of inter-link interference that do not occur in FDD or conventional TDD systems: the interference between base stations (from downlinks to uplinks) and the interference between mobile stations (from uplinks to downlinks). We have previously studied these interferences and have concluded that interference between base stations rarely degrades uplink throughput, but interference between mobile stations substantially degrades downlink throughput [5].

This paper proposes a transmission power control (TPC) scheme that improves downlink throughput performance in CDMA/shared–TDD cellular packet systems. Frequent re-transmissions of the packets degrades link quality in the packet communication systems. The proposed scheme aims to improve downlink quality by raising the downlink transmission power for re-transmission packets. Computer simulation shows that this scheme improves downlink throughput performance without sacrificing uplink throughput.

II. CDMA cellular packet systems using a shared–TDD scheme

A. Shared–TDD scheme

A frame format of a shared–TDD scheme at the base stations is shown in Fig. 1. The shared–TDD frames consist of three types of slots: access slots (A-slot) used only by mobile stations (uplink), broadcast slots (B-slot) used only by base stations (downlink), and information slots (I-slot) shared by both links under the control of the base stations. Control signals are transmitted via the A- and B-slots. The I-slots carry user information and are divided into two parts – the first part is for the downlink and the second is for the uplink – by a movable TDD boundary.

In cellular systems with the shared–TDD scheme, base stations adaptively move the position of the TDD boundary frame-by-frame according to the amount of traffic in each link. The position of the TDD boundary is broadcast to the mobile stations by their base station via the B-slots.

B. Interference between uplinks and downlinks

The positions of the TDD boundaries differ between cells because each base station autonomously controls the TDD boundary of its frames. This is because the ratios of uplink to downlink traffic generally differ between cells. Hence, at around the TDD boundary, the slots used for uplinks in a certain cell may be used for

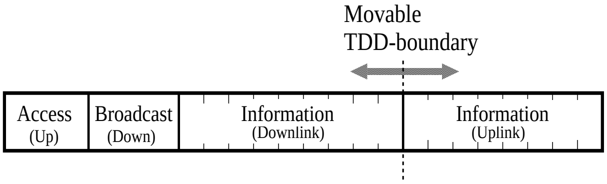

Fig. 1. **Frame format of shared–TDD scheme.**

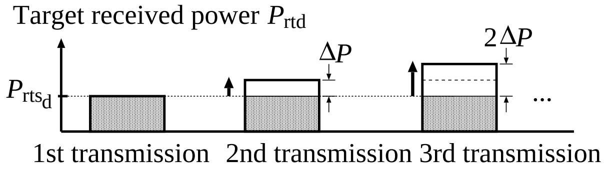

Fig. 3. **Proposed transmission power control.**

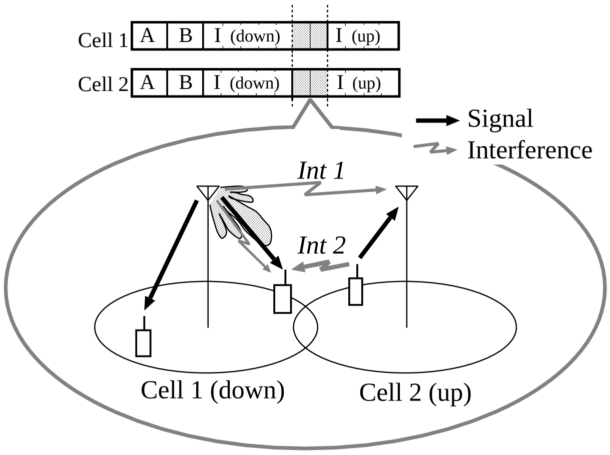

Fig. 2. **Inter-link interference.**

downlinks by adjacent cells, as illustrated in Fig. 2. The different positions of the TDD boundary in adjacent cells cause inter-link interference in CDMA cellular packet systems that use the same frequency band for all cells.

CDMA/shared–TDD cellular packet systems experience two additional types of interference:

- interference between base stations (*Int 1*) and
- interference between mobile stations (*Int 2*).

These do not occur in conventional systems, such as FDD systems and TDD systems with a fixed TDD boundary. As illustrated in Fig. 2, *Int 1* is the interference base stations suffer from downlink signals transmitted by adjacent base stations; and *Int 2* is the interference mobile stations suffer from uplink signals transmitted by mobile stations located in adjacent cells. These interferences have been evaluated and it has been showed that particularly the *Int 2* degrades downlink throughput in CDMA/shared–TDD cellular packet systems [5].

III. Transmission Power Control for Downlinks

The downlink packet transmission can fail if the signal-to-interference ratio (SIR) is low owing to excessive interference at the receiving mobile station. In addition to intra-cell and inter-cell interference, the SIR can be degraded by the inter-link interference *Int 2* in the CDMA/shared–TDD cellular packet systems.

Our proposed TPC scheme aims to reduce the degradation of downlink throughput caused by the inter-link interference. Basically, the packets whose transmission ends in failure are re-transmitted in packet communication systems. The systems should minimize the number of re-transmission packets because frequent re-transmissions substantially degrades link quality. In the proposed scheme, the transmission power is increased for the downlink packets that are re-transmitted by base stations in order to improve downlink quality. The base stations control a target received power P_{rt_d} at mobile stations for downlink packets. The target received power P_{rt_d} is increased as the number of re-transmissions increases, as illustrated in Fig. 3. The P_{rt_d} is initially set to a downlink standard target received power P_{rts_d}. For each re-transmission, the P_{rt_d} is increased by ΔP:

$$P_{\text{rt}_\text{d}} = P_{\text{rts}_\text{d}} + (N_{\text{tx}} - 1) \cdot \Delta P \ , \tag{1}$$

where N_{tx} is the number of transmissions. The proposed scheme improves the SIR for re-transmitted packets by increasing P_{rt_d}, and thus improves the downlink throughput.

IV. System Model

The service area in our system model consists of 19 hexagonal cells, as shown in Fig. 4. We only focused on two typical cases: one in which the slots are used for uplinks in the center cell and for downlinks in the other cells (Fig. 4(a)) and the other in which the slots are used in the opposite case(Fig. 4(b)).

The following conditions were assumed in the model:

- Base stations are located at the centers of the cells and broadcast a pilot signal with constant transmission power. Mobile stations are uniformly distributed across the cells.
- The uplink and downlink packets are transmitted between mobile stations and the base stations, whose pilot signal is the strongest at mobile stations, by direct-sequence (DS)/CDMA. The spreading sequences used in arriving packets do not collide.
- The multiple access protocol is slotted-ALOHA. Synchronous acquisition of the frames and slots is perfect at all base stations. Spreading sequences used in downlink packets are synchronous, but those used in upnlink packets are asynchronous at base stations.
- Each radio channel suffers propagation loss and shadowing fluctuation with a log-normal distribution, but it does not suffer Rayleigh fading.
- Perfect TPC is carried out for both links. TPC compensates for both propagation loss and shadowing. The transmission power is constant over

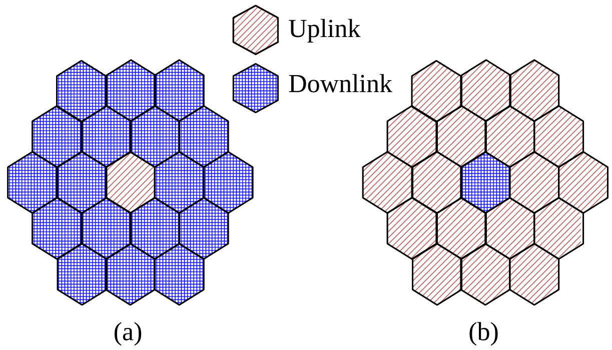

Fig. 4. **Cell model.**

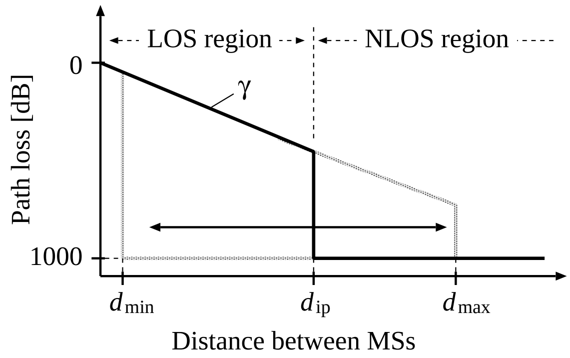

Fig. 5. **Simplified model of interference between MSs.**

the duration of one packet transmission. The uplink target received power $P_{\mathrm{rt_u}}$ is the same for all uplink packets ($P_{\mathrm{rt_u}} = P_{\mathrm{rts_d}} - \Delta P_{\mathrm{rt}}$, where ΔP_{rt} is the difference between uplink and downlink target received powers).

A. Propagation model

We used three types of propagation models in this study. New propagation models are assumed for the propagation of interference waves between base stations or between mobile stations, different from the conventional propagation model between base and mobile stations.

A.1 Between base and mobile stations

A propagation model with path loss of attenuation coefficient α has been generally used for the propagation between base and mobile stations. The path loss of a packet transmitted by the i-th mobile station and received at the j-th base station can be expressed as

$$P_{\mathrm{ls_{bm}}}(i,j) = \frac{10^{S(i,j)/10}}{d(i,j)^{\alpha}}, \tag{2}$$

where $S(i,j)$ is the shadowing fluctuation in the path from the i-th mobile station to the j-th base station, and $d(i,j)$ is the distance between them.

A.2 Between base stations

The propagation model used for *Int 1* was the conventional one (attenuation coefficient: α), but we also took into account a gain obtained by beam tilt of base station antennas. The path loss between the i-th and j-th base stations can be expressed as

$$P_{\mathrm{ls_{bb}(i,j)}} = \frac{1}{2G_t \cdot d(i,j)^{\alpha}}. \tag{3}$$

where G_t is the ratio of radiation level of the main beam region to that of the sidelobe region in the horizontal plane at each base station antenna.

A.3 Between mobile stations

A simplified model is proposed for the interference caused by *Int 2*. As illustrated in Fig. 5, the propagation of interference waves is categorized into either line-of-sight (LOS) or non-line-of-sight (NLOS) regions. The attenuation coefficient in the LOS region is γ ($2 \leq \gamma < \alpha$). In the NLOS region, the interference is assumed to be negligible. Point d_{ip}, separating the LOS region from the NLOS region, is given randomly for each propagation path and is distributed uniformly between d_{min} and d_{max}. The path loss between the i-th and j-th mobile stations can be expressed as

$$P_{\mathrm{ls_{mm}}}(i,j) = \begin{cases} \dfrac{10^{S(i,j)/10}}{d(i,j)^{\gamma}} \ ; & d(i,j) \leq d_{\mathrm{ip}} \\ 1/10^{100} \ ; & \text{otherwise} \ . \end{cases} \tag{4}$$

B. DS/CDMA Channel Model

The average received power of a packet transmitted by the i-th station with transmission power $P_{\mathrm{tx}}(i)$ and received at the j-th station is expressed as

$$P_{\mathrm{rx_{pq}}}(i,j) = P_{\mathrm{tx}}(i) \cdot P_{\mathrm{ls_{pq}}}(i,j), \tag{5}$$
$$p \text{ and } q = \text{either } b \text{ or } m.$$

At the j-th base station, the SIR of the uplink packets transmitted by the i-th mobile station is calculated as

$$SIR_{\mathrm{up}}(i,j) = \frac{PG \cdot P_{\mathrm{rx_{bm}}}(i,j)}{I_{\mathrm{up_b}} + I_{\mathrm{down_b}}}, \tag{6}$$

where PG is the processing gain, $I_{\mathrm{up_b}}$ is the total interference power of other uplink packets, and $I_{\mathrm{down_b}}$ is that of downlink packets arriving from other base stations. $I_{\mathrm{up_b}}$ and $I_{\mathrm{down_b}}$ are given by

$$I_{\mathrm{up_b}} = \sum_{\substack{k=1 \\ k \neq i}}^{K_u} P_{\mathrm{rx_{bm}}}(k,j) \tag{7}$$

and

$$I_{\mathrm{down_b}} = \sum_{k=1}^{K_d} P_{\mathrm{rx_{bb}}}(k,j), \quad (8)$$

where K_u is the number of arriving uplink packets at the base station and K_d is the number of downlink packets arriving from other base stations.

At the j-th mobile station, the SIR of its downlink packet transmitted by the i-th base station is calculated as

$$SIR_{\mathrm{down}}(i,j) = \frac{PG \cdot P_{\mathrm{rx_{bm}}}(i,j)}{I_{\mathrm{down_m(in)}} + I_{\mathrm{down_m(ex)}} + I_{\mathrm{up_m}}}, \quad (9)$$

where $I_{\mathrm{down_m(in)}}$ is the total interference power of other downlink packets transmitted by the i-th base station, $I_{\mathrm{down_m(ex)}}$ is that of downlink signals transmitted by the other base stations, and $I_{\mathrm{up_m}}$ is that of uplink packets arriving from mobile stations located at other cells. $I_{\mathrm{down_m(in)}}$, $I_{\mathrm{down_m(ex)}}$, and $I_{\mathrm{up_m}}$ are given by

$$I_{\mathrm{down_m(in)}} = (1 - F_o) \cdot \sum_{\substack{k=1 \\ k \neq j}}^{K_{\mathrm{di}}} P_{\mathrm{rx_{bm}}}(i,k), \quad (10)$$

$$I_{\mathrm{down_m(ex)}} = \sum_{k=1}^{K_{\mathrm{de}}} P_{\mathrm{rx_{bm}}}(k,j), \quad (11)$$

and

$$I_{\mathrm{up_m}} = \sum_{k=1}^{K_u} P_{\mathrm{rx_{mm}}}(k,j), \quad (12)$$

where K_{di} is the number of downlink packets transmitted by the i-th base station, K_{de} is the number of the other base stations that transmit downlink signals, and K_u is the number of arriving uplink packets at the j-th mobile station. F_o is an orthogonality factor defined as the fraction of total received power that will be experienced as intra-cell interference due to multipath propagation. The F_o is 1.0 for perfect orthogonality and 0.0 for non-orthogonality.

When the received signal level is considered constant over the duration of a packet, the packet error rate $P_e(i,j)$ can be assumed by [6]

$$P_e(i,j) = \begin{cases} 0\,; & SIR(i,j) \geq SIR_{\mathrm{req}} \\ 1\,; & \text{otherwise}\,, \end{cases} \quad (13)$$

where SIR_{req} is the SIR that required for a base station to receive packets correctly.

C. Traffic Model

New packets arrive only in the observed slots at intervals that follow an exponential distribution with an average of T_{slot}/G in each cell, where the slot duration is T_{slot} and the offered load (the average number of generated packets per slot duration per cell) is G. Base or mobile stations transmit their packets, whose length is the same as the slot duration with the exception of guard time, at the next head of downlink or uplink I-slot. If no acknowledgment arrives after a packet is transmitted, the station re-transmits the packet after a re-transmission delay, which has an exponential distribution with an average of T_{delay}. The packets are discarded when the number of re-transmissions reaches N_{max}.

TABLE I

Simulation parameters.

Cell radius	500	[m]
Propagation loss coefficients	α: 3.5, γ: 3.0	
Point from LOS to NLOS (d_{ip})	0–500 (uniform)	[m]
Shadowing	σ: 7.0	[dB]
Processing gain (PG)	16	
Required SIR (after despread)	5.0 (both links)	[dB]
Difference ΔP_{rt} between uplink and downlink P_{rt}s	6.0 ($P_{\mathrm{rt_d}} > P_{\mathrm{rt_u}}$)	[dB]
Packet generation (only in observed slots)	Poisson (time), uniform (space)	
Re-transmission delay (T_{delay})	0.04	[s]
No. of re-transmission (N_{max})	2	
Gain of beam tilt (G_t)	10	[dB]
Downlink orthogonality (F_o)	1.0 (perfect)	

D. Performance Measures

The uplink and downlink throughput, S_u and S_d were evaluated using computer simulation. The throughput S is defined as $N_{\mathrm{suc}}/N_{\mathrm{slot}}$, where N_{suc} is the total number of correctly received packets at the destination stations and N_{slot} is the total number of observed slots. Namely, S means the average number of correctly received packets per slot per cell.

V. Performance Evaluations

The simulation parameters are listed in Table I. Throughputs were observed at the center cell in the 19-cell model.

A. Downlink throughput

The downlink throughput S_d of the center cell when the uplink offered load G_u in each adjacent cell is a parameter is shown in Fig. 6. The slots were used for downlinks in the center cell and for uplinks in the other cells, as shown in Fig. 4(b). Figure 6 shows the S_d for the conventional scheme (dashed lines) and the proposed scheme (solid lines) when $\Delta P = 6.0$ dB. The S_d for both schemes degrades as the uplink load G_u in adjacent cells increases, indicating that interference from up to down links (*Int 2*) substantially affects downlink throughput performance. With the proposed scheme, the S_d is better than that of the conventional scheme across all downlink loads for all values of the uplink load in adjacent cells. This is because the successful reception rate for the re-transmitted packets is improved owing to the increased transmission power. The rate of improvement in S_d increases with the uplink load G_u. For $G_d = 6.0$ and $G_u = 3.0$, the proposed scheme outperforms approximately 20% over the conventional scheme.

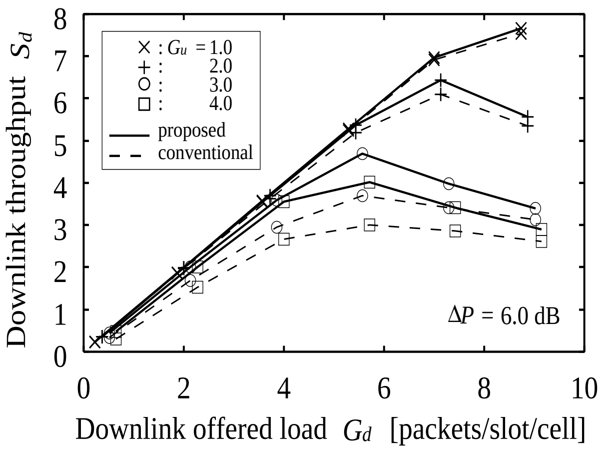

Fig. 6. **Downlink throughput S_d versus downlink offered load G_d with the adjacent cells uplink offered load G_u as a parameter when ΔP is 6.0 dB.**

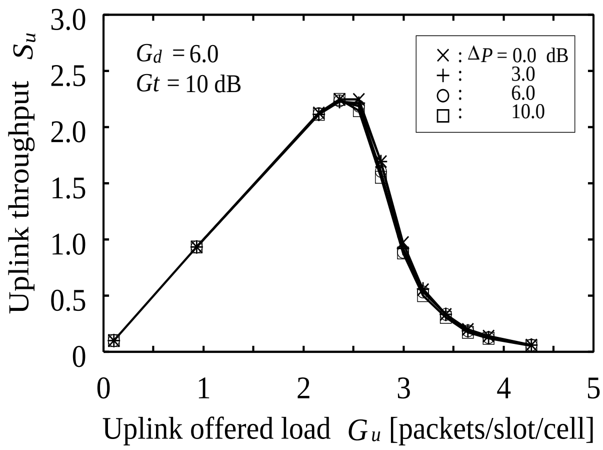

Fig. 8. **Uplink throughput S_u versus uplink offered load G_u with ΔP as a parameter when the adjacent cells downlink offered load G_u is 6.0.**

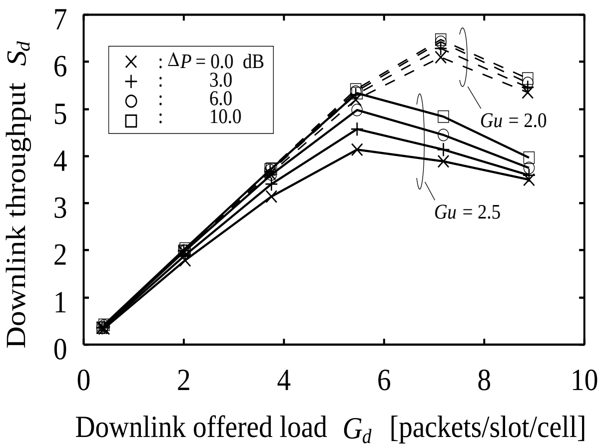

Fig. 7. **Downlink throughput S_d versus downlink offered load G_d with ΔP as a parameter when the adjacent cells offered load G_u is 2.0 or 3.0.**

Figure 7 shows the downlink throughput S_d of the proposed scheme for various increases ΔP in the target received power under the same conditions as for Fig. 6. The S_d improves with ΔP for both G_u. The improvement in S_d with increasing ΔP depends on the uplink offered load G_u in the adjacent cells: the proposed scheme improves the downlink throughput S_d as the G_u becomes large. It follows from these results that the proposed scheme improves the downlink throughput in slots that suffer *Int 2*.

B. Effect on uplink throughput

Figure 8 shows the uplink throughput performance S_u of the proposed scheme in the center cell for various increases ΔP when $G_d = 6.0$ and beam tilting gain G_t = 10 dB. The slots were used for uplinks in the center cell and for downlinks in the other cells, as shown in Fig. 4(a). The proposed scheme has almost the same S_u for ΔPs regardless of the uplink load. These results makes it evident that the proposed scheme does not degrade uplink throughput.

VI. Conclusions

This paper has proposed the downlink transmission power control scheme to reduce the effect of inter-link interference when a shared–TDD scheme is applied to CDMA cellular packet communication systems. The proposed scheme increases the transmission power for downlink re-transmission packets. Computer simulation showed that the proposed scheme improves the downlink throughput performance in slots with inter-link interference. The effect of increasing downlink transmission power on uplink throughput was negligibly small. The proposed scheme can improve downlink capacity without sacrificing uplink capacity in CDMA cellular packet systems using a shared–TDD scheme.

Acknowledgments

The authors would like to express their gratitude to Yoshihiko Ishikawa, Dr. Shoichiro Yamasaki, and Dr. Kohji Takeo for their valuable advice and assistance with this study.

References

[1] M. Inoue, H. Morikawa, and M. Mizumachi, "A new duplex method for integrated voice/data wireless communications," in Proc. IEEE ICUPC'95, pp. 888–892, Tokyo, Nov. 1995.

[2] W. Wong, C. W. Sundberg, and N. Seshadri, "Shared time division duplexing: an approach to low-delay high-quality wireless digital speech communication," IEEE Trans. Veh. Technol., vol. 43, no. 4, pp. 934–944, Nov. 1994.

[3] L. Chen, S. Yoshida, H. Murata, and S. Hirose, "A dynamic timeslot assignment algorithm for asymmetric traffic in multimedia TDMA/TDD mobile radio," IEICE Trans. Fundamentals, vol. E81-A, no. 7, pp. 1358–1366, July 1998.

[4] D. G. Jeong and W. S. Jeon, "CDMA/TDD system for wireless multimedia service with traffic unbalance between uplink and downlink," IEEE J. Select. Areas Commun., vol. 17, no. 5, pp. 939–946, May 1999.

[5] K. Mori, T. Kobayashi, T. Yamazato, and A. Ogawa, "Throughput evaluation in CDMA/Shared–TDD packet systems in a cellular environment," in Proc. IEEE WCNC'00, Chicago, IL, Sept. 2000.

[6] K. Toshimitsu, T. Yamazato, M. Katayama, and A. Ogawa, "A novel spread slotted aloha system with channel load sensing protocol," IEEE J. Select. Areas Commun., vol. 12, no. 4, pp. 665–672, May 1994.