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Multihop Cooperative Transmissions for Asymmetric Traffic Accommodation in CDMA/FDD Cellular Networks

Kazuo Mori, Takeo Saga, Katsuhiro Naito, and Hideo Kobayashi

Abstract—The asymmetric traffic between uplink and downlink over recent mobile communication systems has been conspicuous because of providing new communication services. This paper proposes an asymmetric traffic accommodation scheme adopting a multihop cooperative transmission technique for CDMA/FDD cellular networks. The proposed scheme employs the cooperative transmission technique in the already proposed downlink multihop transmissions for the accommodation of the asymmetric traffic, which utilizes the vacant uplink band for the downlink relay transmissions. The proposed scheme reduces the transmission power at the downlink relay transmissions and then suppresses the interference to the uplink communications, and thus, improves the uplink performance. The proposed scheme is evaluated by computer simulation and the results show that it can achieve better throughput performance.

Keywords—asymmetric traffic, cooperative transmissions, multihop transmissions, CDMA, FDD, cellular systems

I. Introduction

MOBILE communication networks have recently provided various services besides voice service and have conveyed various traffic such as data and video traffic in addition to voice traffic. The characteristics of the traffic over recent mobile communication networks has been changing because of providing these new multimedia communication services. From the view point of traffic symmetry between uplink (mobile to base station) and downlink (base to mobile station), multimedia communications generally have asymmetric characteristic in their traffic volume. Moreover, the degree of this asymmetry would vary with time and geographical locations and this causes time-varying and geographical non-uniformity in the communication quality across the service area in mobile communication networks.

However, current mobile communication networks, such as the third generation cellular networks, have a symmetric structure, in which uplink and downlink occupy the same frequency bandwidth, because the symmetric structure is suitable for traditional voice communication, which exhibits symmetric characteristic between the uplink and downlink traffic. The asymmetric traffic would waste the radio resource and degrade its utilization in the mobile communication networks with symmetric radio resource assignments. Many approaches have, therefore, been proposed to efficiently accommodate asymmetric traffic in mobile communication networks [1]–[9].

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These researches for efficiently accommodating asymmetric traffic have been mainly carried out focusing on mobile networks employing time division duplexing (TDD) scheme [1]–[7] because the TDD scheme has an ability to adaptively assign radio resources (time slots) to uplink or downlink according to the balance in the traffic between both links. However, there is little research performed for mobile networks with frequency division duplexing (FDD) scheme except [8] and [9]. The current major commercial mobile networks, for example the GSM networks and the W-CDMA networks, employ the FDD scheme all over the world, and therefore, it is considerably important to investigate the accommodation of asymmetric traffic for FDD mobile networks and to achieve its efficient scheme.

For CDMA/FDD cellular networks, we have recently proposed an asymmetric traffic accommodation scheme using a multihop transmission technique [9]. In this conventional scheme, the multihop transmission [10] is employed in downlink communications, which require the large transmission power at their single-hop transmissions. In these multihop transmissions, moreover, the vacant uplink band is used for the downlink transmissions from relay stations (RSs) to destination mobile stations (MSs) and between RSs, hereafter called "relay transmissions", and then, the conventional scheme achieves a capacity enhancement in the downlink communications. However, it can not avoid the degradation in the capacity of the uplink communications due to the additional interference from the downlink relay transmissions carried out in the uplink band.

This paper proposes an efficient asymmetric traffic accommodation scheme using multihop cooperative transmissions to overcome the drawback of the conventional scheme. The proposed scheme introduces the cooperative transmission technique [11] in the conventional downlink multihop transmissions in order to improve the transmission quality in the downlink multihop transmissions. The proposed scheme reduces the transmission power of the downlink transmissions carried out in the uplink band and then suppresses the interference to the uplink communications, and thus improves the uplink capacity. Owing to the quality enhancement in the downlink communications by the cooperative transmissions, the proposed scheme can keep the improvement in the downlink capacity even if the transmission power is reduced in the downlink relay transmissions. The proposed scheme is evaluated by computer simulation to demonstrate its effectiveness.

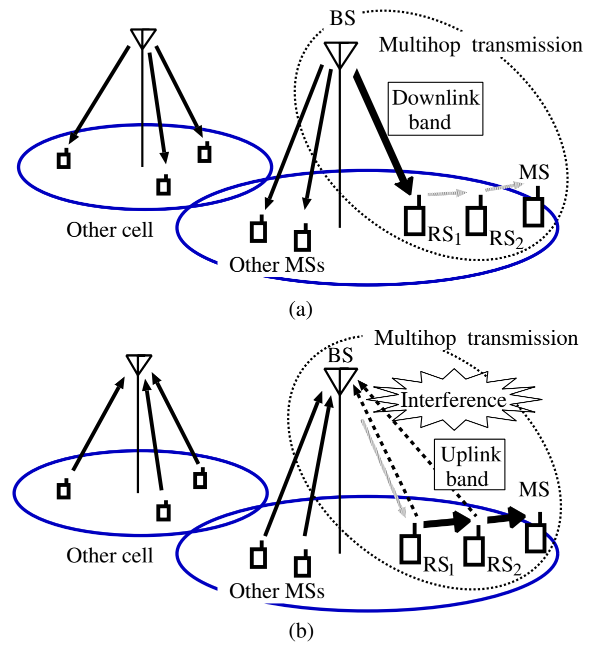

Fig. 1. Conventional multihop transmission for downlink communications. (a) First hop transmissions (from BS to RS) in downlink band. (b) Relay transmissions (from RS to RS/MS) in uplink band.

II. Conventional Asymmetric Traffic Accommodation using Multihop Transmissions

In current CDMA/FDD cellular networks, the fixed bandwidth is assigned for both links and the base stations (BSs) can not reassign their bandwidth resources. Therefore, for increase in downlink traffic, it is impossible to increase the downlink bandwidth even when the uplink bandwidth is large enough for the current uplink traffic. In this situation the network needs to increase the downlink channel capacity to achieve efficient asymmetric traffic accommodation. Then, the conventional scheme introduces the multihop transmission technique for the downlink communications to accommodate more downlink traffic. This downlink multihop transmission utilizes an available (vacant) bandwidth assigned to the uplink for downlink communications to achieve more capacity enhancement in the downlink. In this multihop transmission, the transmissions from BSs to RSs are carried out in the downlink band like the normal multihop transmission, whereas the relay transmissions between RSs and from RSs to destination MSs are carried out in the uplink band, as illustrated in Fig. 1.

Therefore, this multihop transmission employs decode-and-forward (DF) relay, and the packet with trasmission errors are not forwarded to the next stations.

A. Multihop transmission using the uplink band

The conventional scheme transmits the downlink signal by using multihop transmissions in the case when the transmission quality degrades in the downlink and the uplink quality is still good enough. Packet reception rates $p_{\rm rec}^{\rm d}$ and $p_{\rm rec}^{\rm u}$ are employed as an indicator of the transmission quality for the downlink and uplink, respectively. They defined as a ratio of the number of packets successfully received at the destination stations to the number of packets transmitted from the source stations in a given cell. Each BS monitors the packet reception rates for a certain observation period $T_{\rm ob}$ [slots].

Before transmitting the downlink signals, BSs compare monitored $p_{\rm rec}^{\rm d}$ and $p_{\rm rec}^{\rm u}$ with $p_{\rm rec}$-thresholds: $Th_{\rm rec}^{\rm d}$ and $Th_{\rm rec}^{\rm u}$ for the downlink and the uplink, respectively. And also they compare the transmission power $P_{{\rm BS}_{\rm sgl}}$, which is the power at the BS in the case of the direct (single-hop) transmission from the BS to the MS, with both a power-threshold $Th_{\rm pw}$ and total transmission power $P_{\rm mlt}$ in the case of the multihop transmission, which is defined as:

$$P_{\rm mlt} = P_{{\rm BS}_{\rm mlt}} + \sum_{i=1}^{N_{\rm hop}-1} P_{{\rm RS}_i}, \quad (1)$$

where $P_{\rm BSmlt}$ and $P_{{\rm RS}_i}$ $(i = 1, 2, \cdots)$ are the transmission power at the BS and the RSs on the multihop route, respectively. $N_{\rm hop}$ is the number of hops on it.

After these comparisons, the BSs decide to transmit the signals by using multihop transmission if the following two conditions are satisfied simultaneously:

(i) $p_{\rm rec}^{\rm d} < Th_{\rm rec}^{\rm d}$ and $p_{\rm rec}^{\rm u} > Th_{\rm rec}^{\rm u}$

(ii) $P_{{\rm BS}_{\rm sgl}} > Th_{\rm pw}$ and $P_{{\rm BS}_{\rm sgl}} > P_{\rm mlt}$.

The first condition is for the channel quality in both links and indicates that the multihop transmission is selected if the downlink has lower quality and the uplink has higher quality than the given levels $(Th_{\rm rec}^{\rm d}, Th_{\rm rec}^{\rm u})$. The second is for transmission power and indicates that the multihop transmission is selected if the transmission power in the single-hop case is larger than both the given level $(Th_{\rm pw})$ and that in the multihop case.

B. Relay route selection

For the relay route selection, the conventional scheme employs a selection method minimizing total transmission power, as described in [12],[13].

In this method, the destination MS calculates the total transmission power $P_{\rm mlt}$, which is given by Eq.(1), for each candidate multihop route by using route search signals, which are transmitted from BS and RSs and contain the transmission power $P_{{\rm RS}_i}$ for each hop. And then, the destination MS selects the relay route whose $P_{\rm mlt}$ is the smallest, and sends back the routing information to its BS.

C. Motivation of this work

This conventional scheme achieves a capacity enhancement in the downlink communications through the downlink multihop transmissions using the vacant uplink band. However, this scheme has a drawback which the capacity of the uplink communications degrades due to the additional interference from the downlink relay transmissions carried out in the uplink band.

The motivation of this work comes from this drawback of the conventional scheme and the objective of this paper

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is to eliminate the performance degradation in the uplink communications with the conventional asymmetric traffic accommodation scheme.

III. Asymmetric Traffic Accommodation using Multihop Cooperative Transmissions

To overcome the drawbacks in the conventional scheme, we propose a novel asymmetric traffic accommodation scheme adopting multihop cooperative transmissions.

To eliminate the degradation in the uplink capacity, the suppression of the interference is required in the uplink band. The straightforward way to suppress the interference is to reduce the transmission power in the relay transmissions for the downlink packets. However, this approach also leads to the degradation in the downlink communications, and therefore, we have to provide the interference suppression method for the uplink band with keeping the improvement in the downlink capacity achieved by the conventional scheme.

To achieve this requirement, the proposed scheme introduces the cooperative transmissions in the conventional downlink multihop transmissions in order to obtain further improvement in the transmission quality in the downlink multihop transmissions. And then, it reduces the transmission power at the relay transmissions carried out in the uplink band in order to suppress the interference in the uplink band from the downlink relay transmissions

A. Multihop cooperative transmission

The cooperative transmission is a technique which improves the received signal quality through spatial diversity gain caused from signal combining of the received signals from multiple RSs located between the source station and the destination station.

The proposed scheme introduces this technique to the downlink multihop transmissions and employs the similar method as that proposed in [14]. Figure 2 shows an example of the system configuration in the proposed scheme. In the multihop transmission, each RS and MS may receive the signal not intended for itself due to signal propagation phenomena in the wireless communication environments. For example in Fig. 2, the destination MS may receive the signals transmitted from BS and RS_1 intended for RS_1 and RS_2, respectively. The received signal at the MS from RS_2 is basically same as those transmitted from BS (which is intended for RS_1) and from RS_1 (which is intended for RS_2), and therefore, the MS can combine these signals to improve the received signal quality: signal to interference ratio (SIR).

Due to this diversity gain, even if the transmission power in the relay transmissions ($RS_1 \rightarrow RS_2$ and $RS_2 \rightarrow$MS in Fig. 2) is reduced, the MS can ensure the equal or superior received signal quality to that for the conventional scheme. This suggests that the improvement in the downlink capacity is kept with the reduction of the transmission power in the relay transmissions.

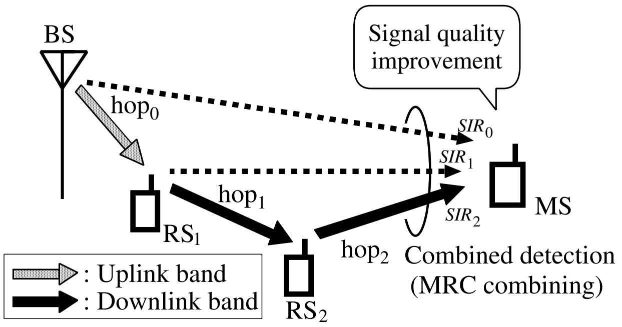


Fig. 2. Multihop cooperative transmission (3-hop transmission case) for downlink communications.

B. Signal combining

For diversity combining, the proposed scheme employs a well-known maximal ratio combining (MRC) [15]. As described in [15], assuming the same noise at each signal, the signal to noise ratio (SNR) $\gamma_{\rm div}$ after MRC is given by $\gamma_{\rm div} = \sum_{i=1}^{M} \gamma_i$, where M is the number of combined signals and γ_i is the SNR of the i-th signal.

In the proposed scheme, assuming the same interference against each received signal from the BS or RS at the destination MS, the combined SIR $SIR_{\rm div}$ after MRC at the MS is given by:

$$SIR_{\rm div} = \sum_{i=0}^{N_{\rm hop}-1} SIR_i \ , \tag{2}$$

where SIR_i is the received SIR of the signal from the i-th hop ($i = 0, 1, \cdots, N_{\rm hop} - 1$) at the MS.

C. Transmission power reduction in relay transmissions

Transmission power control (TPC) is mostly applied for CDMA cellular networks and transmission power depends on the target SIR at the receiver and the propagation loss from transmitters and receivers in the SIR based TPC. Then, the proposed scheme controls the target SIR at the receiver to reduce the transmission power in the relay transmissions.

In this paper, we propose two power reduction methods: constant power reduction and adaptive power reduction.

1) Constant power reduction (cPR): The constant power reduction (cPR) method reduces the target SIR $SIR^{\rm co}_{\rm tgt}$ in the relay transmissions by a reducing factor $\Delta SIR_{\rm co}$ of a constant value. Then, the transmission power at the RSs is reduced in proportion to the $\Delta SIR_{\rm co}$, leading to the reduction in the interference power from the RSs in the uplink band. As a result, the signal quality would improve at the uplink communications.

The target SIR $SIR^{\rm co}_{\rm tgt}$ [dB] for the relay transmissions in this method is given by:

$$SIR^{\rm co}_{\rm tgt} = SIR_{\rm tgt} - \Delta SIR_{\rm co} \ , \tag{3}$$

where $SIR_{\rm tgt}$ is a target SIR value in the normal transmissions.

2) Adaptive power reduction (aPR): The improvement in the received SIR at the destination MSs owing to the proposed cooperative transmission varies with the MSs or the received signals and the constant power reduction experiences less or excess received SIR, which leads to the degradation in the downlink multihop or the uplink communications. Then, the adaptive power reduction (aPR) method adaptively reduces the target SIR in the relay transmissions according to the improvement in the received SIR at the MSs.

The amount of reduction in the target SIR $\Delta SIR^{(i)}_{\mathrm{adpt}}$ at the i-th RS (for example, RS$_i$ in Fig. 2) or the destination MS is given by:

$$\Delta SIR^{(i)}_{\mathrm{adpt}} = \begin{cases} 0 & ; \quad i=1 \\ \sum_{j=0}^{i-1} SIR_j \; ; & \text{otherwise} \; , \end{cases} \tag{4}$$

where SIR_j is the received SIR of the signal transmitted from the j-th transmitter (BS in the case of j=0) at the i-th receiver. The target SIR $SIR^{\mathrm{adpt}(i)}_{\mathrm{tgt}}$ [dB] at the i-th receiver for the relay transmissions in this method is given by:

$$SIR^{\mathrm{adp}t(i)}_{\mathrm{tgt}} = SIR_{\mathrm{tgt}} - \Delta SIR^{(i)}_{\mathrm{adpt}} \; . \tag{5}$$

In this case, if $SIR^{\mathrm{adp}t(i)}_{\mathrm{tgt}} \leq 0$ then the $(i-1)$-th RS discards the packet and does not forward it to the next i-th receiver.

Accordingly, employing the cooperative transmission and the transmission power reduction methods mentioned above, the proposed scheme would eliminate the degradation in the uplink communications with keeping the improvement in the downlink communications.

IV. Simulation Model

To evaluate the performance of the proposed scheme, we carried out computer simulations assuming CDMA/FDD cellular networks with the following conditions:

- The service area consists of 19 cells with a two-ring configuration. BSs are located at the center of the cells.
- MSs are uniformly distributed across the cells. The number of MSs in each cell is constant: N_{MS}.
- The multiple access protocol for the uplink is slotted ALOHA. The downlink channel also has a slot structure. Slot synchronization is perfect among cells for both links.
- Each packet employs a unique spreading sequence so that those used by arriving packets do not collide.
- TPC is the SIR based control with the target SIR SIR_{tgt} and is perfect without errors.

A. DS/CDMA channel model

1) Propagation model: Each radio channel suffers propagation loss P_{ls} with distance attenuation and shadowing fluctuation.

For the propagation between BSs and MSs(RSs), the distance attenuation has an attenuation coefficient α_{BM} and shadowing fluctuation which follows a log-normal distribution with a standard deviation (SD) of σ_{BM} [dB] because this propagation is categorized into macro-cell propagation.

The propagation in the relay transmissions is considered to be micro-cell propagation, which is modeled as 2-path propagation model with a direct path and a reflecting path on the ground. Therefore, its distance attenuation has an attenuation coefficient α_{RM1} before the break point d_{bk} [m] and α_{RM2} after the break point, and its shadowing fluctuation follows a log-normal distribution with a standard deviation of σ_{RM} [dB].

2) SIR calculation: In the CDMA network, the packets interfere with other packets arriving from within the service area.

Thus, the uplink SIR $SIR^{\mathrm{u}}(i)$ of the desired packet i can be calculated as

$$SIR^{\mathrm{u}}(i) = PG \cdot P_{\mathrm{rx}}(i) \Big/ \Big(\sum_{\substack{k=1 \\ k \neq i}}^{K_{\mathrm{u}}} P_{\mathrm{rx}}(k) + \sum_{k=1}^{K_{\mathrm{rm}}} P_{\mathrm{rx}}(k) \Big), \tag{6}$$

where $P_{\mathrm{rx}}(x)$ is the received signal power of the packet x, PG is processing gain, K_{u} is the number of arriving uplink packets at the BS from the service area, K_{rm} is the number of downlink relay packets arriving from the service area. In this formula, the second term of the denominator represents the interference power from the downlink relayed packets, which is transmitted in the uplink band.

The downlink SIR $SIR^{\mathrm{d}}_{\mathrm{BM}}(i)$ at the single-hop transmission and the transmission from BSs to RSs in the multihop transmission can be calculated as

$$SIR^{\mathrm{d}}_{\mathrm{BM}}(i) = PG \cdot P_{\mathrm{rx}}(i) \Big/ \Big\{ (1-F_o) \sum_{\substack{k=1 \\ k \neq i}}^{K_{\mathrm{di}}} P_{\mathrm{rx}}(k) + \sum_{k=1}^{K_{\mathrm{de}}} P_{\mathrm{rx}}(k) \Big\}, \tag{7}$$

where K_{di} is the number of downlink packets arriving from the same BS at the MS (RS), and K_{de} is the number of downlink packets arriving from other BSs. F_o is an orthogonality factor defined as the fraction of total received power that will be experienced as intra-cell interference due to multi-path propagation [16].

The downlink SIR $SIR^{\mathrm{d}}_{\mathrm{RM}}(i)$ at the relay transmissions in the uplink band can be calculated in almost the same way as that of the uplink packets, which is

$$SIR^{\mathrm{d}}_{\mathrm{RM}}(i) = PG \cdot P_{\mathrm{rx}}(i) \Big/ \Big(\sum_{k=1}^{K_{\mathrm{u}}} P_{\mathrm{rx}}(k) + \sum_{\substack{k=1 \\ k \neq i}}^{K_{\mathrm{rm}}} P_{\mathrm{rx}}(k) \Big) \; , \tag{8}$$

where the first and second terms of the denominator represent the interference power from the uplink packets and other downlink relayed packets, respectively.

B. Packet error probability

The transmission power is assumed to be constant for the duration of a packet, that is, the SIR is constant for a packet duration. In this paper, we assume the packet error probability $P_e(i)$ can be approximated by

$$P_e(i) = \begin{cases} 0 \; ; & SIR^{\mathrm{u}}(i) \; or \; SIR^{\mathrm{d}}(i) \geq SIR_{\mathrm{req}} \\ 1 \; ; & \text{otherwise} \; , \end{cases} \tag{9}$$

where SIR_{req} is the SIR required for the receivers to receive packets successfully [17].

TABLE I
SIMULATION PARAMETERS

	Symbol	Value	
Cell radius	R_{cell}	500	[m]
Distance att. coefficient	$\alpha_{\mathrm{BM}}, \alpha_{\mathrm{RM1}}, \alpha_{\mathrm{RM2}}$	3.5, 2.0, 4.0	
SD of shadowing	$\sigma_{\mathrm{BM}}, \sigma_{\mathrm{RM}}$	7.0, 7.0	[dB]
Break point	d_{bk}	45	[m]
Processing gain	PG	16	
Orthogonality factor	F_o	0.6	
Required SIR	SIR_{req}	5.0	[dB]
Target SIR	SIR_{tgt}	6.0	[dB]
Observation period	T_{ob}	200	[slots]
Threshold for p_{rec}	$Th^{\mathrm{u}}_{\mathrm{rec}}, Th^{\mathrm{d}}_{\mathrm{rec}}$	0.0, 0.8	
Distance-threshold	Th_{dist}	300	[m]
The number of MSs	N_{MS}	100	
The number of hops	N_{hop}	2	
Traffic asymmetry factor	R_{asym}	0.7	

C. Traffic model

1) Asymmetric traffic: Each cell has the same traffic load G_{up} in the uplink, G_{dn} in the downlink and the total traffic load G_{to}, which is the sum of G_{up} and G_{dn}. The traffic load G_{up}, G_{dn} and G_{to} are defined as the average number of generated packets during a slot duration per cell. To simulate the asymmetric traffic conditions, G_{up} and G_{dn} are set to a different value and a traffic asymmetry factor R_{asym} is defined as a ratio of G_{dn} to G_{to}.

2) Packet generations: The uplink and downlink packets arrive following a Poisson arrival with an average of G_{up} and G_{dn} in each cell, respectively. The length of the packets is the same as the slot duration. BSs and MSs transmit their packets at the head of the slot. The source MS for the uplink packet and the destination MS for the downlink packet are selected randomly among the MSs located in the cell at which the packet arrives. The packets which the receiving station fails to receive successfully are discarded without re-transmissions.

V. PERFORMANCE EVALUATIONS

A. Simulation parameters and evaluated metric

In our simulations, we use the parameters listed in Table I. Instead of the power-threshold Th_{pw} for the criterion of transmission power $P_{\mathrm{BS_{sgl}}}$ in the single-hop route, we can use a distance-threshold Th_{dist} [m] which is converted from Th_{pw} by using the propagation model between BSs to MSs without the shadowing.

The throughput performance S_{up}, S_{dn} and S_{to} [packets/slot/cell] for the uplink, the downlink, and the total (uplink + downlink) are evaluated in the center cell of the service area. The throughput is defined as the average number of successfully received packets at the destinations per slot per cell.

The performance for the proposed scheme is compared with the conventional scheme employing the downlink multihop transmissions and only single hop transmissions with a symmetric bandwidth assignment. The proposed scheme also has a symmetric bandwidth assignment. The number of hops N_{hop} is limited to 2 for both the conventional and the proposed multihop transmissions.

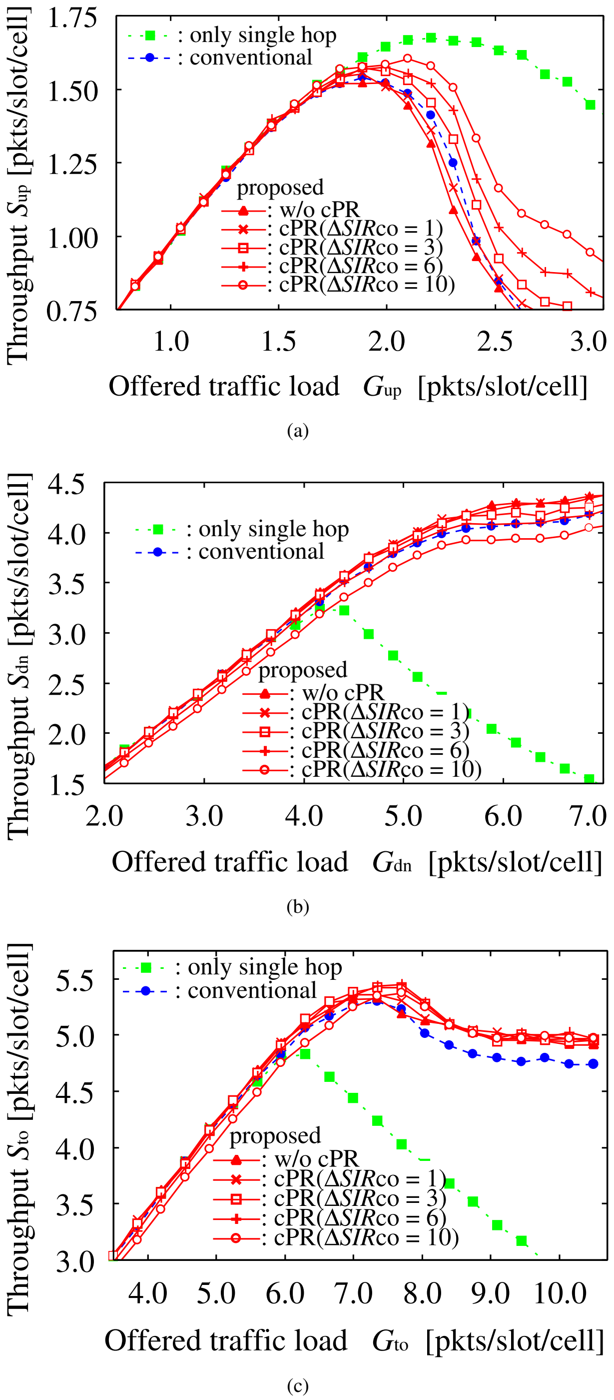


Fig. 3. Throughput performance for the proposed scheme with the constant power reduction (cPR) method as a function of offered traffic load. (a)Uplink performance S_{up} versus G_{up}. (b)Downlink performance S_{dn} versus G_{dn}. (c)Total performance S_{to} versus G_{to}.

B. Throughput performance

Figure 3 show the throughput performance: uplink S_{up} in Fig. 3(a), downlink S_{dn} in Fig. 3(b), and total S_{to} in Fig. 3(c) for the network employing the proposed scheme with/without the constant power reduction (cPR) method, the conventional multihop scheme, and only single hop case, as a function of the offered traffic load. For the proposed scheme with cPR, Fig. 3 shows the throughput for various values of the reducing factor ΔSIR_{co} of 0 ("w/o cPR" in the figure), 1, 3, 6, and 10 [dB].

For the uplink, the throughput S_{up} for the proposed scheme improves with increasing ΔSIR_{co} from the conventional one, and the performance degradation below the only single hop case is getting small with increasing ΔSIR_{co}. Around the peak throughput, the proposed scheme achieves smaller degradation (-3.7%) than the conventional scheme (-7.6%). This comes from the reduction of the transmission power in the relay transmissions and then the suppression of the interference power to the uplink communications.

For the downlink throughput S_{dn}, the proposed scheme slightly improves the throughput for small values of ΔSIR_{co}, compared with the conventional scheme. Of course, the downlink throughput for the proposed scheme greatly improves from the single hop case. However, the performance degrades with increasing ΔSIR_{co}, unlike the uplink throughput, and for the large ΔSIR_{co} (= 10 [dB] for example), the proposed scheme has worse performance than the conventional one. Therefore, we can find clear trade off between uplink and downlink throughput for varying the value of ΔSIR_{co}.

For the total throughput S_{to}, due to this trade off, the proposed scheme employing middle values of ΔSIR_{co} (= 3 or 6 [dB] for example) achieves the best performance and improves the total throughput compared with the conventional scheme.

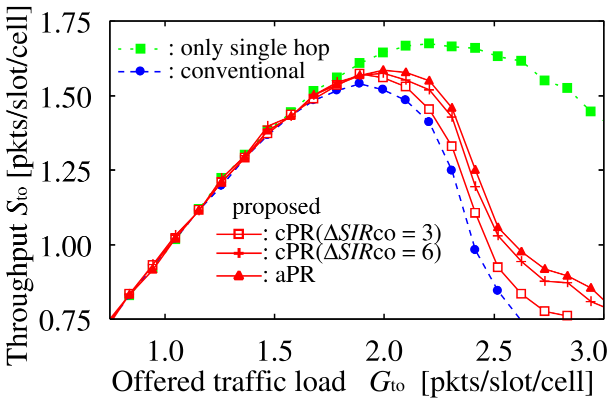
Figure 4 shows the throughput performance for the network employing the proposed scheme with the adaptive power reduction (aPR) method. This also shows the performance for the proposed scheme with cPR, the conventional scheme, and the only single hop transmission case.

Roughly speaking, the proposed scheme with aPR achieves almost the same performance as the proposed scheme with cPR employing adequate ΔSIR_{co} (= 6 [dB]) and slightly improves the uplink and total performance, compared with the conventional scheme. This comes from the ability of the proposed aPR method which the amount of reduction in the transmission power at the relay transmission can be adaptively decided according to the individual multihop transmission.

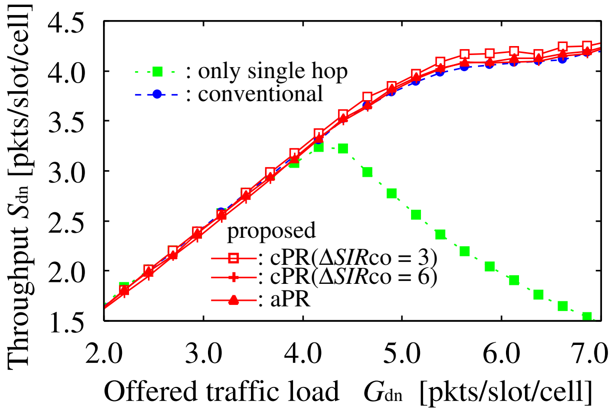
VI. Conclusions

This paper discussed the asymmetric traffic accommodation in CDMA/FDD cellular packet communication networks. The asymmetric traffic accommodation scheme adopting the multihop cooperative transmission technique has been proposed to enhance the system performance. The throughput performance have been evaluated by computer simulation to demonstrate the effectiveness of the proposed scheme.

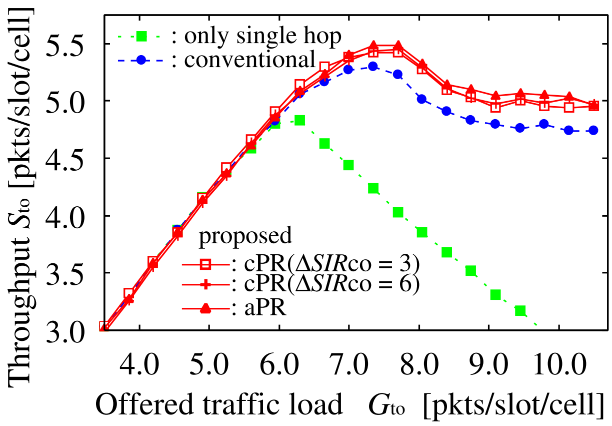
The simulation results show that, compared with the conventional scheme, the uplink throughput improves and the degradation below the single hop case can be eliminated, and then total throughput slightly improves. From these results it can be concluded that the proposed scheme is effective for the accommodation of asymmetric traffic in CDMA/FDD networks.



(a)



(b)



(c)

Fig. 4. Throughput performance for the proposed scheme with the adaptive power reduction (aPR) method as a function of offered traffic load. (a)Uplink performance S_{up} versus G_{up}. (b)Downlink performance S_{dn} versus G_{dn}. (c)Total performance S_{to} versus G_{to}.

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