Packet Scheduling for Cellular Relay Networks by Considering Relay Selection, Channel Quality, and Packet Utility

Rui Zhou, Hoang Nam Nguyen, and Iwao Sasase

Abstract: **In this paper, we propose a packet scheduling algorithm for cellular relay networks by considering relay selection, variation of channel quality, and packet delay. In the networks, mobile users are equipped with not only cellular but also user relaying radio interfaces, where base station exploits adaptive high speed downlink channel. Our proposed algorithm selects a user with good cellular channel condition as a relay station for other users with bad cellular channel condition but can get access to relay link with good quality. This can achieve flexible packet scheduling by adjusting transmission rates of cellular link. Packets are scheduled for transmission depending on scheduling indexes which are calculated based on user's achieved transmission rate, packet utility, and proportional fairness of their throughput. The performance results obtained by using computer simulation show that the proposed scheduling algorithm is able to achieve high network capacity, low packet loss, and good fairness in terms of received throughput of mobile users.**

Index Terms: **Adaptive rate, packet delay, relay selection, scheduling algorithm, throughput, user fairness.**

I. INTRODUCTION

Providing quality of service (QoS) is one of the crucial requirements in wireless high speed data networks which exploit adaptive multi-rate shared channels, such as beyond third generation (B3G) wireless networks and IEEE 802.16 wireless metropolitan area networks (WMAN). In order to achieve user fairness, round robin (RR) scheduling algorithm is proposed. On the other hand, maximum carrier to interference ratio (MCIR) scheduling algorithm can be used to achieve high system throughput. However, as the wireless channel condition is varying, existing scheduling algorithms do not utilize channel resources efficiently [1], [2].

Recently, opportunistic scheduling has drawn much research interests due to the efficient usage of channel resources, by developing rate adaptation schemes to increase data transmissions selectively on a link when it offers good channel quality [1]. In contrast, opportunistic manner always causes unfair to users who experience poor channel quality. The modified largest delay weight algorithm [3] is considered as a throughput optimal proportional fairness scheduling, which provides packets with long waiting time higher priority to be served. Furthermore, to provide QoS requirement for different traffic classes (delay sensitive traffic and delay tolerant traffic) [4], the proportional fairness based scheduling algorithms have been proposed in [5]–[8], where different traffic classes are distinguished, and delay bounded packet scheduling algorithms are provided. However, in these studies, high priority is given to delay sensitive packets, whereas a lot of delay tolerant packets would suffer long delay. More seriously, compared with users having good channel condition, the users with poor channel condition have to suffer from low priority. Thus, the low performance of such users becomes the bottleneck of scheduling design for system throughput enhancement.

In contrast to the conventional cellular systems, which use base stations (BSs) to transmit packets to mobile stations (MSs) directly, wireless relaying cellular network architecture has been proposed [9], by taking the advantages from the multi-hop networks, where the throughput-optimal scheduling strategies are considered with the queuing systems and routing for time varying channels [10], [11]. In the architecture, a MS can access the core network by connecting to BS directly in cellular mode or via other terminals, which operate as relays forwarding packets of MSs [12], [13]. A unified cellular and ad-hoc is proposed in [14] by introducing a routing protocol and proportional fairness scheduling in extension of 3G cellular.

Most of the previous works focus on the architecture of the relaying networks, there is little research considering the interaction between the relay selections and scheduling algorithms according to our knowledge. In high speed wireless networks, the scheduling decision should be made very quickly time slot by time slot, where the selection for scheduled user affects the system throughput significantly. Furthermore, the selection of the relay might be the bottleneck if the scheduled user has to receive its packets via a relay. Thus, in order to improve the system capacity and packet QoS support, more efficient packet scheduling algorithms are needed in relaying networks. In this paper, we propose a packet scheduling algorithm for relaying cellular networks by considering relay selection where MSs can use cellular adaptive multi-rate and user relay channels. Nowadays, more cell phones, PDAs, and laptops are equipped with several wireless interfaces. Although the utilization of more resources (e.g., energy, bandwidth) is required as compared to the conventional single hop, the cost of such utilization could be reduced by sharing the information (e.g., SNR, traffic) between the cellular channel and ad hoc channel. Since the relay selec-

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tion information is only fed back to BS, there is no inter-MS transmission.

Our objective is to improve system throughput and guarantee user's QoS for different traffic classes. In order to improve user fairness in terms of received throughput, our algorithm also introduces user throughput as a part of the scheduling index by comparing it with the overall average throughput. The proposal can also be recognized as a cross-layer approach, where the signal-to-noise ratio (SNR) based multi-rate support at physical layer offers primitives in an agile manner to fluctuations in channel conditions and channel utilization. The proposed scheduling algorithm considers both short term information such as available transmission rate, and the long term information such as user received throughput and packet delay constraint. Since different delay bounds are given to different traffic classes as QoS requirements, scheduling priority of packets is given by considering not only transmission rate of their destination MSs but also their waiting time in the data queue. Compared with Round Robin and MCIR scheduling algorithms, performance results obtained by using computer simulation show that the proposed scheduling algorithm can achieve higher overall throughput, less packet loss and better user fairness. The remainder of this paper is organized as follows. First, the system model is introduced in Section II. In Section III, our proposed packet scheduling algorithm by considering relay selection is described and analyzed. Section IV gives the numerical results and discussions before we conclude this paper in Section V.

II. SYSTEM DESCRIPTION

We consider a 3G-like cellular system with high speed downlink shared cellular channel. Mobile users access the cellular channel in a time division multiple access (TDMA) fashion. Fig. 1 shows the system model, where MSs are dual-mode, having both cellular and ad hoc relaying radios (without loss of generality, only central cell in the multi-cell model is shown in the figure). Without confusions we denote MS as the mobile user in the network, and relay stations (RSs) as the MSs which act as relays for other MSs. In contrast, subscriber stations (SSs) are denoted as the MSs which are end users connecting directly to BS or RSs. Each cell consists of a BS and a set of finite MSs. BS maintains the separate queues for each MS with different traffic classes. In addition, we assume that data rates achieved by the ad hoc relaying radio are assumed to be much higher than those achieved by the cellular radio. This is usually true because, for example, transmission rates up 54 Mb/s can be achieved for IEEE 802.11g.

Due to the symmetric channels we consider downlink without loss of generality in this paper, since uplink case can be analyzed in a similar manner. In the cellular channel, time is divided into constant time slots, where MSs are sharing the multi rate adaptive channel. BS selects an available transmission rate level for a MS based on its received SNR (denoted as γ) when scheduling its packets. In case a packet is selected to transmit to ith MS, BS selects the appropriate transmission rate by following condition:

$$\gamma_i \geq \gamma_L \tag{1}$$

where γ_L denotes the required SNR corresponding to rate level L, i denotes the number of the MS. Thus, the transmission rate calculated by a SNR-rate function f for MS i at time slot t is expressed as,

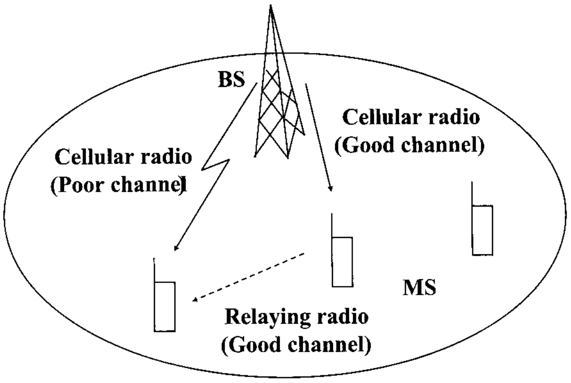


Fig. 1. System model of relaying cellular networks.

$$r_i(t) = f(\gamma_i(t)) \tag{2}$$

where f compares the user SNR to the required SNR for each transmission rate level and selects the proper rate level for the user.

By exploiting dual mode terminal, an active MS is able to choose other MSs which are in its relaying radio range and have better channel quality as its RS. Communication links between RSs and MSs use frequency spectrum which is only available to relaying radio and does not consume the spectrum of cellular shared links. Assume that BS can transmit control messages including the decision of relay selection and scheduling signaling to all MSs in an individual control channel in the cell. By synchronizing and transmitting the control message in the cellular control channel, MSs connecting with RSs can also listen to this channel and feedback their SNR information. Received SNR is assumed to be constant during transmission of a single packet. By shifting some MSs having poor cellular channel condition to connect with others having good cellular channel condition when the ad hoc channel between them is good, BS can allocate the system resource more efficiently.

Since packets are transmitted in a high speed channel to RSs and MSs, BS and RS can be considered to keep stable to provide connections during the transmission, while the channel condition is fixed. The objective of this paper focuses on the BS scheduling decision and relay selection. For the ad hoc link, we assume that the packets can be managed to be served with interference free channel by different relays due to the high transmission performances. Different RSs do not interfere each other, while MSs could only be assigned to RSs within its relaying radio range. Due to mobility, the cellular channel quality of RS is varying. According to the feedback information which may report different choices of relay or no relay available, BS can reallocate relay or establish direct connection in next time slot.

We consider both delay sensitive and delay tolerant traffic, which are denoted as streaming packets and best effort packets, respectively. A streaming packet has to be transmitted within a delay bound, otherwise it is dropped. On the other hand, a best effort packet is set to have a virtual delay bound. Although it is counted to have excessive delay, the system would fix its priority after its delay getting larger than the delay bound instead of dropping the packet. Thus, BS could select the destination MSs with poor cellular channel condition to connect with RSs with good cellular channel condition. We consider an independent traffic flow model in which for each MS independent sources generate data packets for transmission. For streaming packets, packet drop occurs not only due to the delay bound but also the buffer overflow in BS. In contrast, best effort packets would be dropped only due to the data queue overload.

In this paper, we focus on the resource allocation problem in the relaying networks. Since MAC layer could be separated from physical layer, we consider the MAC layer could guarantee the error-free transmission with proper rates while the physical layer would provide retransmission or error recovery. In cellular relay networks, packet delay should be calculated with either the direct mode or the relay mode, where ω is denoted as waiting time in the data queue and σ is denoted as transmission delay. Here, packet transmission delay σ from BS is calculated by the packet size divided by the transmission rate. Although the relay has the advantages of throughput enhancement, extra delay might be caused by the relay due to the queuing delay and transmission delay. In order to evaluate the delay performance for the comparison between direct and relay transmission, we introduce a parameter τ for the delay of relay. The total delay is calculated as following,

$$d = \begin{cases} \omega + \sigma, & \text{direct connection,} \\ \omega + \sigma + \tau, & \text{relaying connection} \end{cases} \quad (3)$$

where the relay transmission delay τ is an average value of relay links for simplicity. Packets might be forwarded in different routes to their destination. Therefore, the packets sent directly or via different RSs would arrive in different order as compared to their original order due to different transmission rate and waiting time. In this case, those packets can be reordered in destination MSs after being received. According to (3), transmission delay σ of packet depends on the available transmission rate.

III. PACKET SCHEDULING ALGORITHM

Compared to the conventional single hop cellular networks, relaying networks could benefit not only the users with poor cellular channel but also those with good channel. There are mainly two incentives for relay nodes to spend their resources on others. From the system's point of view, distribution of traffic load to the relay nodes could improve the aggregated system throughput and reduce the loss of packets. On the other hand, the relay nodes could get more resources (e.g., time slots) from the BS since fewer resources are used for MSs with low transmission rates (compared to non-relay case). In this section, we propose a scheduling algorithm by considering relay selection which takes into account the user's variable transmission rate based on their received SNR, packet delay requirement of multi traffic classes, and user fairness constraints.

A. Scheduling Index

Maximum two hop relay connection is considered, since by trading off between a major portion of possible performance gains and implementation complexity, the limiting the number of hops to two is a good design choice [15]. Due to the assumption that relay radio exploits a high speed channel, the channel condition between a MS and its RS would be kept stable until the RS completes the transmission of packets to the MS. In the relaying channel, a MS periodically broadcasts a beacon signal containing its ID within relaying range. The contents of each beacon signal include the MS ID, SNR level in the cellular channel and a pilot signal. Each MS only selects the MSs which have better SNR level as its potential relays (maximum 3) and report these IDs to BS so that the BS can maintain the list of possible MSs which can become RSs of others. If a MS does not report its ID of beacon signal after a defined period e.g. 10s, BS would consider that this MS has moved out. Therefore, BS can select other MSs as RSs within the relaying range. Since all the scheduling decisions are made by BS and RS will forward the relaying packets after receiving them, the MS does not have to report its selection of potential relays to RSs but only to BS. Let N denote the total number of MSs in a cell. Several MSs act as RSs, thus, we use the $N \times N$ matrix $H = [h_{i,j}]$ to denote the relay selection performed by BS, which satisfies,

$$h_{i,j} = \begin{cases} 1, & \text{if link } \overrightarrow{ij} \text{ is available} \\ 0, & \text{direct connection.} \end{cases} \quad (4)$$

By considering neighbor MSs within their relaying range, $h_{i,j}$ is set to 1 when MS j experiences the best channel quality among neighbors of MS i, while $i \neq j$. Note that if $h_{i,j} = 1$ and $i = j$, MS i directly connects to BS and can be selected as a RS. The value of the entity in the matrix is decided by BS to maximize the total performance of the networks. In order to improve the system throughput by using relays, BS would schedule the packet to RS for the MS which could connect to a RS with higher transmission rate. According to (4), for the MS i connected to RS, the available scheduling rate, $\varepsilon_i(t)$, considered by BS is presented as,

$$\varepsilon_i(t) = \sum_{j=1}^{N} h_{i,j} r_j(t) \quad (5)$$

where r_j is the transmission rate of cellular link of MS j. For each i, $h_{i,j}$ has only one non-zero value. BS selects only one RS for a MS when the MS is chosen for scheduling, although one MS could have more than one potential RS. Note that, the SSs connected to RSs replace their available transmission rate by their RSs' transmission rate to increase their scheduling priority. BS performs the relay selection by comparing the available scheduling rate for each MS with its available relay and selects appropriate values for H.

The scheduling decision consists of three parts: rate opportunistic index, packet utility index, and user fairness index. For MS i connecting to BS via RS j, the SS's available scheduling rate is replaced by the RSs' achieved rates, i.e., $h_{i,j} = 1$. In contrast, for MS k connecting to BS directly, the scheduling rate is its own transmission rate of cellular link with $h_{k,k} = 1$. By comparing the available transmission rate with the average, giving high priority to the MSs with high transmission rate could gain larger system throughput. On the other hand, MSs with poor cellular channel conditions could get higher priority by cooperating with the relay selection. Therefore, we use transmission rate of

MS i normalized to sum of all the MSs' as the rate opportunistic scheduling index, $R_i(t)$, which is expressed as,

$$R_i\left(t\right) = \frac{\varepsilon_i\left(t\right)}{\sum\limits_{i}^{N} \varepsilon_i\left(t\right)}. \tag{6}$$

The scheduler (BS) would use more resources for MSs who have better channel quality to increase the system throughput. In the rate opportunistic index, the scheduler prefers to serve MSs having high transmission rate, or SSs can connect to RSs with good channel quality although they have poor channel condition.

We depict the packet utility in terms of delay as shown in Fig. 2 to support QoS for different traffic classes. If packets are for streaming traffic, we can use a utility function that increases concavely and goes up near the delay bound. However, the utility would fall to zero after the delay getting larger than the delay bound, which refers to dropping loss of streaming packets. In the opposite, the utility increases convexly for best effort packets. Packet utility would keep the value 1 after the delay getting larger than the delay bound. Thus, the packet drop would be caused only by queuing drop in BS.

According to the packet utility function, the proposed scheduling algorithm assigns higher priority to streaming packets compared with best effort packets due to their urgency. In contrast, the priority of best effort packet is assigned with the delay bound. In the scheduler the larger the utility is, the faster the packet would be served. Consider the head packet in data queue of MS i, the packet utility scheduling index, $U_i(t)$, is shown as,

$$U_i\left(t\right) = \begin{cases} \left(\frac{d_i(t)}{D_S}\right)^2 W_S,\ t \le D_S, & \text{streaming packet,} \\ \min\left(\left(\frac{d_i(t)}{D_B}\right)^2, 1\right) W_B, & \text{best effort packet} \end{cases} \tag{7}$$

where $d_i(t)$ is denoted as the packet delay for the packet of MS i. Delay bound of streaming traffic D_S is smaller than the delay bound of best effort traffic D_B. W_S and W_B are denoted as weights for streaming and best effort traffic, respectively, which represent the priority for transmission. Practically, we set the value of W_S larger than the value of W_B to give the streaming packet higher priority. Packet delay depends on both available transmission rate and relaying selection, while packets would be dropped if queuing delay is higher than D_S. In contrast, the utility would increase convexly until the bound for best effort packets. In order to guarantee packet delay performance, packets with longer delay utility should have higher priority for transmission. Since our proposal gives a virtual delay bound to best effort packets, the priority of them would not increase after their queuing delay become larger than their delay bound. We define utility to be a larger value when the packet is experiencing longer delay in Fig. 2. Our objective here is that BS would transmit the packet which has higher probability to be dropped as quickly as possible. Here, we have to make the tradeoff between the delay performance and user fairness in terms of individual user throughput.

We address the fairness issue to MS received throughput within a period. If the throughput of a MS in a certain period is less than the average received throughput, BS should increase the priority to be served. $T_i(t)$ is the average of throughput received by MS i before time slot t in a certain period, which is denoted as the tracking time. Throughput of MS i, $T_i(t)$, is updated as follows [16],

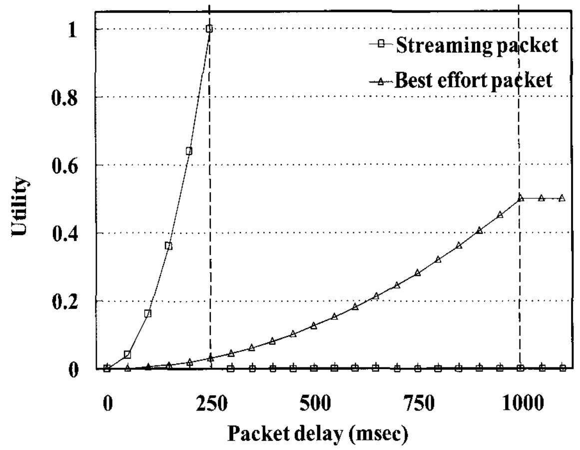


Fig. 2. Utility function.

$$T_i\left(t+1\right) = \left(1 - \frac{1}{t_w}\right) T_i\left(t\right) + \frac{1}{t_w}\phi_i\left(t\right) \tag{8}$$

where t_w is the window size of tracking time, while $\phi_i(t)$ is the current scheduling rate of MS i at time slot t,

$$\phi_i\left(t\right) = \begin{cases} \varepsilon_i\left(t\right), & \text{user } i \text{ is scheduled,} \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

where the throughput of each MS is updated every time slot. Note that, BS schedules one packet in one time, where the transmission for one packet would occupy more than one time slot. In this case, (9) would keep updating until the transmission finished. By selecting the value of tracking time for throughput, the long term throughput constraint can be set to satisfy different fairness requirement. An MS is given high priority when it experiences a bad throughput. The throughput based fairness scheduling index of MS i, $F_i(t)$ is defined as,

$$F_i\left(t\right) = \exp\left(\overline{T}\left(t\right) - T_i\left(t\right)\right) \tag{10}$$

where $\overline{T}\left(t\right)$ is denoted as the average throughput of all MSs expressed as,

$$\overline{T}\left(t\right) = \frac{\sum_i T_i\left(t\right)}{N}. \tag{11}$$

B. Packet Scheduling

Fig. 3 shows the procedure of proposed scheduling algorithm. Our objective of scheduling design is to improve the system throughput while keeping the user fairness and packet QoS by using relay and adaptive channel. Hence, BS makes the decision of scheduling with the criteria given by,

$$I = \arg\max_{1 \le i \le N} R_i\left(t\right) U_i\left(t\right) F_i\left(t\right) \tag{12}$$

- **MS reports its SNR and ID of received beacon signals to BS.**
- **BS compares each user's SNR with others in its relaying range and selects RSs for the SSs with poor celluar channel condition.**
- **Transmission rate index is calulated cooperating with the relay selection.**
- **For each user BS calculates utilities of the first packet for different traffic classes and selects the packet with the largest utility.**
- **BS calculates the throughput index $T_i(t)$ (there is no packet drop in relaying link).**
- **BS calculates the scheduling index for each ML, and selects the user with the largest value to serve.**

Fig. 3. Scheduling procedure.

BS would select the MS with the largest value of the scheduling index for transmission, by considering requirements for both MSs and their packets. By multiplexing the transmission rate index with packet utility, we can see that the SSs using relay with higher transmission rate can also achieve higher utility value.

IV. PERFORMANCE SIMULATIONS

A. Simulation Model and Assumptions

In this section, we carry out the computer simulation in terms of throughput, packet delay and user fairness by using the proposed scheduling algorithm. Our simulation is performed in a 9-cell model, where we focus on central cell. Each cell covers a square area with the range 800 m × 800 m. We assume that there is no collision between relaying links. MSs could receive from a RS in the radio range of 150 m. The variable rate channel experiences path loss, and follows the Rayleigh fading model for nomadic MSs. We assume that BS uses 10% of its total power for signaling channel, which becomes the intra-cell interference for data transmission. In contrast, the inter-cell interference is caused by neighbor BSs. At the beginning of the simulation we allocate the mobile nodes randomly in the cellular range by using a uniform distribution. Since the mobile nodes are expected to move in a practical network, the most commonly mobility model called random waypoint model [17] is used in this paper. For simplicity, the random waypoint model used in the simulation is assumed to keep the mobile nodes moving in the cellular range with the maximum speed of 5 meter per second.

The simulation is performed in a system level. The packet size and transmission rate used for simulation are assumed to be the real information bits. Packets with constant length are generated for each MS, equal for both streaming and best effort packets. Packet size is 900 bytes. We emulate the multi rate system, where we use 4 levels of transmission rates for simplification, although the system would have more transmission rate levels. The time slot duration is 1 msec. We emulate the multi rate system, where we use 4 levels of transmission rates for simplification, although the system would have more transmission rate levels [18]. Different SINR levels would be converted to the 4 levels of transmission rates, where the users with the SINR less than 0 dB would be considered as outage users. The users with SINR between 0dB and 4 dB, 4 dB and 8 dB, 8 dB and 12 dB would be assigned the transmission rates through level 1 to level 3 as shown in the table 1. In contrast, users with the SINR above 12 dB would be transmitted with level 4 transmission rate. A bursty traffic model is simulated for best effort traffic. BS has finite separated data queues of both streaming and best effort packets for each MS. Thus, packet loss is occurred for streaming packets which could not be transmitted within delay bound. For best effort traffic, packets get dropped due to the data queue overloaded.

Since there is no communication between MSs to select a relay, the overhead would not be so much even the number of MSs is increasing. Here, the overhead of selecting the relay is only the report of the potential relays to BSs in the cellular channel. Each MS only reports not more than 3 potential relays, the overhead in selecting relay is acceptable. On the other hand, the overhead in the ad hoc channel is only the broadcast of beacon signals. Since we use a slow mobility model in the simulation, the MS would only broadcast the beacon signal periodically (e.g., once 10 s). Thus, the overhead would not affect the network performance.

In our proposed algorithm, SS could connect to RSs who have better channel gain with relaying radio instead of direct connection with BS in a poor cellular channel as shown in Fig. 1. Each MS can feed back its received SNR and ID of received beacon signals to BS with the dedicated control channel. The simulation results are obtained considering received SNR levels and adaptive transmission rates shown in Table 1. We consider fixed numbers of MSs from 60 to 210 and compare our proposed algorithm with different scheduling algorithms:

- RR: Round Robin scheduling in a relay case, where BS schedules for each MS in a round robin fashion one after another.
- MCIR: Maximum CIR scheduling with relaying, BS selects the MS with best transmission rate for every scheduling decision.
- PNR: Proposed scheduling algorithm without relaying, where the available transmission rate of the MS depends only on received SNR.
- PR: Proposed scheduling algorithm with relaying.

For comparison, RR and MCIR algorithms are performed in a relaying fashion by using the proposed relay selection scheme. That is the BS compares both direct path and relay path for each MS and chooses the path with higher transmission rate for scheduling.

B. Performance Results

Fig. 4 shows the user relay connectivity ratio and outage probability. Since there are 4 levels of transmission modes in the simulation, while the SNR of the user could satisfy the lowest transmission level and the location of the user could not find another user as a relay in its relay range, the user is considered as an outage user. The relay connectivity refers to the normalized probability for MS to connect with a relay. As the user density

Table 1. Simulation parameters.

Symbol	Quantity	Value
R_B	Cell range (square)	800 m × 800 m
R_A	Relaying range	150 m
D_S	Streaming packets' delay bound	250 msec
D_B	Best effort packets' delay bound	1000 msec
W_S	Weight for streaming packets	1.0
W_B	Weight for best effort packets	0.5
D_R	Delay caused by relaying (buffering and propagation)	20 msec
t_w	Tracking window	5000 msec
σ	BS transmission delay	1, 2, 4, 8 msec
τ	Transmission delay of relay	20 msec
P	BS transmitting power	2w
SH	Shadowing attenuation Mean: Standard deviation:	 0dB 8dB
L	Available rate level: Level 1: Level 2: Level 3: Level 4:	Rate: 0.9 Mbps 1.8 Mbps 3.6 Mbps 7.2 Mbps
Tr_S	Constant arrival streaming traffic	12 kbps / User
Tr_B	Arrival best effort traffic Mean (on time): Mean (off time):	16 kbps / User 3 sec 15 sec
B	Buffer size (BS)	100 kb / User
T_S	Simulation duration	3 hours
PL	Pathloss Attenuation (R = distance from BS)	(in dB) $98.6+38.0\log R$
Sh	Shadowing Attenuation (Gaussian variable) Mean: Standard deviation:	(in dB) 0 8

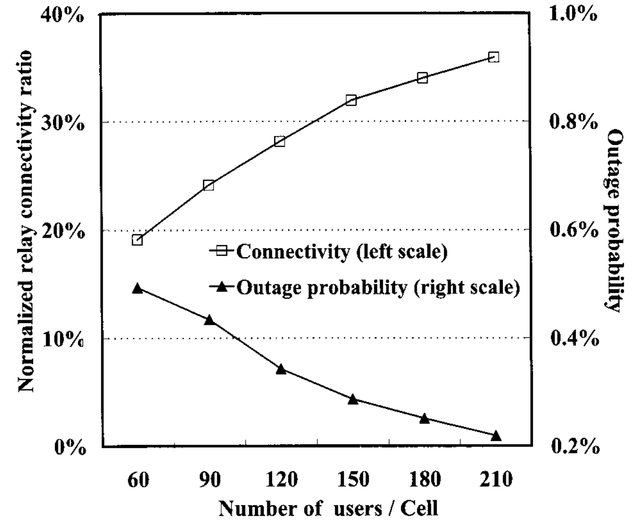


Fig. 4. Performance of relay connectivity.

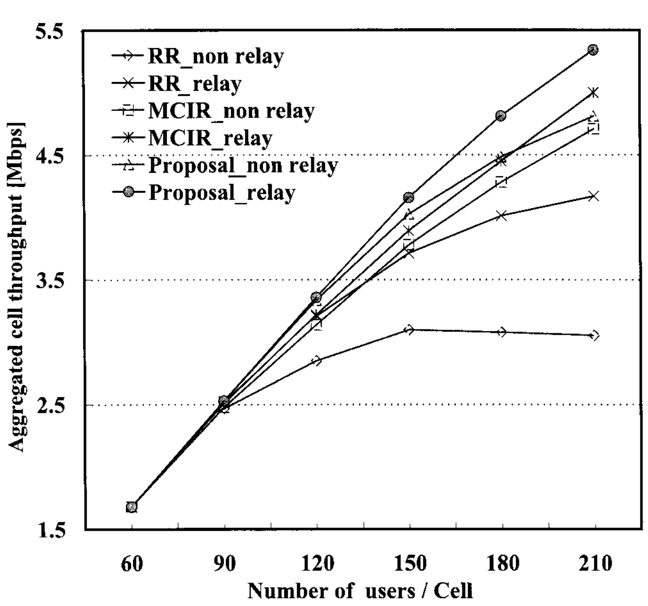


Fig. 5. Performance of aggregated system throughput.

increases, an SS has more chances to connect a RS whose channel is good. Higher user density can also reduce the user outage probability.

Fig. 5 shows the aggregated cell throughput of different scheduling algorithms. In order to show the relaying gain we also compare the RR and MCIR algorithms without relaying, which is clear that relaying systems could gain higher throughput when the number of users increases. Packets can be transmitted to MSs via the RSs with much higher transmission rates. The overhead in the cellular channel is only the reporting of potential relays. Here, we assume that these IDs are reporting in the signaling channel with the feedback of SNR, which would not make significant impact to the aggregated throughput. The total improvement of the proposed algorithm is gained from two components: best effort packets enhancement and streaming packets which could be sent before their delay bound. In contrast, RR with relaying still suffers low throughput because of the inefficient channel usage, where it serves user by user. On the other hand, MCIR with relaying could not have the best performance, since it only selects the MSs who have good channel quality or whose RSs have good channel quality, while streaming packets for other MSs are dropped.

Fig. 6 provides a detailed explanation for Fig. 5, which shows the throughput comparison of scheduling algorithms with packets transmitted via relay and directly from BS. 'RR traffic sent directly' means the throughput directly sent by BS. The aggregate throughput is the summation of 'RR non relay traffic' and 'RR relay traffic,' thus, in total the throughput provided by RR is less than the throughput provided by MCIR. In this figure we want to show the imbalance between the traffic sent directly and sent via relay. Only the traffic received via relay in the proposed algorithm increases significantly with the number of users, since the scheduling decision encourages the SS with poor channel quality to connect to a relay. In contrast, MCIR algorithm only selects a certain number of MSs to transmit, no matter the SS connects to a relay or has the good channel itself.

Fig. 7 shows the packet loss rate of streaming packets. Packet loss is caused by streaming packets which could not be transmitted within the delay bound. Without relaying, BS should transmit all packets directly to MSs. Thus, data packet delays for streaming packets increase quickly. If best effort packets have higher scheduling rates and higher packet priority, more best effort packets would be transmitted rather than streaming packets. In contrast, the relaying algorithm shows advantages of separating the traffic to different RSs. Thus, streaming packets do not have to wait for the channel to be released. Relay can improve

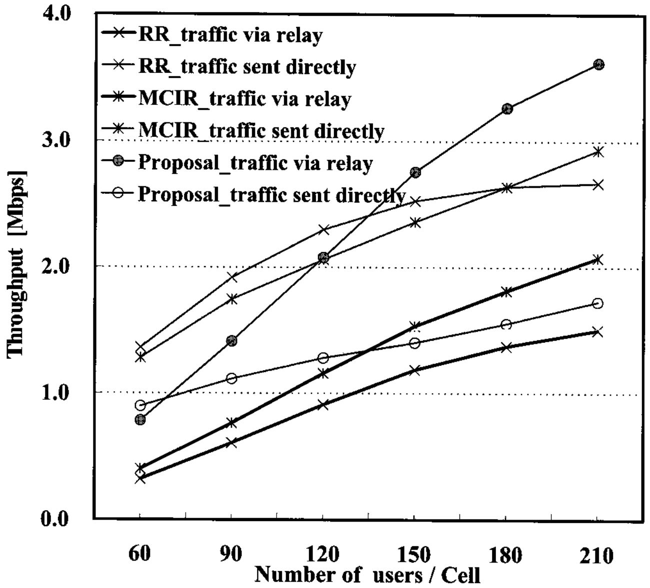


Fig. 6. Performance of packet travel through relaying.

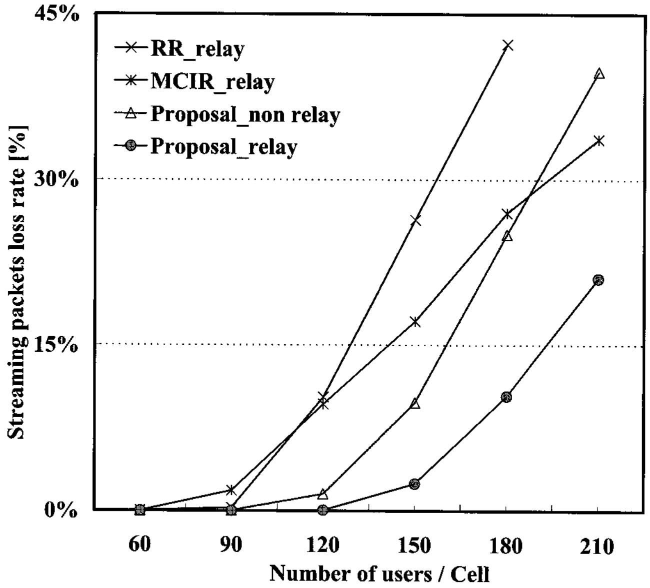


Fig. 7. Performance of streaming packet loss.

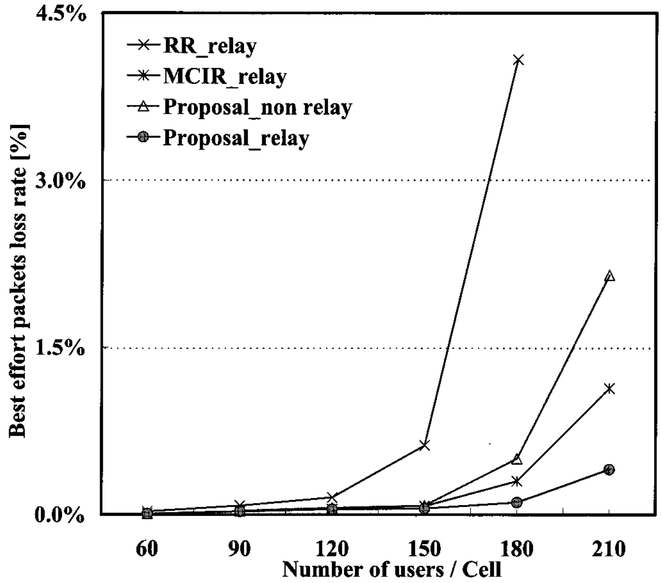


Fig. 8. Performance of best effort packet loss.

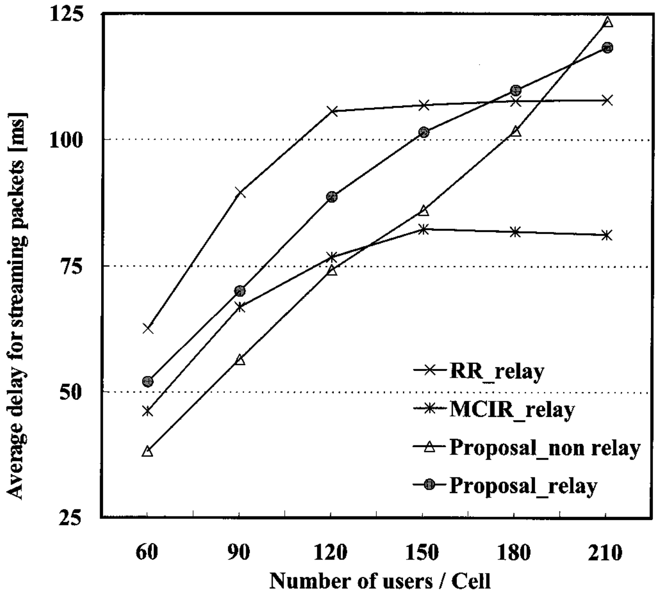


Fig. 9. Performance of average delay for streaming packets.

both the throughput and packet loss performance for the whole system. However, RR could not take the differences among users, where packet loss becomes seriously as the number of users increases.

Fig. 8 shows the packet loss of best effort traffic. In general, best effort packet loss is caused by overloaded data queue in BS. The proposed algorithm can achieve much less packet loss due to the consideration of both packet utility and user throughput. In contrast, MCIR serves only some MSs with good channel, thus, best effort packets would be dropped for the rest MSs. On the other hand, RR suffers the low capacity, which could not satisfy high rate data traffic. In this paper, two types of the traffic are assumed which would be dropped due to their waiting time or queue status, shown in Figs. 7 and 8. For MCIR, both streaming traffic and web traffic get larger loss ratio than the proposed scheme due to the packets for the users suffering long waiting time or queue drop. Although BS can always selects the highest transmission rate users to transmit more packets for these users in MCIR scheme, the proposed scheme could also serve such users by delaying their transmission for other poor users.

Fig. 9 shows average streaming packet delay for different algorithms, while Fig. 10 compares that of best effort packets. Since streaming packets are dropped after their delay getting larger than their bound, the RR algorithm provides better delay performance for streaming traffic. However, best effort traffic suffers high delay. MCIR algorithm has good results for both traffic classes due to the reason that packets transmitted belong to MSs with good channel. Relaying algorithm can get better performance compared with no relaying case, although it does not perform short delay. However, most of streaming packets

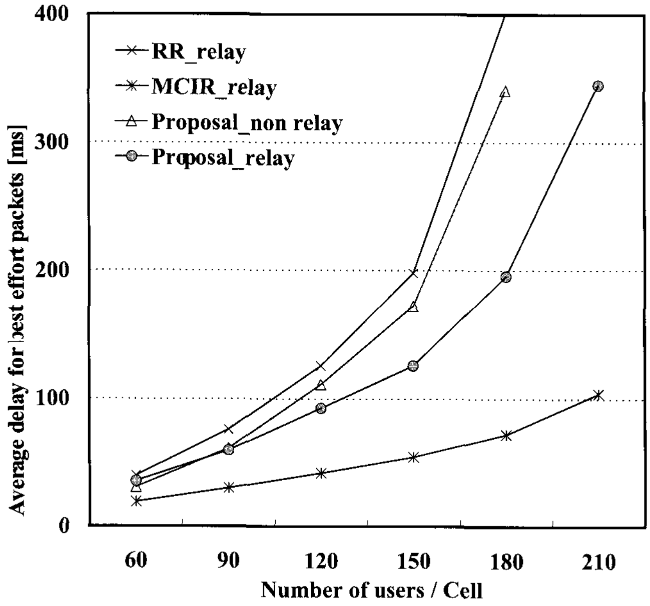


Fig. 10. Performance of average delay for best effort packets.

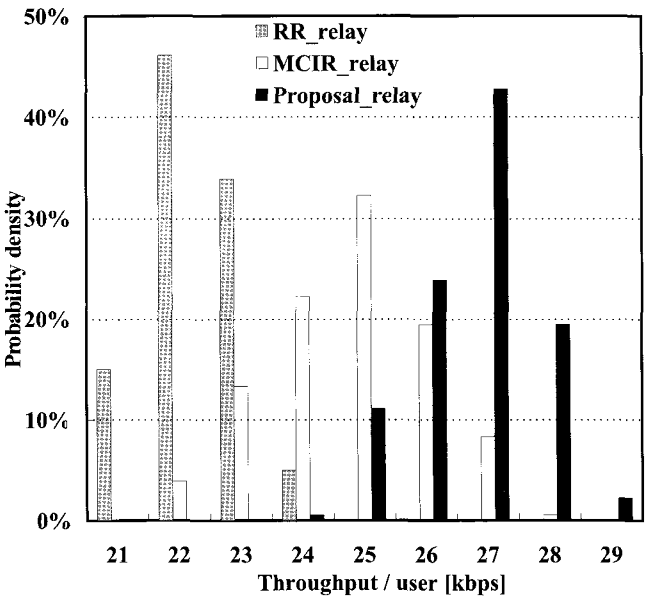


Fig. 11. Comparison of user fairness.

are transmitted within delay bound.

Fig. 11 shows the comparison of fairness among three scheduling algorithms. RR algorithm has the best user throughput distribution which means good fairness performance by treating MSs one by one. In contrast, MCIR only takes care of MSs with good channel condition so that it has the worst throughput distribution due to bad fairness performance. Taking the trade-off between fairness and throughput performances, the proposal can get better fairness performance than MCIR while gaining the largest throughput. We address the fairness issue from a throughput point of view. In order to get a similar throughput among the users, RSs may spend more resources for MSs with poor cellular channel. However, in contrast to the resource utilization the aggregated throughput has been improved.

V. CONCLUSION

We have proposed a packet scheduling algorithm considering relay selection for relaying cellular networks which exploit adaptive channels as well as constraints of user transmission rate, user throughput, and packet QoS. We take into account both relay selection and adaptive high speed channel to improve the overall system performance, where BS could switch the destination MSs with poor cellular channel by connecting to other MSs with good cellular channel within their relay range. By selecting users who get high transmission rates as relays, the proposed scheduling algorithm can provide high throughput, users' fairness and guaranteed packet QoS. Simulation results show the improvement of the total system throughput performance, less packet loss and delay. In this paper, we focus on the throughput enhancement and delay performance, thus, we assume the mobile nodes would have resource utilization for relaying. Further evaluation of the channel efficiency and improvement of the resource utilization would be considered as our future works.

REFERENCES

[1] H. Fattah and C. Leung, "An overview of scheduling algorithms in wireless multimedia networks," *IEEE Wireless Commun.*, pp. 76–83, Oct. 2002.

[2] Y. Ofuji, A. Morimoto, S. Abeta and M. Sawahashi, "Comparison of packet scheduling algorithms focusing on user throughput in high speed downlink packet access," in *Proc. IEEE PIMRC*, Sept. 2002, pp. 1462–1466.

[3] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, "Providing quality of service over a shared wireless link," *IEEE Commun. Mag.*, pp. 150–154, Feb. 2001.

[4] D. Zhao, X. Shen, and J. W. Mark, "Radio resource management for cellular CDMA systems supporting heterogeneous services," *IEEE Trans. Mobile Comput.*, vol. 2, no. 2, pp. 147-160, Apr.–June 2003.

[5] M. Andrews and L. Zhang, "Scheduling over a time-varying user-dependent channel with applications to high-speed wireless data," *J. ACM*, vol.52, no.5, pp. 809–834, Sept. 2005.

[6] Q. Liu, S. Zhou, and G. B. Giannakis, "Cross-layer scheduling with prescribed QoS guarantees in adaptive wireless networks," *IEEE J. Sel. Areas Commun.*, vol. 23, no. 5, pp. 1056–1066, May 2005.

[7] H. Jiang, W. Zhuang, and X. Shen, "Cross-layer design for resource allocation in 3G wireless networks and beyond," *IEEE Commun. Mag.*, pp. 120–126, Dec. 2005.

[8] F. D. Angelis, I. Habib, G. Giambene, and S. Giannetti, "Scheduling for differentiated traffic types in HSDPA cellular systems," in *Proc. IEEE GLOBECOM*, Dec. 2005, pp. 36–40.

[9] H. Wu, C. Qiao, S. De, and O. Tonguz, "Integrated cellular and ad hoc relaying systems: iCAR," *IEEE J. Sel. Areas Commun.*, vol. 19, pp. 1105–2115, Oct. 2001.

[10] L. Tassiulas and A. Ephremides, "Stability properties of constrained queueing systems and scheduling policies for maximum throughput in multihop radio networks," *IEEE Trans. Autom. Control*, vol. 37, no. 12, pp. 1936–1948, Dec. 1992.

[11] M. J. Neely, E. Modiano, and C. E. Rohrs, "Dynamic power allocation and routing for time varying wireless networks," in *Proc. IEEE INFOCOM*, Mar. 2003, pp. 745–755.

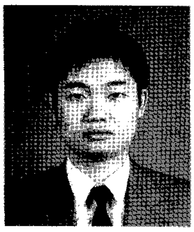
[12] D. Cavalcanti, D. Agrawal, C. Cordeiro, B. Xie, and A. Kumar, "Issues in integrating cellular networks, WLANs, and MANETs: A futuristic heterogeneous wireless network," *IEEE Wireless Commun.*, pp. 30–41, June 2005.

[13] D. Zhao and T. D. Todd, "Cellular CDMA capacity with out-of-band multihop relaying," *IEEE Trans. Mobile Comput.*, vol. 5, no. 2, pp. 170–178, Feb. 2006.

[14] H. Luo, R. Ramjeey, P. Sinhaz, L. Liy, and S. Lu, "UCAN: A unified cellular and ad-hoc network architecture," in *Proc. MOBICOM*, Sept. 2003, pp. 353–367.

[15] J. Cho and Z. J. Haas, "On the throughput enhancement of the downstream channel in cellular radio networks through multihop relaying," *IEEE J. Sel. Areas Commun.*, vol.22, pp. 1206–1219, Sept. 2004.

[16] A. Jalali, R. Padovani and R. Pankaj, "Data throughput of CDMA HDR: A high efficiency high data rate personal communication wireless system," in *Proc. IEEE VTC2000*, May 2000, pp. 1854–1858.
[17] Network simulator. [Online]. Available: http://www.isi.edu/nsnam/ns2/
[18] 3GPP TS 25.306 V5.7.0, "UE radio access capabilities," Dec. 2003.



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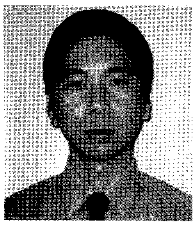

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