Improvement of Channel Efficiency in Mobile Communications by User Relay Scheme

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Abstract: In this paper, we propose a new access method named UR (User Relay) scheme to improve the channel efficiency in mobile communications. In UR scheme, packets of a data terminal that do not demand real time communications are relayed by other terminals during their inactive periods, which are communicating with the base station through a fixed channel at that time. Simulation results show that with UR scheme, the blocking probability and the throughput are improved considerably with an allowable increase in the average delay.

key words: mobile communications, user relay scheme, channel efficiency, multimedia communications

1. Introduction

In mobile communications, the shortage of frequency resource is an increasingly serious problem over time because of the increase in the number of users, especially those users who utilize interactive data applications such as e-mail and Web browsing. Therefore, utilizing the frequency resource in an efficient manner is a very important issue.

In conventional mobile communications, a fixed channel is assigned to a Mobile Terminal (MT) during its holding time of a call. We call this access method a fixed-assignment access method. The fixed-assignment is suitable for the transmission of the real time information such as voice and video. However, when the information to be transmitted is highly bursty as in the interactive data communications such as on-line chat and Web browsing, there are relatively long periods of inactivity. Then the channel capacity is wasted and channel efficiency is very low. Even for the voice communications, since the voice-activity cycle is only 35-40 percent of the holding time [1]-[3], a considerable waste of frequency resource exists. Also for the broadband transmission of motion pictures, as the bit rate varies immensely due to data compression, a considerable waste of frequency resource also exists.

In this paper, we propose a new access method named UR (User Relay) scheme in order to overcome the inefficiency described above. In this scheme, packet communication is used among MTs each other and between MTs and a Base Station (BS). Many packet data, such as those of interactive data communications and short message communications in e-mail, do not demand real time communication and the traffic load of them are very small. In UR scheme, these data packet can be relayed by the other MTs during their inactive periods (i.e. the periods of inactivity of a data communication terminal, and the voice-inactivity cycle of a voice call), which are communicating with the BS through a fixed channel at that time. We named the access method, which is used in UR scheme to relay non-real time data packets among MTs, relay access method, comparing with the fixed-assignment access method

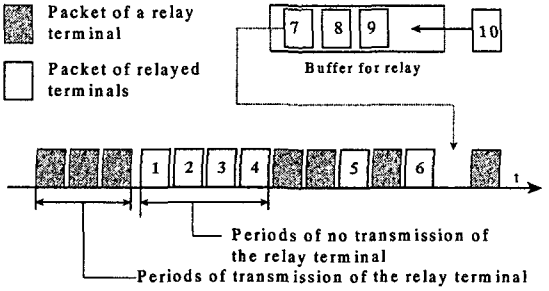

Fig.1 Time chart of packet relay

2. UR (User Relay) scheme

2.1 The network environment for UR scheme

UR scheme is suitable for multimedia communications composed of voice and data communications. Therefore, all the terminals are required to transmit voice and data in packets and have relay abilities. In this paper, we discuss only the uplink protocol, i.e. MT-to-MT and MTs to the BS protocols relating to the Common Air Interface. In UR scheme, MTs are divided into two states: relay MT and relayed MT. Relay MT is an MT communicating with the BS by a fixed-assignment channel and is relaying the data packets from relayed MTs. The MTs transmitting voice packets and data packets may be in the state of relay MT. Relayed MT is an MT communicating with the BS via relay MT. Relayed MT can only be the MT transmitting non-real time data. The packets from the relayed MT are at first transmitted to the relay MTs nearby in order to be relayed to the BS.

In UR scheme, the relay MT receives and saves packets from the relayed MT, then transmits the saved packets to the BS in its non-transmitting period. Fig. 1 shows the basic idea of UR scheme in a time chart

2.2 The transmitting and receiving procedure in UR scheme

The network using UR scheme is shown in Fig.2. In UR scheme, an MT with a voice call always applies for an allocation of a fixed channel and communicates directly with the BS, in order to insure the transmission of information in real time. But in the case of a data call, a call setting does not made between the MT and the BS. Instead, using the frequency band given for relay access method, the packets are transmitted to the relay MTs in a predetermined relay radius. If there are any relay MTs receiving the packets successfully, these MTs save packets from the relayed MT, then transmit saved packets to the BS in their inactive period as we can see in Fig.1. If there are more than two packets simultaneously transmitted, a packet collision occurs. Even in the packet collision, the packet with the largest power can be received successfully, if the power is greater by a certain amount of dB than the summation of the power of other colliding packets. This amount of power difference is called the capture ratio. In data communication, the capture ratio is set to 12dB generally [4].

The base station broadcasts acknowledgement (ACK) signals to the all MTs in the service area via downlink control channel. Then the relayed MT can determine by the ACK whether the packet has been relayed successfully or not. If no ACK for the packet received in a predetermined duration, the packet is retransmitted according to the selective repeat protocol [5]. Also if no ACK received in a predetermined maximum waiting time for repeated retransmission, the relay method is assumed to be impossible because of no relay MT, and the fixed-assignment access method is used to communicate with the BS directly. The data MT accessing successfully with fixed-assignment access method, may become relay MT. The reasons of the reception of no ACK are (1) There's no relay MT in the relay radius of the relayed MT. (2) Packet collisions were happened. (3) The relay MT can not relay the packet timely because of being busy to transmit own packets.

We introduce the following control for the low traffic load in order to avoid the unnecessary delay of a data MT, which may be caused by the failure of becoming a relayed MT due to the scarce relay MTs nearby. The base station, according to the channel occupation by MTs, broadcasts fixed-assignment access permit (FAP) flag though the downlink control channel. The data MT senses the symbol before it attempts a call. If FAP has been sensed, affluent idle channels are assumed to exist and fixed-assignment access method is applied without trying relay access method. On the other hand, if FAP has not been sensed, no abundant idle channel is assumed to exist, and fixed-assignment access method

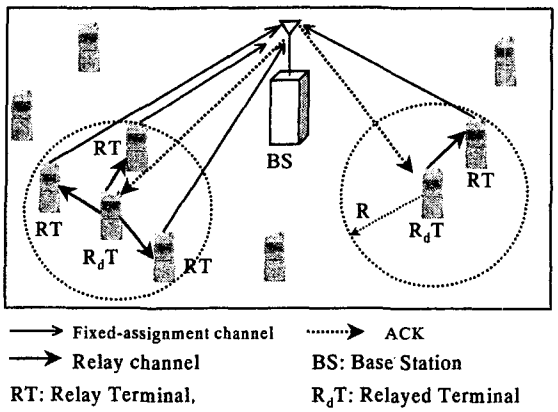

Fig.2 UR scheme

cannot be applied. Therefore, packet is transmitted to the relay MTs nearby, applying the relay method.

2.3 The channels in UR scheme

In UR scheme, we designed two types of uplink traffic channel to transmit packet to the BS. One is called fixed-assignment access channel(FAAC). When a relay MT communicating with the BS directly in fixed-assignment access method, this channel is used. The other is called relay channel(RC). It is the common channel used to transmit packets from relayed MT to relay MTs in a random-access manner. The total uplink traffic channels in the conventional fixed-assignment access method are rearranged into n fixed-assignment access channels and 1 relay channel. In order to relieve the collision caused by the random-access, we allocate m times bandwidth of the fixed-assignment channel to the relay channel. The relations between them are as follows:

$$\begin{aligned} B_T &= n * B_C + B_R \\ B_R &= m * B_C \qquad (m > 1) \end{aligned} \tag{1}$$

where B_R is the bandwidth of a relay channel, B_C is the bandwidth of a fixed-assignment channel, B_T is the total bandwidth of uplink traffic channel in the conventional fixed-assignment access method, N (N=n+m) is the total number of uplink traffic channel in the conventional fixed-assignment access method.

3. Performance evaluation of UR scheme by simulation

3.1 Simulation model

Parameters in Table 1 are used to evaluate the performance of UR scheme.We use the TDMA in fixed-assignment access method and the slotted ALOHA in relay method. Channel occupation ratio(COR) is defined as the ratio of the number of fixed-assignment channels occupied by the terminals to the total fixed-assignment channels.

3.2 Result of the simulation

3.2.1 Basic performances (blocking probability, throughput and average delay)

Table 1 Simulation parameters

Size of BS	Quadrangle (1km×1km)
Total number of channel	105
Number of $FAAC_s$	101
Bandwidth ratio	4
Capture ratio	12dB
Holding time of voice call	Exponential distribution with mean holding time of 3 minutes
Standby time of voice call	Exponential distribution with mean standby time of 15 minutes
Holding time of data call	Exponential distribution with mean holding time of 12 minutes
Standby time of data call	Exponential distribution with mean standby time of 60 minutes
Voice-activity cycle	Exponential distribution with mean talking time of 1 second
Voice-inactivity cycle	Exponential distribution with mean silent part of 1.35 second
Distribution of packet generation	Poisson distribution with 3 packets per second
Time duration of a packet	RC: 25ms $FAAC_s$: 100ms
MT distribution	two dimensional uniform distribution
Mobile velocity of MT	Random value with maximum value of 25km/s
Path loss exponent	2.0
Number of data terminals to Number of voice terminals	1:1
Simulation time	60h
Average waiting time for packet retransmission	Exponential distribution with mean waiting time of 700ms
Maximum waiting time	800ms
COR	0.85

The simulation results for the three basic performances (blocking probability, normalized throughput and average delay) of UR scheme are shown in Fig. 3, Fig.4 and Fig.5. In those figures, R is relay radius, FA method is the conventional Fixed-Assignment Access method, and the horizontal axis is the traffic load per channel

As seen from Fig.3 and Fig.4, both the blocking probability and throughput of UR scheme have improved significantly, especially under the situations of high traffic load, compared with those of the conventional fixed-assignment access method. To verify the superiority of UR scheme from another point of view, Table 2 shows the allowable traffic load and the attained throughput at the maximum blocking probability of 0.03, which is a design standard's value. In Table 2, the optimum relay radius 130m is used. In the Table, L is the allowable traffic load per channel, IRL is the increasing rate of L, S is the attained normalized throughput and IRS is increasing rate of S. As seen from Table 2, the traffic load and throughput increase

Table 2 Traffic per channel, throughput and average delay at blocking probability of 0.03

	FA method	UR scheme		
		R=65m	R=130m	R=190m
L	0.92	0.94	1.06	1.02
IRL		2.2%	15.2%	11.9%
S	0.32	0.33	0.37	0.358
IRS		3%	15.6%	11.8%
Delay	168ms	562ms	756ms	843ms

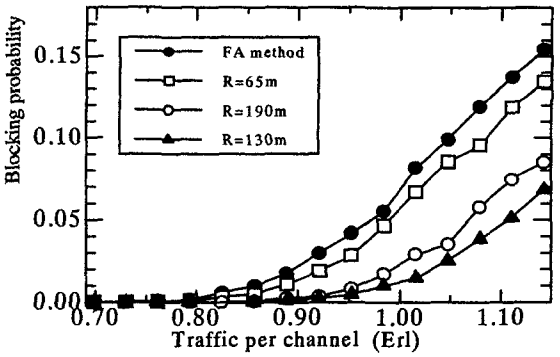

Fig.3 Blocking probability vs Traffic per channel

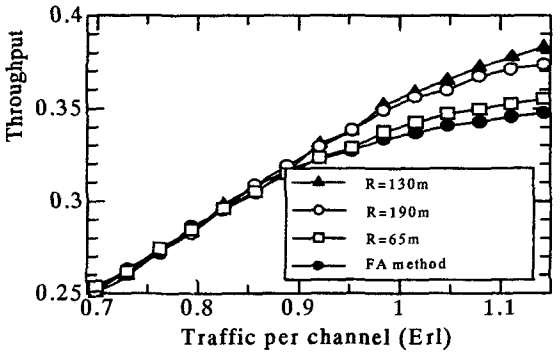

Fig.4 Throughput vs Traffic per channel

about 15%, compared with those of the conventional fixed-assignment access method.

The average delay is defined as a delay from packet generation to the reception of it at the BS. The simulation result of the delay for the relayed MTs is shown in Fig.5. Although the delay for the relayed MTs in UR scheme depends on the relay radius and the traffic load, the increase in the delay compared with the conventional fixed-assignment method is allowable for the practical use of interactive data communications. In data services, which do not demand real time communications, such a delay satisfies the needs of PCS/PCN [6] and thus, is not a problem in practice. As for the relay radius of 65m, a relatively long delay can be seen under a low traffic load situation. This is because only a small number of relay MTs may be available for a relayed MT within such a small relay radius.

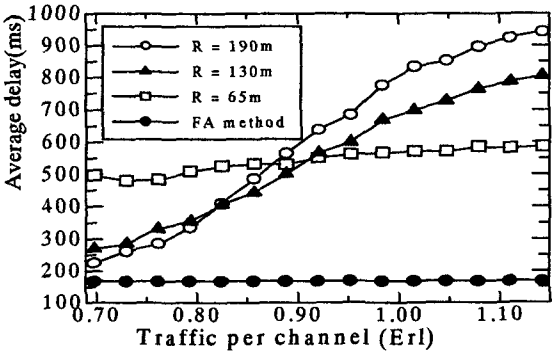

Fig.5 Average delay vs Traffic per channel

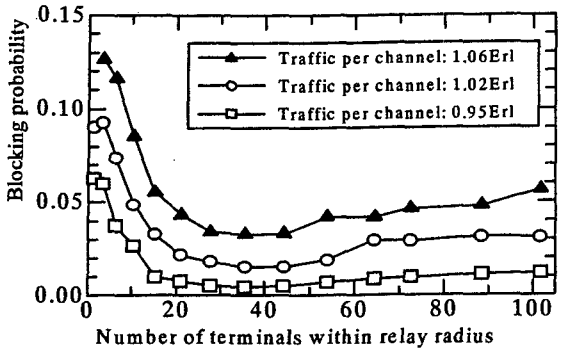

Fig.6 Blocking probability vs Number of terminals within relay radius

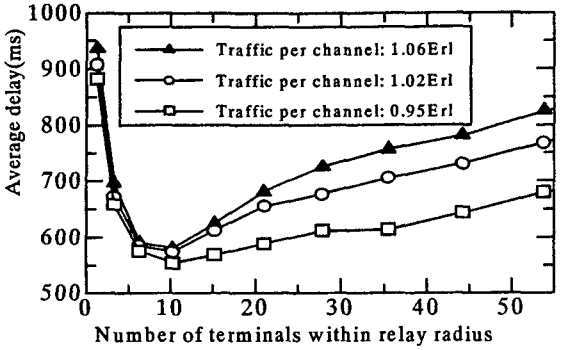

Fig.7 Average delay vs Number of terminals within relay radius

3.2.2 The number of terminals within relay radius : The optimum relay radius

The number of terminals within relay radius has a influence on blocking probability, throughput, average delay and other performance measures. Whether the packet sent from a relayed MT can be received by any relay MTs successfully, rests with the number of relay MTs within the relay radius.

Fig.6 shows the relation between blocking probability and NR (the number of relay MTs within the relay radius). Although these measures vary with the traffic load, they show the same tendency with NR. When NR is too small, the number of relay MTs near a relayed MT will be too small and hence, almost no data packets of relayed MT can be relayed. Therefore, most data terminals must transmit their data with fixed-assignment access method. The characteristics of blocking probability is even less than conventional fixed-assignment access method. On the other hand, when NR is too large, although many relay MTs may exist near a relayed MT, the number of successfully relayed packets are reduced because of serious packet collisions. Consequently, a large number of data terminals must use fixed-assignment access method. The characteristics of blocking probability become worse with the increase of NR. Therefore, the optimum NR with respect to the blocking probability is about 36. With the parameters in Table1, the optimum relay radius is about 130m.

Fig.7 shows the relation between average delay and NR. With the same reason for the blocking probability, the characteristic of average delay is concave with the increase of NR. The optimum NR with respect to the average delay is about 10, which is less than that for the blocking probability. The reason is as follows. As relayed packets increase, the packet collision and the waiting time of relay MTs will also increase, resulting in an increase in the average delay. However, the blocking probability does not increase immediately so much, because many relayed MTs do not suffer from the serious packet collisions yet, and because many relayed MTs should not change to fixed-assignment access method yet. Since the blocking probability is more important than the average delay in this situation, we adopt the optimum relay radius (=130m) for the blocking probability.

4. Conclusions

In this paper, we proposed a new access method named UR scheme to improve the channel efficiency of the mobile communication, and discussed the several features of the scheme. In UR scheme, non-real time packets can be relayed by MTs which are communicating with the BS via fixed-assignment channels during their inactive periods. Simulation results show the considerable improvement on the blocking probability and the throughput performance in comparison with those of the conventional fixed-assignment access method. The cost of UR scheme is the slight increase of the average delay, which is allowable for the practical use of interactive data communication. We will report the power control of relayed MT and the capacity of relay buffer in the future paper.

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