高度交通システム 7−4
（2001. 11. 16）

パケットルーティングを用いた移動体ネットワークにおける端末送信電力に関する一検討

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本稿では，自営系無線通信システムを前提とし，移動端末同士が基地局を介さない自律分散的なパケットルーティングを実現する移動体通信ネットワークを提案する．本ネットワークにおいて，特に端末送信電力をパラメータとした端末間干渉等の影響について検討すると同時に，提案ルーティングアルゴリズムを巧妙に利用した送信電力制御を提案し，干渉の軽減を図る．計算機シミュレーションの結果，提案アルゴリズムが端末の位置変化に応じて適応的にパケットルーティングを実現しながら，送信電力制御による干渉軽減効果を実現することを確認できた．

Study on Transmission Power for Mobile Network with Autonomous Packet Routing

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This paper proposes an autonomous packet routing algorithm that provides an intelligent wireless network structure for private mobile communication systems. The proposed algorithm senses the preferable paths for packet transmission, which are dynamically generated among terminals according to traffic conditions. We evaluate interference situations caused among mobile terminals by using computer simulations, and conducts feasibility study on the private mobile network. Moreover, we propose to apply a new transmission power control to our routing algorithm in order to prevent throughput degradation due to interference. Computer simulation confirms that the power control effectively reduces interference among terminals.

I. Introduction

While large amounts of mobile communication services are supported by existing base stations and public networks, another kind of demands for private communication systems are also increasing rapidly. Among such private systems, mobile network that is constructed by several mobile terminals and needs no base station infrastructure is considered to become one of the most attractive service forms for the next generation land mobile communication systems. Such a private network without the base station is expected to effectively realize its services under the situation base stations are not adequately prepared, or are out of services for some reasons. And its network construction capability can also be effectively employed in IVC (Inter-Vehicle Communication) systems, which is one of the most remarkable research fields of ITS (Intelligent Transport Systems).

In such a private mobile network, packet communication links between terminals are fundamentally established in a form of direct transmission between terminals, not supported by relay transmission via the base stations. However, if each terminal can also relay the received packet for another terminal just like the base station, such a relay transmission enables packet routing [1] in the mobile network, thereby

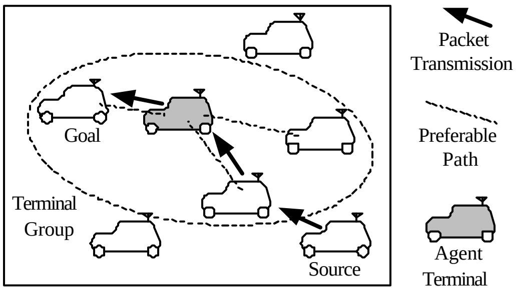

Figure 1: Concept of packet routing.

improves communication throughput in the system. In order to achieve effective packet routings, we have proposed a packet routing algorithm for such a mobile network in previous paper [2], and confirmed throughput improvement effect by the packet routings. One of the most remarkable features of the proposed algorithm in [2] is its autonomous control. Because dynamic fluctuations of situations, such as position of each terminal, and radio propagation characteristics, on mobile networks make it difficult to conduct centralized control, the autonomous control in [2] is considered very suitable for the mobile networks.

For the mobile network, on the other hand, the interference among terminals is a dominant factor that determines the system performance and at the same times the system capacity. The packet transmission power of each terminal could also become interference on other terminals, which is expected to become serious problem especially on autonomous packet routings. Therefore, the system configuration as to such transmission power is considered very important for the mobile network. Thus, in this paper, detailed evaluation about such interference according to the transmission power is conducted by using computer simulations. Moreover, we introduce a new transmission power control that exploits our packet routing algorithm in order to improve throughput performance even in the situation interference effect becomes serious.

II. Concept of Terminal Group

A. *Definition of preferable path and terminal group*

Figure 1 shows the concept of packet routings employed in our system. The figure depicts the situation where a source terminal tries to send its packet to a goal terminal. Here, the long distance between those two terminals makes the direct packet transmission difficult. Then, the source terminal conducts packet routing with relay transmission by another terminal.

In the proposed scheme, we introduce a selection method of preferable path that is defined as the path with good propagation conditions. Moreover, we define terminals set in which terminals are connected via preferable paths as a terminal group as shown in Fig. 1. Here, we assume that any two terminals in a terminal group can achieve packet transmission successfully using the preferable path. If the source terminal manages to send the packet to a terminal belonging to the same terminal group as the goal terminal, successful packet transmission toward the destination is guaranteed as in Fig. 1.

B. *Terminal-group construction method*

How to construct the terminal group according to real situations are important problems in the proposed scheme. We introduce the terminal group construction algorithm that is based on the received power for each terminal, thereby adaptively and autonomously construct the star formed sub-network as a terminal group [3], where one agent terminal is directly connected each of the other terminals via the preferable path. By introducing such a star formed group shown in Fig. 1, a packet that reaches a terminal

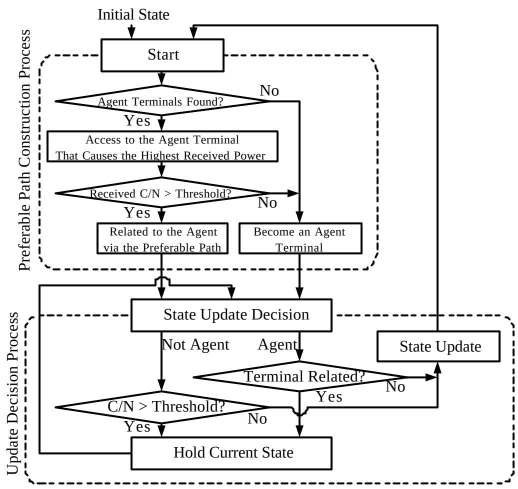

Figure 2: Flow Chart for Terminal Group Construction.

in a group can be relayed to any terminal in the group via the agent terminal.

Figure 2 shows a flow chart of the proposed terminal group construction algorithm employed in the proposed routing scheme. As a general definition, we assume that any terminal in the network is belonging to one terminal group. If there is a terminal that is connected to no other terminal via preferable path, such a terminal is defined to be also an agent terminal and to construct a terminal group by itself. As a result, any terminal except for agent terminal is connected to a certain agent terminals via preferable path. In other words, terminal group construction algorithm is an algorithm that provides some classifications among terminals whether each terminal is an agent or not. First of all, a terminal to be classified, which we describe as terminal *X*, searches for other agent terminals that are already classified. If there are no agent terminals around, terminal *X* is classified as an agent terminal. If agent terminals are found, terminal *X* measures the received signal power from each, and identifies the terminal providing the highest power, which we denote as agent terminal *Y*. Then, terminal *X* calculates the received *C/N* ratio (Carrier power

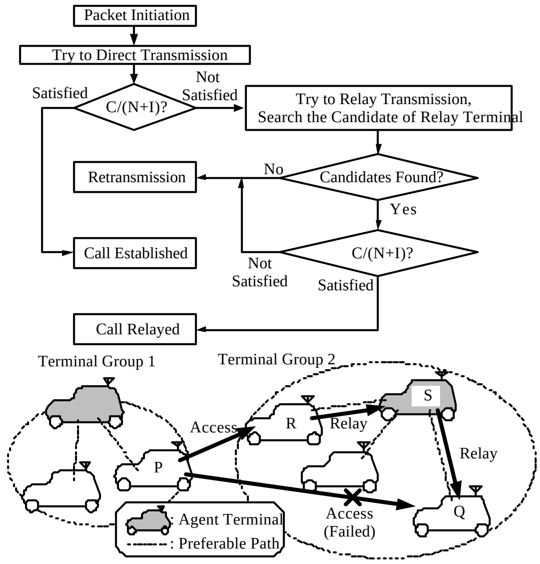

Figure 3: Packet routing scheme.

to Noise power ratio) from terminal *Y*. If it is higher than the preliminary threshold, we define such a *C/N* ratio as CN_{agent}, terminal *X* is related to the agent terminal *Y* via the connection of preferable path. If it is lower, terminal *X* is classified as an agent terminal. Moreover, we have introduced two different conditions of classification update for agent and non-agent terminal respectively. The condition for agent terminal is that no terminal is related to it. And the condition for the other terminals is that the received *C/N* ratio from its agent terminal falls below the CN_{agent}. At certain intervals, each terminal examines such a condition, and updates its own classification if the condition is satisfied.

After the terminal group construction, every terminal possesses the information whether its own classification is an agent or not. Moreover, every agent terminal also possesses the terminals' ID that is related via preferable path, and the non-agent terminals possess the ID of their own relating agent terminals

III. Proposed Packet Routing Algorithm

A. *Basic algorithm for packet routings*

The proposed algorithm for packet routing is shown as a flow chart in Figure 3. First of all, a terminal *P* that sends a packet to another terminal *Q* tries to achieve direct transmission. We evaluate the transmission quality between two terminals, using the *C/(N+I)* ratio (Carrier power to Noise and Interference power ratio). If the achieved *C/(N+I)* for the transmission between *P* and *Q* satisfies the preliminary *C/(N+I)* threshold, which we denote as CNI_{th}, then *C/(N+I)* condition is satisfied, and *P* successfully sends its packet to *Q*. If it is not satisfied, *P* accesses other terminals to try to find a terminal *R* belonging to the same terminal group as terminal *Q* that satisfies the *C/(N+I)* condition between *P* and *R*. Terminal *R* then becomes a candidate for a relay terminal, and terminal *P* sends its packet to such a candidate. The behavior of the candidate that received such a relayed packet is determined the simple rules for each terminal as follows:

1) A non-agent terminal should send the received packet that is addressed to another terminal to its relating agent terminal.
2) An agent terminal should send the received packet that is addressed to another terminal to such addressed terminal.

Thus, we can achieve an autonomous and adaptive packet routing between terminals by exploiting the terminal groups. In the case of Fig. 3, the candidate *R* sends the received packet from *P* to its agent *S*, then sends the packet to the destination *Q*, as determined by above rules. As for each transmission such as *R* to *S*, or *S* to *Q*, the condition *C/(N+I)* should also be satisfied.

B. *Time-space diagram of the proposed algorithm*

In this section, we explain about the time-space diagram for realization of the proposed routing algorithm.

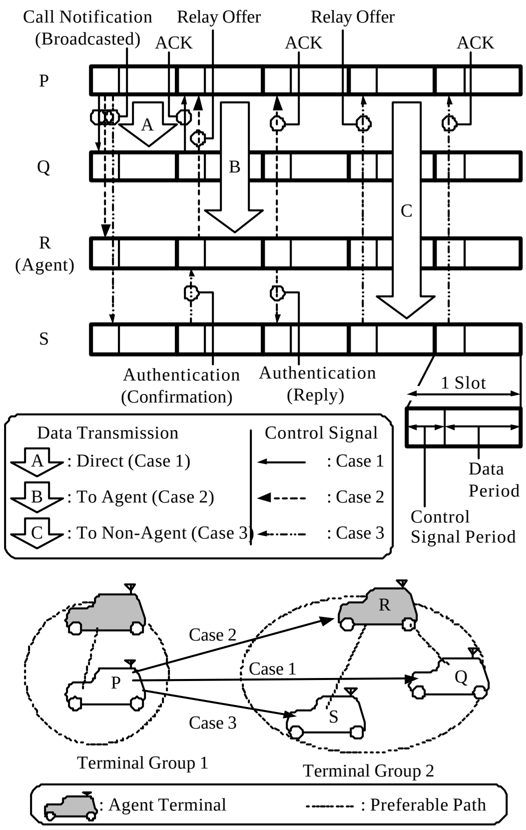

Figure 4: Time-space diagram of proposed algorithm.

Figure 4 shows time-space diagram for the proposed packet routing algorithm. As shown in the figure, we have introduced the Slotted ALOHA type access scheme for the proposed IVC network. The time period for one slot is shared by control signal period and data signal period as in Fig. 4. The control signal period is used for the control signal transmission such as ACK (ACKnowledgement) and NACK (Negative ACK) and other typical signals for the proposed algorithm. On the other hand, the data signal period is equivalent to the packet length, and is used for the packet data transmission. We assume the call initiation terminal ID, the call destination terminal ID, and other necessary information for proposed packet routing algorithm are also included in this period as the packet header

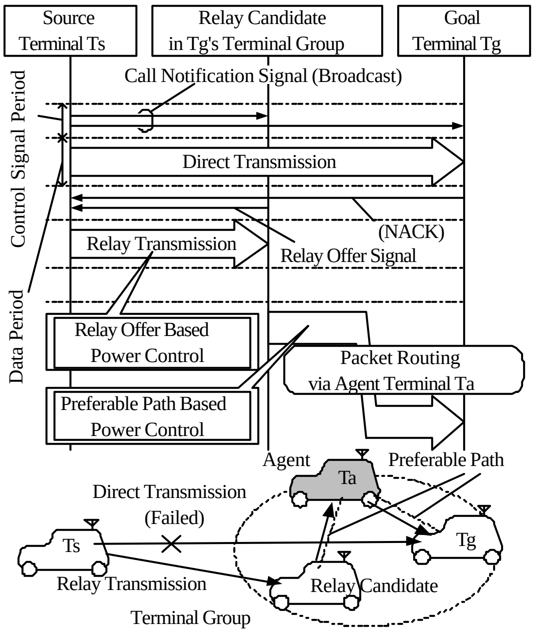

Figure 5: Transmission power control for proposed algorithm.

In the proposed algorithm, when a terminal generates its packet, such a source terminal, terminal *P* in Fig. 4, first broadcasts the call notification signal using the control signal period and then sends its packet using the successive data signal period. In the case of Fig. 4, the packet transmission is successively conducted and terminal *Q* sends ACK signal to *P* using the control signal period in the following slot. This is the direct transmission case noted as Case 1 in Fig. 4.

In the case of relay transmission when such a direct transmission fails, the call notification signal effectively works. Case 2 in Fig. 4 shows such relay transmission toward an agent terminal. In this case, at the packet initiation of *P*, its call notification signal reaches to an agent terminal *R*. Then *R* examines whether the destination terminal *Q* is related to *R* via preferable path. If such a preferable path exists between them, *R* sends the relay offer signal using the control signal period. Finally, *P* conducts relay transmission after receiving such a relay offer signal.

Case 3 in Fig. 4 shows relay transmission toward non-agent terminal. This is equivalent to the case the call notification signal is received by non-agent terminal, *S* in Fig. 4. In this case, *S* sends the authentication signal to its agent *R* to confirm *Q* is related to *R*. After *R* returns the reply signal, *S* sends relay offer signal to *P*. Finally, *P* conducts the relay transmission to *S*. In both cases of relay transmission, the excessive transmission delay is caused due to the time period for control signals transmission. Such an excessive delay is 1 slot period in Case 2, and 3 slots period in Case 3.

Since the call notification signal is broadcasted to several terminals as shown in Fig. 4, several call offer signals can be returned to the packet initiation terminal. In such case, the source terminal accepts the call offer that reaches first. Moreover, the call initiation terminal accepts the call offer having highest signal power when several call offer signals are reached in the same period.

C. *Transmission power control for proposed algorithm*

In the mobile network, dynamic fluctuation of interference is also expected to become serious problem. Terminal could introduce excessive transmission power, because propagation condition is difficult to expect. Such an excess power could degrade transmission performance of other terminals in a form of interference. In this case, transmission power control that reduces power level to the minimum level needed for transmission is preferable in order to suppress interference.

Such power control is easily conducted in the proposed packet routing algorithm by using several information employed in the algorithm. Figure 5 shows a concept of proposed transmission power control. At relay transmission in the algorithm, a source terminal can estimate propagation condition using relay offer signal received form the relay candidate. Moreover, in packet routing process in a terminal group, information about the preferable paths are also utilized to estimate the propagation conditions. If such estimated loss of the propagation path is P_{loss}, C/N ratio for the receiver side CN_{rx} is estimated as follows,

$$CN_{rx} = P_{tx} + P_{loss} - N \quad (1).$$

Here, P_{tx} is transmission power, and N is noise power. If such P_{rx} satisfies the conditions below,

$$CN_{rx} > P_{ref} + P_{margin} - N \quad (2),$$

where P_{ref} is reference level that is needed as the received level and P_{margin} is a margin, we conduct transmission power control of which control gain P_{delta} is given by

$$P_{delta} = P_{ref} + P_{margin} - N - CN_{rx} \quad (3).$$

Then, transmission power after power control P_{tx}' becomes,

$$P_{tx}' = P_{tx} + P_{delta} \quad (4).$$

IV. Computer Simulation Results

A. *Simulation conditions*

Table 1 shows the simulation conditions. The received power of each signal is subject to path loss with a decay factor of 3.5 and log-normal shadowing with a standard deviation of 6.5 dB. Call generation is subject to the Poisson process. For simplicity, we assume that each terminal that initiates its call transmits 1 packet occupying 1 slot in our simulation.

We have introduced square-shaped simulation area of $4L$ by $4L$, where terminals are uniformly distributed.

We set CNI_{th} value to 10 dB in this paper. The successful transmission of the packet is determined by $C/(N+I)$ condition based on CNI_{th}, as previously mentioned. The threshold for terminal group construction CN_{agent} is also set to 10 dB. If packet transmission fails, the packet sender holds such a packet in its buffer and conducts retransmission within 2 slots period. If 12 slots period is passed from the packet initiation, such packet is discarded as a blocked call.

Table 1: Simulation Conditions.

Path loss factor	3.5
Standard deviation of log-normal shadowing	6.5
Packet arrival	Poisson process
Terminal distribution	Uniformly
Simulation area	Square area (4.0 L by 4.0 L)
CNI_{th}	10 dB
CN_{agent}	10 dB
Packet retransmission	Within 2 slot (randomly)
Packet timeout	After 12 slots

Moreover, we are introducing a parameter CN_{trans} that reveals transmitting power of each terminal. CN_{trans} is equivalent to the received C/N ratio at the distance of L from the transmitter.

B. *Throughput performance*

Figure 6 and 7 shows the throughput performances for the proposed algorithm according to CN_{trans} and input traffic, respectively. We evaluate the number of packets that are successfully transmitted to call destination terminals as throughput. Moreover, the performances of the conventional packet transmission that employs no relay transmission are also shown in those figures. In this subsection, no power control as mentioned previous section, in order to evaluate basic characteristic of the proposed algorithm.

As for both of proposed and conventional algorithm in Fig. 6, throughput increases according to CN_{trans}. In Fig. 7, throughput almost same as input traffic is achieved in low traffic region for the case CN_{trans} is 40 dB. However, in

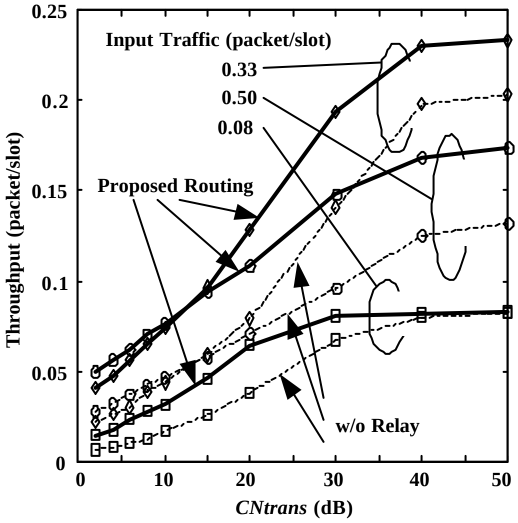

Figure 6: Throughput versus CN_{trans}.

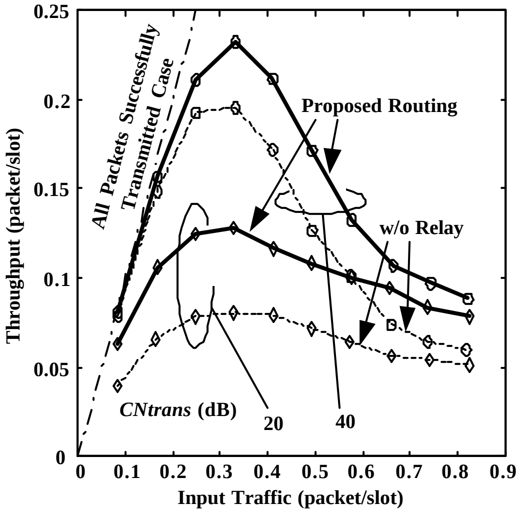

Figure 7: Throughput versus input traffic.

high traffic region of Fig. 6, throughput is rapidly decreasing even if CN_{trans} is high. Such degradation is caused by serious interference due to traffic. In Figs. 6 and 7, we can see the proposed algorithm improve throughput almost all situations compared with the conventional algorithm. This is because the proposed algorithm can achieve sufficient *C/(N+I)* between terminals by exploiting relay transmission in the situations transmission power is low, or interference power is high.

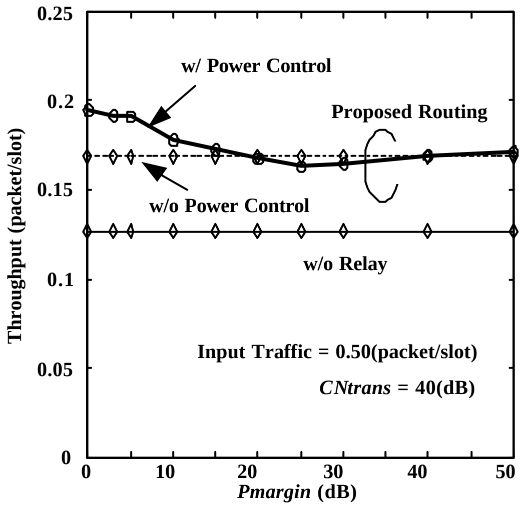

Figure 8: Throughput versus P_{margin}.

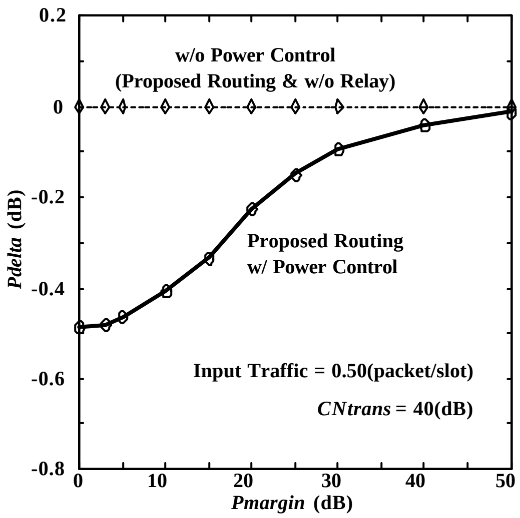

Figure 9: Average transmission power versus P_{margin}.

C. *Power control effects*

We evaluate the effect of proposed power control. Figure 8 shows the throughput performances according to P_{margin}. In Fig. 8, CN_{trans} and input traffic are set to 40 dB and 0.50 packet/slot. This is equivalent to the situation interference seriously degrading the throughput performance in spite of high transmission power of each terminal as shown in Figs. 6 and 7. For these evaluations in this subsection, we introduce the reference level value as $P_{ref} - N = 10$ dB, which assumes the received *C/N* ratio of the same value.

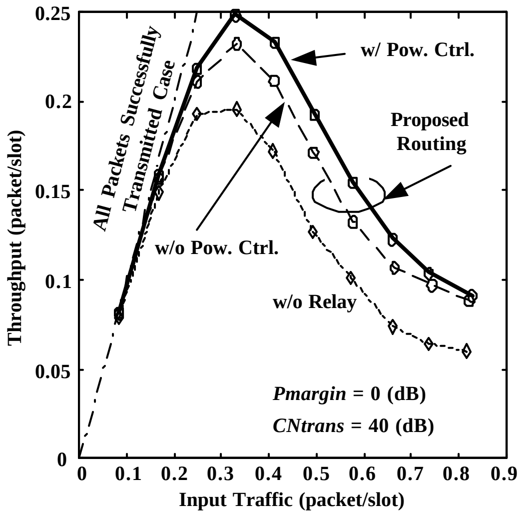

Figure 10: Throughput versus input traffic.

As a comparison, the performances of previous two algorithms without power control in Fig. 6, 7 are shown in Fig. 8. The lower P_{margin} introduces strict power restriction closer to the reference level. In low P_{margin} region, the throughput for proposed algorithm with power control is improved compared with that without power control. This is because excess transmission power is decreased by power control, thereby reducing interference. However, the suitable P_{margin} value that can cope with different situation than Fig. 8 case is expected to become also different. Further research about such P_{margin} value is a future study.

Figure 9 shows transmission power according to P_{margin} in the same situation as Fig. 8. Average value of employed P_{delta} is shown in the figure. If the case power control is introduced, average transmission power for each terminal is decreased according to P_{margin} descend. We can conclude such power decreasing contributes to not only interference improvement shown in Fig. 8, but also power savings for transmitter.

Figure 10 shows throughput performance of that power control employing algorithm in the same situation as Fig. 7, where preferable P_{margin} , 0 dB expected in Fig. 8 and 9, is also employed. We can see that performance is improved in higher traffic region, where serious interference among terminal is expected. We can also conclude excess power reducing effect by power control decreases total interference in the network.

V. Conclusions

We proposed an intelligent packet routing algorithm for future private mobile network. The proposed algorithm achieves autonomous packet routing by introducing preferable path and terminal group. We evaluate the effects on throughput performance caused by transmission power, and introduce a transmission power control utilizing our routing algorithm. Computer simulation confirms that the proposed algorithm can achieve a high throughput performance than a system without packet routings by coping with the terminal conditions, and that power control effectively works not only for preventing interference but also for transmission power savings. More detailed configuration about the power control that flexibly copes with various situations will be considered as a future study.

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