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# 모바일 애드혹 네트워크를 위한 Isochronous MAC 프로토콜의 분석적 모델 연구

## ( Analytical Model of Isochronous MAC Protocol for MANET )

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( Ung Heo and Jaeho Choi )

요 약

본 논문은 모바일 애드 혹 네트워크에서 실시간 서비스를 지원하기 위한 새로운 매체 접속 기법 time-slot reservation coordination function(TRCF)과 이를 평가하기위한 수학적 모델을 제시한다. 모바일 애드 혹 네트워크에서 실시간 서비스 지원을 위한 연구는 대부분 DCF를 활용해 왔다. 그러나 이런 연구들은 지연에 민감한 실시간 트래픽을 지원할 수 없다. 우리의 프로토콜은 TRCF와 DCF 두 부분으로 구성되어진다. TRCF는 실시간 서비스를 위해 예약 기법이 적용된 TDMA 기반 모드(MODE)이고 DCF는 best effort 트래픽 지원을 위해 IEEE 802.11 표준의 기능이 그대로 유지된다. 그리고 실시간 서비스를 위해 64Kbps 음성 전화 서비스를 고려한다. 본 논문은 또한 제안된 MAC을 평가하기 위해 마코프 체인을 사용한 성능 분석 모델을 제시한다. TDMA의 특성을 고려하여 시간변화에 따른 마코브 체인의 상태와 천이 확률이 유도된다. 제안된 성능 평가 모델을 통해 음성 전화 서비스가 연결되어지기까지 소요되는 평균대기 시간, 처리량, 지연과 같은 성능 측정값을 도출한다.

Abstract

In this paper a novel medium access control mechanism is investigated as a means to support real-time services. The primary goal is to provide constant-bit-rate voice call services to pairs of autonomous mobile nodes operating in ad hoc networks. Here, a time-slot reservation based MAC is considered to provide real-time voice calls, and a new MAC called the time-slot reservation coordination function (TRCF) is presented. In addition to this isochronous type MAC protocol development, the proposed protocol is modeled using a Markov chain in order to predict its behavior. The performance of TRCF is analytically derived and the performance measures such as average wait time taken for a call connection and throughput are obtained.

**Keywords:** ad hoc networks, MAC, reservation, Markov chain, analytical model

## I. Introduction

Recently, the mobile ad hoc network (MANET) is drawing much attention. The MANET is a self-configured, infrastructureless spontaneous network connecting together autonomous nodes with a routing capability. Its application can be found in strategic military operation, emergency rescues and medical assistant.

This paper is concerned with MANET and the focusof investigation is on its medium access control. The typical medium access mechanism for wireless LAN implemented using IEEE 802.11x is the distributed coordination functions (DCF) or EDCF. Those are de facto MAC standards developed mainly for a small scale network coordinated by an access point (AP). Without any of centralized coordination such as the AP, however, the DCF itself can not provide a satisfactory data service, and any type of isochronous service is almost impossible. In other

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words, in the case of the MANET, it requires of a highly sophisticated medium access control mechanism other than the DCF.

The target of our MAC investigation is on isochronous applicationssuch as voice call services. In such a real-time application, the voice packets should be exchanged with a stringent quality of service in terms of delay and throughput. Since the DCF or EDCF provides no options for a real-time service in MANET, much research effort is followed in this area within this decade.

Among various MANET MAC approaches recently proposed, the time-slot reservation methods are getting successful results for providing real-time services because they can support constant-bit-rate communications, i.e., 32 kbps CBR in voice calls. For those are closely related to our study, it is worthwhile to mention some of their literatures.

Ref. [3]~[7] are MAC techniques designed specially for real-time supports in MANET. Specifically, in Ref. [3]~[6], the super-frame is divided into time-slots and the time-slot itself is further sub-divided into several fields for control and data bursts. When the network gets congested, however, the performance tends to degrade more rapidly because the whole time-slot has to be wasted when collision occurs in the contention phase of the time-slot.

On the other hand, Ref. [7] implements a reservation coordination function (RCF) that replaces PCF; and the real-time packet transmission is supported by reserving a small portion of time in RCF. The DCF part gets a few modifications that it not only performs its typical function of supporting best-effortdata service but also coordinates reservation time allocation in RCF for real-time services. When the contention for the medium increases, however, the higher occurrence of collisions in the DCF period can hamper the reservation process, and the real-time performance readily degrades. This in turn affects best-effort service adversely because of increasing control overhead due repeated reservation requests in the DCF period.

As pointed above, in order to ensure the real-time service support, a time-slot reservation based scheme is most effective. However, there are a couple of places to be improved. One is toward improving time-slot utilization by minimizing time-slot drops when the control packet for time reservation results in collision. The basic approach taken in this paper is to allow a number of retransmissions of time-reservation request control packet within the same time-slot. It significant improves time utilization. Another one is completely separating the DCF function from that of TRCF. Comprehensive, the new MAC proposed has a similar super-frame structure found in Ref. [7], but the DCF is untouched. Particularly, both reservation control and real-time data bursts are sent only during the TRCF period. By separating isochronous and asynchronous services into two independent parts, the important role of the DCF in IEEE 802.11 can be preserved.

Now, another half of our investigation is concerning with modeling the proposed MAC. By exactly modeling the transient and stationary process of MAC operations, one can analytically predict the behavior of the MAC. In other words, by deriving the characteristic parameters such as the probability of control packet transmission and the probability of successful control packet transmission, the performance measures such as throughput, delay and average wait time can be obtained.

Bianchi [1] early in this decade managed to propose a stationary Markov chain model for predicting the performance of the standardIEEE 802.11 DCF. Including his results and other follow-up researches, the Markov chain model description has shown its effectiveness because it inherently fits the probabilistic nature of channel and node states in various stages of the medium access processes. Even though his model is not complete, his approach can be extended to other MAC modeling.

After presenting TRCF protocol development, the modeling for TRCF is followed using Markov chain. For the given Markov chain model of TRCF,the characteristics parameters are analytically derived, and the performance estimation measures such average wait time taken for a call connection and throughput are obtained. The details are followed in the later sections.

In the following, the new MAC protocol design for real-time service supports is presented in Section Ⅱ. In Section Ⅲ, the analytical modeling of the proposed MAC is described using the Markov chain. The characteristic parameters are analytically derived, and performance estimation measures such as average wait time taken for acall connection and throughput are obtained. Finally, the conclusions are made in Section Ⅳ.

## Ⅱ. Proposed MAC scheme

In this section, a novel medium access control method for supporting isochronous services in MANET is presented. The proposed MAC protocol is named 'time-slot reservation coordination function (TRCF).'Along with TRCF, the DCF is assumed to support typical asynchronous data services. In other words, similarly to PCF and DCF combination in the original form of the IEEE 802.11 MAC, the proposed MAC is consisted of TRCF and DCF combination. In the following of the section, details of TRCF are discussed.

### 1. Frame Structure

The proposed TRCF is a time-slot reservation based medium access control mechanismparticularly for a real-time service such as a voice call. Assuming that the MAC super-frame is time-synchronized among the nodes by some means such as GPS, the super-frame is divided into two periods TRCF and DCF; and the TRCF is further sub-divided into timeslot as shown in Fig. 1.

One of the prominent concepts adopted in TRCF is allowing multiple time-slot reservation contentions within the same time-slot. This mechanism increases the probability of reserving the time-slot by a node and also improves the channel utilization. The node winning the contention can begin voice packet transmissions using the reserved time-slot from the next super-frame and continues on until it finishes the call. The packet exchange between two nodes is time-slot based half duplex.

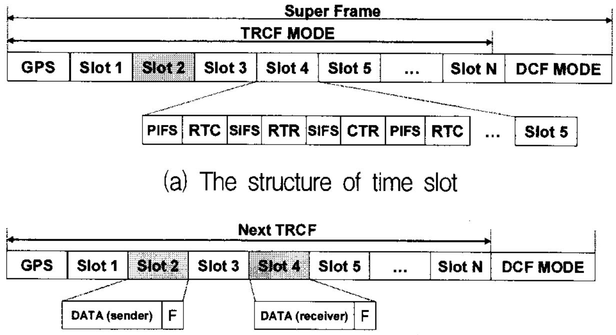


그림 1. 수퍼프레임 구조
Fig. 1. Structure of super-fame.

In TRCF medium access handshaking, three control packets should be successfully exchanged in order to reserve a time-slot for a voice call as follows:

Step 1. The call initiator transmits the request-to-call (RTC) control packet.

Step 2. The called party replies with the ready-to-response (RTR) control packet upon receiving RTC.

Step 3. The caller confirms the time-slot reservation with the confirm-to-reservation (CTR) control packet.

CTR also helps neighbors to update their

| 2 | 2 | 6 | 6 | 1 | 1 | 4 |
|---|---|---|---|---|---|---|
| Frame Control | Duration | SA | DA | TTS | RTS | FCS |

(a) RTC 제어패킷 형식

| 2 | 2 | 6 | 6 | 1 | 1 | 7 | 4 |
|---|---|---|---|---|---|---|---|
| Frame Control | Duration | SA | DA | TTS | RTS | TBM | FCS |

(b) RTR 제어패킷 형식

| 2 | 2 | 6 | 6 | 1 | 1 | 4 |
|---|---|---|---|---|---|---|
| Frame Control | Duration | SA | DA | TTS | RTS | FCS |

(c) CTR 제어패킷 형식

SA : Source Address DA : Destination Address TTS : Transmitting Time Slot
RTS : Receiving Time Slot TBM : Table Bit Map

그림 2. TRC/RTR/CTR 제어패킷
Fig. 2. RTC/RTR/CTR control packets.

reservation tables. The three control packets are shown in Fig. 2.

### 2. Real-time voice call management

Let's consider a real-time voice call service that is supported by TRCF. There are four stages in TRCF MAC setting up a voice call as follows:

Stage 1. Initiation and call request - In this stage, beacons are exchanged and the active nodes are time-synchronized. Its illustration is shown in Fig. 3.

Stage 2. Call reservation - As soon as a call request arrives to a node, the node sends out RTC and performs 3-way handshaking RTC-RTR-CTR. Its procedures are shown in Fig.4.

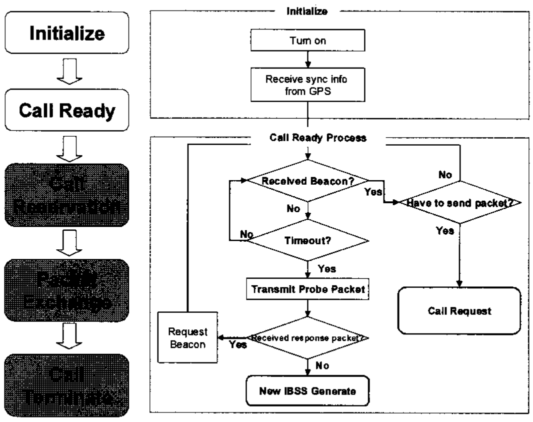


그림 3. 음성 패킷의 생성과 초기화 과정
Fig. 3. Initiation stage and voice call arrival.

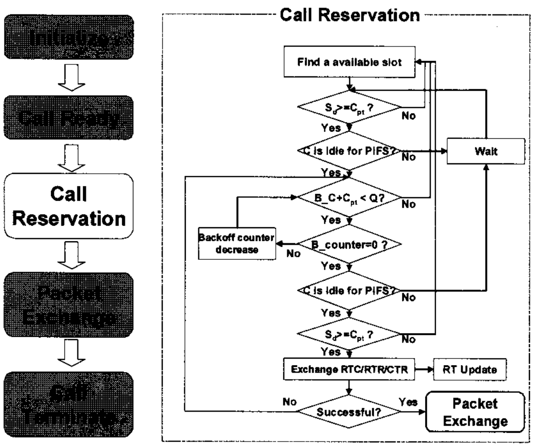


그림 4. 음성 통화 예약 과정
Fig. 4. Call reservation stage.

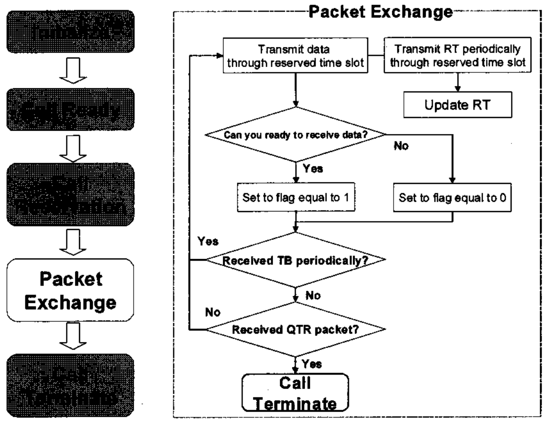


그림 5. 음성 패킷 교환 과정
Fig. 5. Voice packet exchange stage.

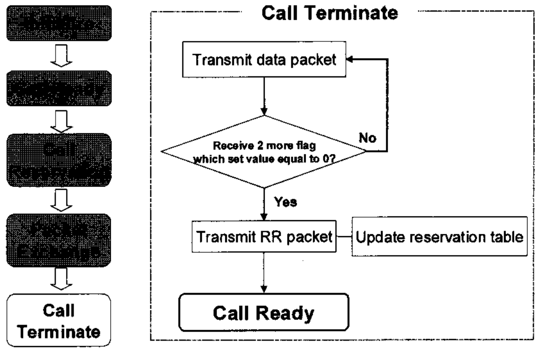


그림 6. 음성 통화 종료 과정
Fig. 6. Call termination stage.

Stage 3. Voice packet exchange - Once RTC-RTR-CTR gets done successfully, the time-slots are reserved in the TRCF period of the current super-frame, and the voice packet exchange begins from the next super-frame. The process is shown in Fig. 5.

Stage 4. Call termination - As soon as conversation between two parties terminates, the resources reserved for the call need to be explicitly released. The release sequence is followed in Fig. 6.

## III. Analytical Modeling

Up to this point, we have been focusing on a new MAC design. However, verifying its behavior for supporting a real-time service such as voice call in MANET is another challenging task. In this section we try to build an analytical model for TRCF by using a Markov chain and use that model to assess its behavior. And finally, the performanceprediction measures such as average wait time taken for voice call connection and throughput are analytically derived.

## 1. Modeling using Markov chain

Over the decade, several modeling methods have been proposed; and one of most efficient and accuratemodeling methods has been the state transition model based on Markov chain. The most successful Markov chain model can be the one proposed by Bianchi [1]. He has modeled the IEEE 802.11 DCF using a stationary Markov chain and derived analytical expressions for predicting DCF performance in terms of saturationthroughput and delay. Since his investigation is on DCF for asynchronous data service under AP coordination, his conditions and results are no longer valid for the real-time service in MANET. However, the probabilistic approach found using Markov chain is still very useful tool that also can be extended in TRCF analytical modeling.

Consider the state transition diagram in Fig. 7. On voice call request arrival, the TRCF begins medium access handshaking by transmitting the RTC burst within the contention section of an idle time-slot as

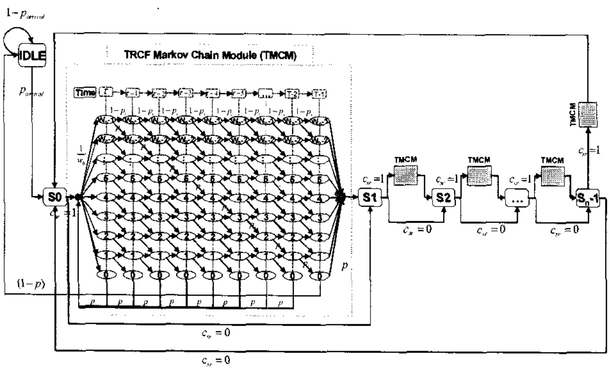


그림 7. TRCF 상태 천이도
Fig. 7. State transition diagram for TRCF.

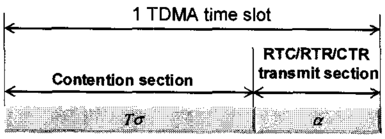


그림 8. 타임 슬롯의 구조
Fig. 8. Time partition of a time-slot.

soon as the back-off counter expires. The time-sectionpartition within the time-slot is shown in Fig. 8. When the RTC transmission is successful followed by RTR and CTR exchanges, the node can begin to send voice packets from the next super-frame by using the reserved time-slot.

On the other hand, when collision occurs during RTC control packet transmission, the node has to back-off with a back-off value randomly selected from a back-off window. In this investigation the back-off window is fixed with $[0, w_0 - 1]$, however, the binary exponential back-off window also can be used. As long as enough time is left in the contention-sectionof the time-slot, not only the collided nodes but also neighboring nodes can participate in another round of medium contention. Themedium contention continues over the next available time-slots and super-frames untilbeing connected; and the number of retries can also be fixed.

## 2. Performance analysis

In order to assess the behavior of TRCF, the analytical expressions for meaningful parameters such as the probability of control packet transmission and the probability of successful RTC control packet transmission are derived. Moreover, the performance estimation measures such as average wait time taken for a call connection and throughput are obtained in this section.

Table 1 summarizes various factors, and variables and parameters used in derivation of analytical expressions. First, consider some basic transition probabilities. When the channel is idle for $\sigma$duration, which is the smallest time unit, the backoff counter decrements by one with:

$$P\{(w-1, k, \tau+1)|(w, k, \tau)\} = p_i \tag{1}$$

or it freezes with:

$$P\{(w, k, \tau+1)|(w, k, \tau)\} = 1 - p_i \tag{2}$$

After being in the current time-slot for $T\sigma + \alpha$ time, the probability being in the next,idle time-slot

표 1. 사용된 변수와 파라미터 정의
Table 1. Definitions of variables and parameters used.

| Parameters | Descriptions |
|---|---|
| $\sigma$ | The unit slot time for each transition |
| $w$ | Backoff counter |
| $k$ | TDMA time slots |
| $s$ | Total TDMA time slots |
| $P_{arrival}$ | Call request probability |
| $p_i$ | The probability of channel idle for $\sigma$ duration |
| $1-p_i$ | The probability of channel busy for $\sigma$ duration |
| $p$ | Collision probability |
| $1-p$ | The probability of a successful TDMMA time slot reservation |
| $c_{sr}$ | 1 : TDMA time slot is open<br>0 : TDMA time slot was already reserved |
| $T\sigma$ | The period of contention to obtain TDMA time slot |
| $\delta$ | Propagation delay |
| $\alpha$ | $PIFS+RTC\_time+\delta+SIFS+RTR\_time+\delta+SIFS+CTR\_time+\delta$ |
| $\hat{\alpha}$ | $PIFS+RTC\_time+\delta+SIFS+RTR\_timeout$ |

that is:

$$P\{(\hat{w}, k+1\, Mods, \alpha\tau)|(w, k\, Mods, \tau)\} = \frac{c_{sr}}{w_0} \quad (3)$$

In case of RTC burst collision, the probability of going into another round of medium contention in the current time-slot is as follows:

$$P\{(w, k, \hat{\alpha}\tau)|(0, k, \tau)\} = \frac{p}{w_0} \quad (4)$$

$$(w+\hat{\alpha}/\sigma) \le Time_{(0,k,\tau)\to(w,k,\hat{\alpha}\tau)} \le ((w_0-w)+\hat{\alpha}/\sigma)\sigma$$

The probability going into first round of medium contention to serve the call request arrival is as follows:

$$P\{(w, k, \tau)|(IDLE)\} = p_{arrival}\frac{(c_{sr})^k}{w_0}\frac{1}{s} \quad (5)$$

The probability of going into IDLE state after sending a control bust successfully is as follows:

$$P\{(IDLE)|(0, k, \forall\tau)\} = 1-p \quad (6)$$

The probability of moving into the next time-slot after having a packet transmission at time T-1:

$$P\{(w, k+1, \tau)|(0, k, T-1)\} = p \quad (7)$$

From the state transition diagram, the probability of control packet transmission is sum of all states with 0 backoff counter value. After some steps of mathematics, it comes out as follows:

$$\gamma = \frac{1}{w_0}\{1+(w_0-1)p_i\} \quad (8)$$

Also, from the derivation result, the probability of successful transmission of control packet within one time slot is as follows:

$$p_{success} = \sum_{j=1}^{w_0/\hat{\alpha}} \frac{\gamma \cdot p^{j-1}(1-p)}{2^{(j-1)\hat{\alpha}}} \quad (9)$$

where j is the number of retransmission and $\hat{\alpha}$ is the time taken for control packet collision detection and the probability of control packet collision is as follows:

$$p = 1-(1-\gamma)^{n-1} \quad (10)$$

where n is the number of active nodes in the ad hoc network field. Finally, we can derive the TRCF MAC performance estimation measures. The first one is the average wait time taken for a call connection. The derivation result is as follows:

$$E\{WaitTime\} = \sum_{j=1}^{w_0/\hat{\alpha}-1} \frac{\varphi \cdot p^{j-1}(1-p)}{2^{(j-1)}} \quad (11)$$

where $\varphi$ is the average time taken by the backoff counter becoming zero within a time-slot

$$\varphi = \frac{1}{wo}\left\{(w_0-1)^2 - \frac{(w_0-2)(w_0-1)p_i}{2}\right\}\sigma \quad (12)$$

## 3. Performance prediction

Using the expressionsfrom the analytical derivation, the typical cases of TRCF MAC performance can be shown using numerical computations. Fig. 9 shows the probability of RTC burst transmission given the different probabilities of channel being idle. Based on results in Fig. 9, the probability of successful RTC burst transmission is shown in Fig. 10. Finally, the most interesting and meaningful performance measure for serving real-time voice call request is the average wait time taken for a call connection and it is shown in Fig. 11.

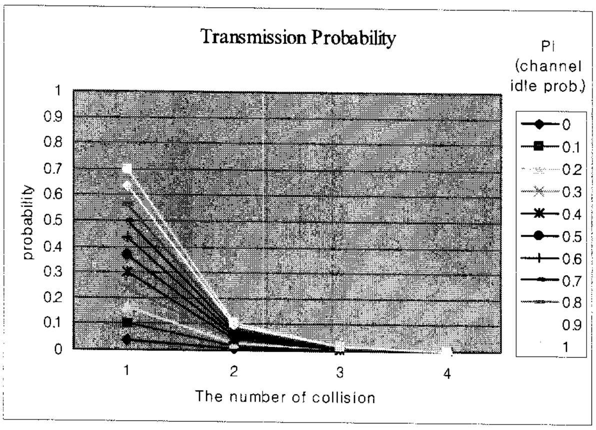


그림 9. 채널의 idle 확률에 따른 전송확률
Fig. 9 Transmission probabilities given various $p_i$.

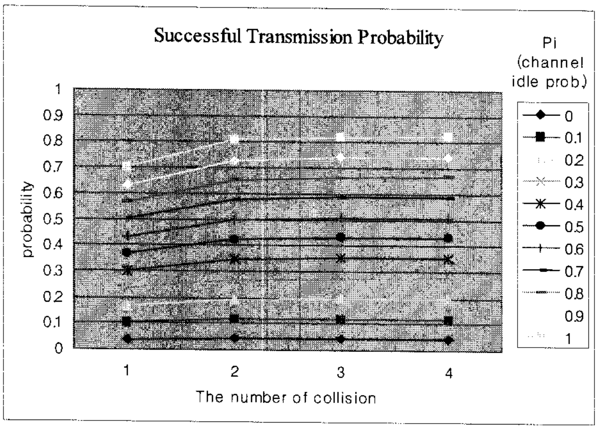


그림 10. 제어 패킷 전송의 성공 확률
Fig. 10. Probability of successful control packet transmission.

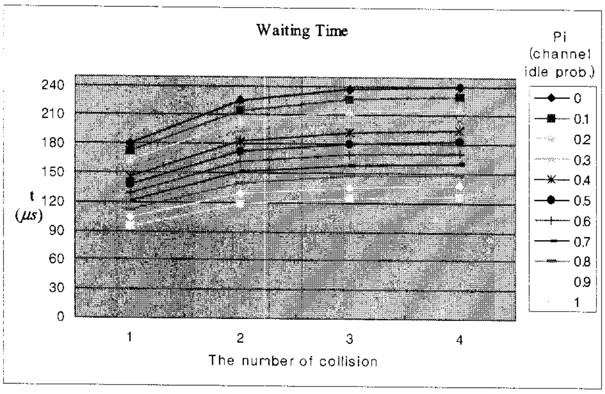


그림 11. 음성 콜 연결까지의 평균 대기시간
Fig. 11. Average wait time taken for voice call connection.

## IV. Conclusions

We have presented a novel medium access control method for supporting real-time servicessuch as a voice call in MANET. Leaving the asynchronous data service supporting DCF untouched, the time-slot reservation based isochronous MAC called TRCF has been designed. Furthermore, in order to assess the behavior of the medium access handshaking operations,the TRCF MAC has been modeled by using Markov chain. Finally, the performance prediction measures such as the average wait time taken for a voice call connectionhas been analytically derived. In the future study, the network simulations will be performed, and the simulation results will be compared to those obtained from modeling.

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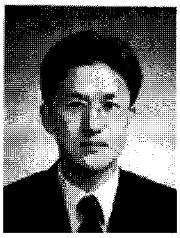
## 저 자 소 개

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