An adaptive backoff algorithm for OFDMA systems

Yao Huang[1] , Hui Tian[2], Cheng Qin[3], Jinghong Li [4] , Jun Zhang[5]
Key Laboratory of Universal Wireless Communications, Ministry of Education
Wireless Technology Innovation Institute, WTI
Beijing University of Posts and Telecommunications, Beijing, P.R.China, 100876
E-mail:[1]huangyao19831003@163.com,[2345]{tianhui, qincheng, lijinghong, zhangjun}@bupt.edu.cn

Abstract—**Orthogonal Frequency Division Multiplexing Access (OFDMA) will be adopted in next generation wireless communication systems, as they provide multiple access channels for initial channel access, resource request, etc. In this paper, for OFDMA systems, an effective and adaptive backoff algorithm is presented based on the Pseudo Bayesian Broadcast algorithm. It not only provides a dynamic backoff window according to the load, but also supports different Quality of Service (QoS) for various access traffics. Through simulation, the proposed algorithm has the advantage of high successful random access rate and low access delay compared with the traditional backoff algorithm.**

Keywords- OFDMA systems, backoff, priority

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) [1] is widely studied, due to its advantage of robustness to multipath selective fading and high spectral efficiency. In OFDM, a single data stream is transmitted over a number of lower rate subchannels. Although the whole band suffers frequency selective fading, each sub-channel is flat fading. Therefore it can effectively be against multi-path effects. Meanwhile, it greatly improves spectrum efficiency, because each subcarrier is orthogonal.

As the evolution of OFDM, OFDMA systems have many logical channels, and allocate these channels to individual terminals. Each terminal can choose subchannels with better conditions for data transmission. Thus it can get multi-users diversity gain in frequency [2].

Random access protocols provide a more flexible and efficient way of managing channel for access. During the random access procedure, terminals must select random access channel to send access requests. If other terminals select the same channel, this situation will result in a collision and these collision terminals will back off and retransmit their access requests. The collision resolution methods employ all kinds of algorithms, such as the backoff algorithm with binary exponential backoff (BEB) or uniform backoff (UB). After a successful random access, they can transmit data packets using the uplink resources assigned by the Node B. Thus, an efficient collision resolution algorithm leads to fast system access and high throughput.

Previous work on backoff mechanism have been extensively investigated, It can be summarized in the following aspects. Window adjustment strategy, which means backoff algorithms select backoff window according to the system condition [3].e.g. UB, BEB. Model construction strategy, which means backoff algorithms is considered in different models, [4][5]. e.g. an infinite population model[6]. Probability adjustment strategy, which means backoff algorithms adjust access probability to avoid system congestion [7].

Besides the backoff algorithm, access level priority should be considered to provide QoS, such as security service, public utilities, emergency service. Since even the system can provide enough resource, an Access Terminal (AT) will consider the time to access the system. In order to prioritization in the access control, priority can be further enhanced by differentiating some parameters of those backoff algorithms.

In addition, Ref. [8] analyzes the performance of both Uniform Backoff algorithm in UMTS-LTE and Binary Exponential backoff algorithm in IEEE 802.16 systems and it considers a dynamic window assignment, but this window doesn't support the QoS. Ref. [9] proposes a novel message transmission scheme in a shared RACH. This paper pays more attention to cyclic-shifted preambles and it doesn't refer to the backoff algorithm. Ref. [10] considers the issue of designing an appropriate reuse factor for random access channels in order to overcome the interference problem in OFDMA multicell environment, the maximum number of allowed retrial is selected based on the load condition. A simple and practical backoff algorithm is presented in [3], but the backoff windows in this algorithm are fixed and different traffics adapt different backoff windows. The Pseudo Bayesian Broadcast algorithm [11] is particularly effective and stable in random access procedure. It is derived by approximating the probability estimation with a Poisson distribution. However, this algorithm only involves a single channel, it doesn't consider multiple channels.

In this paper, we provide a dynamic backoff algorithm with fast retransmission and access priority differentiation. It can obtain high successful random access rate and low access delay, and satisfy QoS requirements. The rest of this paper is organized as follows. Section II describes the background and Section III introduces the presented algorithm. The simulation results are analyzed in section IV. Finally, section V concludes this paper.

II. BACKGROUND DESCRIPTION

In OFDMA systems, there can be M random access channels and F random access preambles (RAPs) in the frequency domain within the random access slot. If the same RAP is selected by more than one AT in the same RACH, a code collisions occurs. Hence, we assume that perfect orthogonality among RAPs simultaneously transmitted by ATs is preserved. Then a system with M RACHs and F RAPs is equivalent to system with $M \bullet F$ RACHs or $M \bullet F$ RAPs [8]. To simplify the analysis, F is set to 1 in every random access slot. Therefore, the number of RACHs can be only considered.

An AT may randomly select one RACH to send access request. But if other ATs select the same random access channel, a collision occurs. Hence, there are three outcomes in the RACH:

Transmission, when only one terminal transmits access request.

Collision, when two or more terminal transmit access request in the same RACH.

Vacancy, when no terminals transmit an access request.

Whenever ATs access requests are not successful, they retransmit after a delay determined by backoff algorithms, such as UB algorithm. As shown in Figure 1 these traditional backoff algorithms will be used when a collision happens. Because they don't take the characteristic of OFDMA systems into consideration and can't make full use of frequency and time resources in OFDMA systems, this will cause unnecessary delay when the load is light. As shown in Figure 2, when the load is not heavy, a collision happens in one of RACHs while other RACHs may be idle. Thus, it isn't necessary to immediately adopt the traditional backoff algorithm to avoid more collisions.

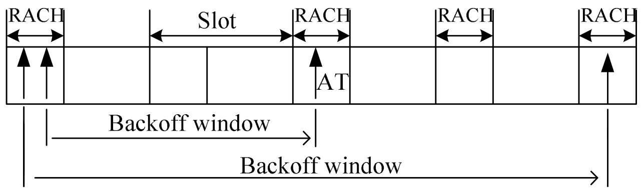

Figure 1 Backoff in single channel.

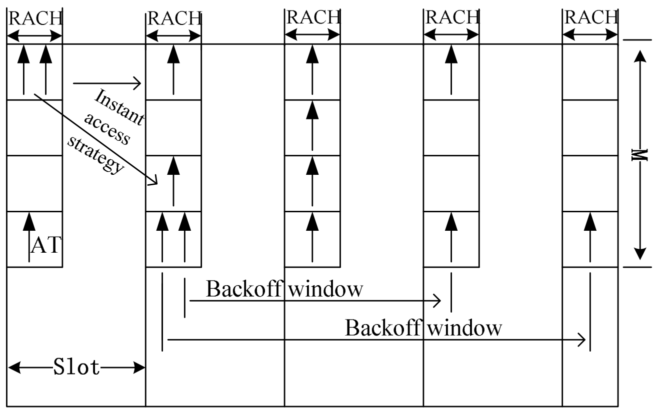

Figure 2 Backoff in multiple channels

As discussed above, we presented an effective and adaptive algorithm to solve this problem. Based on TDD mode, it fully considers multiple access channels characteristic in OFDMA systems. In the uplink, the Node B should estimate the number of ATs which arrive in the next slot according to access requests status in the RACHs. Then it selects the backoff strategy based on the proposed algorithm. In the downlink, the ATs are assigned backoff strategy by the Node B in the first random access response message. This method can efficiently resolve RACHs congestion under some time-varying traffic condition.

III. ALGORITHM DESCRIPTION

In the access process, according to the access requests in uplink, the Node B estimates ATs in the next slot based on the Pseudo Bayesian algorithm. If the number of predicted ATs is smaller than M, the collision terminals can retransmit in the next slot, which is called instant access strategy, and in this situation it doesn't consider backoff scheme. But if the number of predicted ATs is larger than M, the dynamic backoff window assignment mechanism is adopted through the proposed algorithm.

A. *The Pseudo Bayesian Broadcast Algorithm*

The Pseudo Bayesian Broadcast algorithm, which uses the changeable mean to represent the estimated ATs, is optimum given available global information. This algorithm is found to be exceptionally effective in practice since it makes nearly the "best possible use" of the information available on the network in determining the broadcast probabilities to use.

When the RACH is single, let $N(k)$ denote the number of ATs in slot k, then each terminal will get a broadcast probability $b(k)$,which is also the probability sending access request. It's computed from the globally available network and the channel state(i.e., vacancy, success or collision) ,then waiting probability $w(k)=1-b(k)$ .When ATs send access requests in the single channel, the probabilities about channel state are

$$\begin{cases} P\left(\text{vacancy}\middle|N(k)=n\right)=V_{b(k)}(n)=\left(w(k)\right)^{n} \\ P\left(\text{success}\middle|N(k)=n\right)=S_{b(k)}(n)=n\cdot b(k)\cdot\left(w(k)\right)^{n-1} \\ P\left(\text{collision}\middle|N(k)=n\right)=C_{b(k)}(n)=1-\left(w(k)\right)^{n}-n\cdot b(k)\cdot\left(w(k)\right)^{n-1} \end{cases} \tag{1}$$

$N(k)$ can be expressed by the Poisson distribution with mean v, which also means the average number of ATs in every slot. Each AT has only one access request traffic flow, the traffic distribution function can be written as

$$P_{v}(n)=\frac{e^{-v}\cdot v^{n}}{n!} \tag{2}$$

(2) denotes the Poisson density at n for Poisson parameter v. Then Jointing ATs distribution, the probabilities about channel state can be expressed as

$$P_{v}(n)\cdot V_{b(k)}(n)=\frac{e^{-v}\cdot v^{n}}{n!}\cdot\left(w(k)\right)^{n}=e^{-vb(k)}\cdot P_{vw(k)}(n) \tag{3}$$

$$\begin{aligned} P_{v}(n)\cdot S_{b(k)}(n)&=\frac{e^{-v}\cdot v^{n}}{n!}\cdot n\cdot b(k)\cdot\left(w(k)\right)^{n-1} \\ &=v\cdot b(k)\cdot e^{-vb(k)}\cdot P_{vw(k)}(n-1) \end{aligned} \tag{4}$$

$$P_{v}(n)\cdot C_{b(k)}(n)=P_{v}(n)\cdot\left(1-H_{b(k)}(n)-S_{b(k)}(n)\right) \tag{5}$$

Where $P_{vw(k)}(n)=\frac{e^{-(vw(k))}\cdot(vw(k))^n}{n!}$ .From (1)~(5), it is easy to compute the broadcast probability $b(k)=\min\left(\frac{1}{v},1\right)$.

In the Pseudo Bayesian Broadcast algorithm, it considers that updating v which denote the average number of ATs in every slot is as Bayesian manner as possible, while preserving Poisson approximation. If $b(k)=\frac{1}{v}$, the number of ATs still obeys Poisson distribution from (3). When the vacancy happens, the Node B reduces the estimation number of ATs by one, unless v is already less than one, in which case v is set to 0. From (4), the equation yield a new Poisson distribution with mean $v-1$, then the estimation of ATs is also reduced by one. To sum up, when the success and the vacancy happen, the number of estimated ATs will be reduced by one in the next slot.

When the channel state is collision, the distribution about the number of ATs isn't Poisson distribution, but here it is approximately regarded as a Poisson distribution $v+\frac{(v\bullet b(k))^2}{e^{v\bullet b(k)}-v\bullet b(k)-1}$. When $b(k)=\frac{1}{v}$, it can be simplified as $v+\frac{1}{e-2}$. Then the number of ATs will be incremented by $(e-2)^{-1}$ in the next slot.

Through the Pseudo Bayesian Broadcast algorithm, the Node B can estimate the number of access terminals and the probability, when the RACH is single. During each slot, the Node B will [11]:

Set v to $\max(v+\hat{\lambda},1)$, where $\hat{\lambda}$ is an estimate new terminal arrival rate.

For collision, increase v by $(e-2)^{-1}$. For success and vacancy, decrease v by 1.

Broadcast that ATs send the access request with probability $1/v$

We note that the Pseudo Bayesian Broadcast algorithm only needs binary feedback since it only needs to distinguish collisions from no collisions.

B. The proposed algorithm

The proposed algorithm runs under both light and heavy load conditions. The following notations are defined, which will be used in this section:

M : Number of random access channels

p : ATs collision probability

$\lambda_T(k)$: Total arrival rate or the estimated average number of total ATs in slot k

λ: New terminal arrival rate or the average number of new ATs in every slot

$R_{\max}$: The maximum number of retransmission

The new terminal arrival rate in slot obeys a Poisson distribution with mean λ. It's certain that collided AT in the previous slots should be considered. Hence, according to [10], the total arrival rate $\lambda_T(k)$ can be calculated as

$$\lambda_T(k)=\lambda+p\cdot\alpha\cdot\lambda_T(k-1) \tag{6}$$

Where α is the factor which adjusts added arrival rate, α is obtained by

$$\alpha=\frac{\sum_{i=o}^{R_{\max}-1}p^i}{\sum_{i=0}^{R_{\max}}p^i} \tag{7}$$

p is the terminal collision probability in the observed slots, which can be written as

$$p=\frac{E(\text{collisions})}{E(\text{successes})+E(\text{collisions})} \tag{8}$$

Where $E(\text{collisions})$ and $E(\text{successes})$ are respective the number of collisions and the number of successes in the RACHs. Assume that both collisions and no collisions can be detected by the Node B.

When there are collisions caused by competition in the current slot, the proposed algorithm decides whether to back off for the collided terminals in the next slot according to the load. Hence, we should firstly estimate the number of ATs.

In the slot $k-1$, the Node B uses the Pseudo Bayesian Broadcast algorithm to estimate $\hat{N}(k)$. For OFDMA systems, there are M RACHs. The probability that every AT selects one of RACHs is equiprobable and $\lambda_T(k)$ also means the estimated average number of total ATs in slot k . Therefore, the arrival value is $\frac{\lambda_T(k)}{M}$ in every RACH. And every RACH is independent. Hence, the Pseudo Bayesian Broadcast algorithm is adopted in every RACH. We can get:

$$\hat{N}_m(k)=\begin{cases}\max\left(\frac{\lambda_T(k)}{M},\hat{N}_m(k-1)+\frac{\lambda_T(k)}{M}-1\right) & \text{vacancy or success}\\ \hat{N}_m(k-1)+\frac{\lambda_T(k)}{M}+(e-2)^{-1} & \text{collision}\end{cases} \tag{9}$$

Where $m=1,\cdots,M$.

$\lambda_T(k)$ can be get by(6). Then $\hat{N}(k)$ can be written as

$$\hat{N}(k)=\sum_{m=1}^{M}\hat{N}_m(k) \tag{10}$$

In OFDMA systems, there are M RACHs. Thus, the terminals send access requests with the probability $\min\left(1, M/\hat{N}(k)\right)$.

When $\hat{N}(k) \geq M$, the access probability value is $p_b = M/\hat{N}(k)$. Let W denote the average number of waiting slots for a terminal. It is the reciprocal of the best broadcast probability and can be given by

$$W = \frac{1}{p_b} \tag{11}$$

In the UB algorithm, the terminal randomly selects the backoff window between 1 and B. In this range, the access probability follows a Uniform distribution, and its mean is $\frac{B}{2}$. Therefore, W can also be calculated as

$$W = \frac{B}{2} \tag{12}$$

Using (11) (12), B is finally written as

$$B = \frac{2\hat{N}(k)}{M} \tag{13}$$

According to (13), the backoff window B is dynamically adjusted based on the access probability which isn't needed to broadcast in this scheme.

In order to provide access priority, different traffics have a different persistence value P_N which can be default by the systems [12] .Therefore, when ATs with different priority need to backoff, the backoff windows are expressed as $B_{priority} = P_N B$, instead of randomly being selected between 1 and B.

The detailed process of the presented algorithm is shown in algorithm 1.

Algorithm 1

In the slot $k-1$,

Estimate $\hat{N}(k)$ using the Pseudo Bayesian Broadcast algorithm.

If $\hat{N}(k) \geq M$,then

Calculate $B = \frac{2\hat{N}(k)}{M}$ and $B_{priority} = P_N B$

else

Adopt instant access strategy for collided terminals in the slot k

End if

In the slot k,

Collided different priority terminals send access requests based on the backoff scheme or instant access strategy.

The Node B collects the feedback information from each RACH.

$k = k+1$. Go to step 2.

IV. SIMULATION RESULT

The simulator is written in the MATLAB programming language. The new terminal arrival rate obeys a Poisson distribution with mean λ, which is set to be a value between 0.1 and 10 by step of 0.1. The number of RACH is 30 and the maximum number of retransmission is 6. The initial value of p is 0 and it is updated every 6 slots. If $R > R_{\max}$, the access request will be dropped. Simulation results are carried out for 5000 slots. This presented algorithm is compared with the UB algorithm and the BEB algorithm [8].

In the UB algorithm, the backoff window is randomly selected between 1 and B. In this simulation, B is receptively set to 20 and 40. In the BEB algorithm, the backoff window is randomly selected between 1 and $2^i W_0$, where i denote the number of retransmission. In this simulation, W_0 is set to 4.

To evaluate the performance of the proposed algorithm, the radio channel environment is good and access is perfectly known both ATs and the Node B. Meanwhile, two parameters are used. One is the success rate of random access and the other is the average access delay. The simulations are run as λ increases. The success rate of random access ρ is defined as $\rho = \frac{\text{Total number of successful access attempts}}{\text{Total number of access attempts}}$

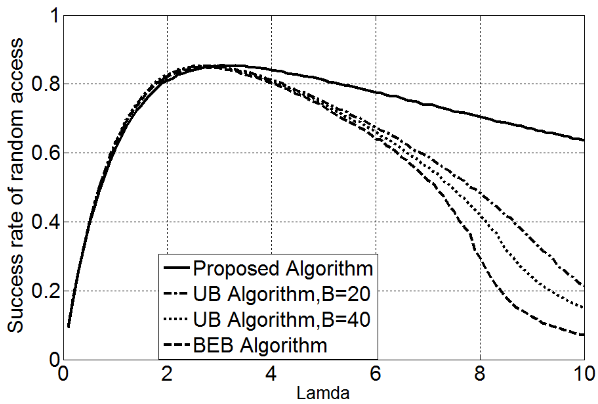

Figure 3 Success rate of random access vs. λ_T

Figure 3 shows the successful random access rate comparison without priority. When the load is light, there are enough RACHs for ATs. Hence, the value of successful random access rate increases quickly. As the load is further added, collisions begin to appear, because the RACHs resources are limited. The greater load will cause more collisions. Therefore, the success rate of random access is down after it reaches a maximum value. But the proposed algorithm improves the success rate of random access after the load becomes heavy. Figure 3 fully indicates that the proposed algorithm has better performance compared with the UB algorithm and BEB algorithm.

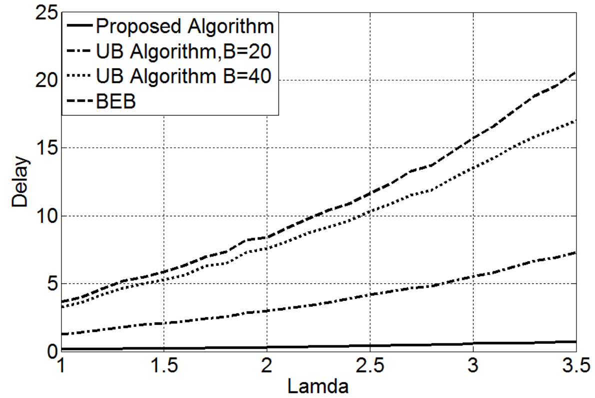

Figure 4 Delay vs. λ_T

Figure 4 shows the average delay of terminals without priority. As the load increases, the number of collision terminals grows, thus the delay also increases. Compared with the UB algorithm and the BEB algorithm, the proposed algorithm performance is better. When the load λ_T isn't heavy, the load of each RACH is corresponding light. Hence the instant access strategy is adopted based on the proposed algorithm. As a result, the delay is small. When the load increased gradually, the collided terminals need to avoid system congestion and they adopt the dynamical backoff windows through the proposed algorithm, thus the delay becomes longer. In Fig.4, the average delay with the presented algorithm is shorter than that with the UB algorithm under condition of both light and heavy load.

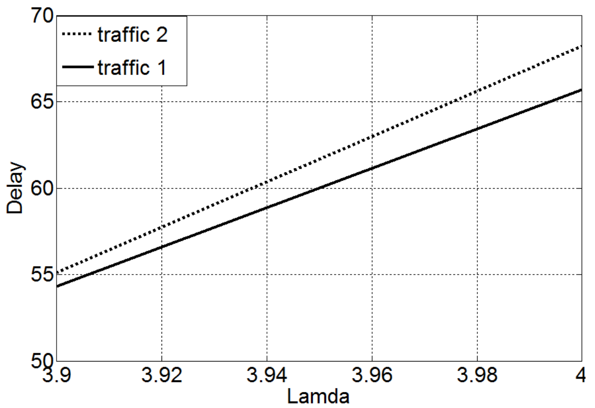

Figure 5 Delay vs. λ_T

Figure 5 shows the average access delay of two traffics terminals in integration traffic environment. The traffic 1 may represents the real-time traffic such as VoIP streams. The traffic 2 may represents non real time traffic such as FTP. Therefore, traffic 1 has higher priority than traffic 2. The arrival rates of two traffics take half of the new arrival rate. For traffic 1 and traffic 2, $P_N = 0.2$ and $P_N = 0.8$, respectively. When the load is not heavy, the difference of the delay between two traffics is not obvious. As the total arrive rate increases, the delay of high access priority is shorter than the delay of low access priority.

V. CONCLUTIONS

This paper presented a novel backoff scheme in OFDMA systems. We consider an adaptive and effective backoff strategy providing QoS guarantee for various traffics. The Node B estimates the number of access terminals in the next slot by the proposed algorithm, then decides whether to adopt backoff algorithm. The simulation results fully indicate that the proposed algorithm is efficient under conditions of both low and high load, and reflect that the algorithm not only improves successful random access rate, but also efficiently supports different access priority traffics transmission in integration traffic environment.

ACKNOWLEDGMENT

This work was jointly supported by the National Natural Science Foundation of China （No.60971125，No.61121001) and the EU FP7 Project EVANS (No. 2010-269323).

REFERENCES

[1] V Melsleh R. , Elgalg H., Haas H. . "On the Performance of Different OFDM Based Optical Wireless Communication Systems," IEEE/OSA Journal of Optical Communication Systems, vol.3, no.8,pp.620-628. Aug.2011.

[2] Bo Bai, Wei Chen, Zhigang Cao, Letaief, K.B. . "Achieving High Frequency Diversity with Subcarrier Allocation in OFDMA Systems," IEEE GLOBECOM 2008, pp. 1-5.

[3] Abedl-HamidY., Gebali F., Gulliver T. A. . "A Reservation-Based Multiple Access Protocol for OFDMA Network with Adaptive Backoff Strategy," IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, 2007, pp.161-165.

[4] A. Nyandoro, L. Libman, and M. Hassan, "Service differentiation using the capture effect in 802.11 wireless LANs," IEEE Trans. Wireless Commun., 2007.vol.6, no.8,pp.2961–2971, Aug.2007.

[5] D. R. Chen and Y. J. Zhang, "Is dynamic backoff effective for multi-rate WLANs?" IEEE Commun. Lett., vol.11,no.8,pp.647-649, Aug.2007.

[6] Y.-S. Liu, "Performance Analysis of Frequency-Hop Packet Radio Networkswith Generalized Retransmission Backoff," IEEE Trans. Wireless Comm.,. vol.1,no.4, pp.703-711, Oct.2002.

[7] M. E. Rivero-´Angeles, D. L.-Rodr´ıguez and F. A. C.-P´erez, "Differentiated Backoff Strategies for Prioritized Random Access Delay in Multiservice Cellular Networks," IEEE Trans. Veh. Tech., vol.58,no.1,pp.381-397, Jan.2009.

[8] Jun-Bae Seo , Leung, V.C.M. . "Design and Analysis of Backoff Algorithms for Random Access Channels in UMTS-LTE and IEEE 802.16 Systems," IEEE Transactions on Vehicular Technology, vol.60,no.8,pp.3975-3989, Oct.2011.

[9] Ping Zhou, Honglin Hu , Haifeng Wang, Hsiao-hwa Chen. "An efficient random access scheme for OFDMA systems with implicit message transmission," IEEE Transactions on wireless communications, vol.7,no.7,pp.2790-2797, July 2008.

[10] Choi,Young june, Suho Park, Saewoong Bahk. "Multichannel random access in OFDMA wireless networks," IEEE Journal onSelected Areas in Communications, vol.24, no.3,pp.603-613, Mar. 2006.

[11] Rivest R ." Network Control by Bayesian Broadcast," IEEE Trans. Inform. Theory, vol.33, no.3, pp. 323-328, .May 1987.

[12] Che Li Lin. "Investigation of 3rd generation mobile communication RACH transmission," Vehicular Technology Conference 2000, IEEE VTS-Fall VTC 2000.52nd , vol.2, pp.662-667, 2000.