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An adaptive Slotted ALOHA Algorithm

***Abstract**. Slotted ALOHA channels are inherent instability and must be equipped with proper control. In this paper, we analyze the principle of p-persistent control algorithm (pPCA) at first, we propose a novel auto-control algorithm which combines the multiple factor into p-persistent auto-control algorithm (MF-pPCA). The simulation demonstrates that the novel algorithm can accelerate the adjusting speed and can acquire stable throughput on the conditions that there is large fluctuation of system load.*

***Streszczenie.** W artykule analizuje sie nowy algorytm pPCA umożliwiający poprawę szczelinowego algorytmu ALOHA w zastosowaniu do przesyłu danych. (**Adaptacyjny algorytm szczelinowy ALOHA**).*

Keywords: slotted ALOHA, p-persistent control algorithm, multiple factor p-persistent auto-control algorithm
Słowa kluczowe: algorytm ALOHA, algorytm PCA.

1 Introduction

With the emergence of radio cognitive technology, the Dynamic Spectrum Sharing network (DSSN) received extensive attention in recent years [1-2]. By exploring the idle spectrum of premier user; the second users can use it to communication. When premier users need to continue conversation, the second users must avoid using these channels, and should explore new idle channel to maintain Communications. The terminal users apply random access mode to share physical channel, which employs OFDM (Orthogonal Frequency Division Multiplexing) modulation with strict symbol synchronization, and An OFDM symbol can carry more than 256 bytes of data.

The medium access control (MAC) layer usually uses distributed random access protocols such as CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) in 802.11 WLAN, However, the channel efficiency is inefficient due to request-to-send/clear-to-send (RTS/CTS) hand-shaking mechanism .Because the additional time such as three SIFS, one DIFS, time of RTS/CTS frame and ACK frame, therefore, the preamble time in 802.11a/b/g being existence, in practice, the data utilize channel time is less. By the mathematic calculating, its performance is inferior to slotted ALOHA protocol. On the other hand, the OFDM symbol in DSSN is bigger than usual OFDM symbol of 802.11a/b/g, the longer the OFDM signal, the larger IFS is. So, slotted ALOHA(S-ALOHA) protocol is used as random access mode in channel sharing.

The slotted ALOHA random access protocol is widely used either independently or as part of different multiple access protocols, it is inherent instability and must be equipped with proper control. Different kinds of retransmission probabilities, especially the familiar and widely accepted exponential back-off retransmission probability, for different values of p_r are analyzed in [3-11]. The selection of a constant value for this exponential retransmission probability p_r is difficult, particularly in a dynamic load condition. Several algorithms are proposed for the stabilized slotted ALOHA system with a dynamic selection of (exponential retransmission probability) p_r . In order to obtain the system stability, those literatures are mainly based on either the estimated total offered load or limited the retransmission number. All those literatures only consider the case of traffic which changed a littler, but the load of radio communication network system is elastic load which changes acutely at most case So, the adjusting time is very long, and it may bring surge when the offered load change acutely.

In this paper, towards the MAC design of dynamic spectrum sharing network, a quasi slotted ALOHA access control protocol was used. A p-persistent control algorithm which used idle probability of slot to estimate offered load was proposed. According to channel information feedback; AP calculates the channel idle probability and transmission probability, then broadcast to user equipment (UE) on feedback slot. The simulations indicate that this algorithm can not quickly attain steady maximum throughput. We propose a novel fast adjust stability algorithm of slotted ALOHA, in which, a multiple factor which accord to the continuous information of CSI is introduced into p-persistent auto-control algorithm. This algorithm can deal with the case that offered load change acutely and make the system stable. The results show that the novel algorithm can accelerate the adjusting speed and can acquire stable throughput on the conditions that there is large fluctuation of system load. Compared to the ordinary p-PCA, the system throughput can increase 10% to 200% when the offered load change between 2~5 times, and the time of adaption can shorten 100% to 300%.The rest of this paper is organized as follows： Section II defines system models. In Section III we describe two control algorithms. Section IV shows the result of simulation. We conclude the paper in Section V.

2 DSSN System model and S-ALOHA formulation

2.1 DSSN System model

DSSN is composed of AP and n UEs (user equipments). And each UE owns 3 transmit/receive channel machines, whose spectrum is 8 MHz. To avoid interference each other, the channel machines work simultaneously. UE communicates with other users through AP. There are 4 data forms, super-frame, frame, OFDM signal and MAC frame, which is illustrated in the Fig. 1. Every super-frame is composed of 16 frames, numbered from 0 to 15, and the number 0 is the first frame. All the frames continue for 10ms. In each frame, there are 40 OFDM signals, which continue for 250us and can carry 2316bit data. In every sub-frame, the first slot is synchronous ones, and the second is the cognition ones, then followed by 38 communicational slots that can carry data.

One of the 38 slots is for switching between uplink and downlink, which separates other 37 slots into 2 part, downlink and uplink. And there are competing and un-competing slot in the uplink and downlink ones. User equipments can randomly access the competing ones in uplink to obtain the resource. Considering that all the users obtain the resources on the competing slot, we assign 2 slots to the competing ones in uplink. To answer to the uplink competing slot, we assign 1 slot to broadcast the states of the competing slot. And the slot structure of DSSN system is illustrated in the Fig. 2.

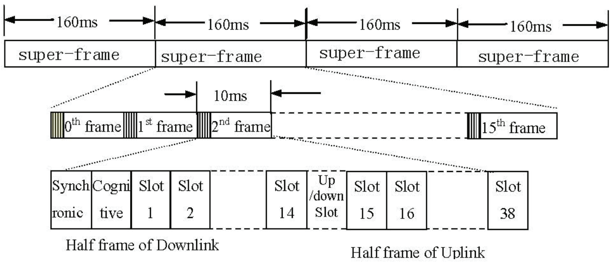

Fig.1. Link layer structure of DSSN

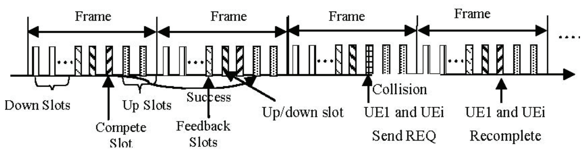

Fig.2. Slot model of DSSN

The User equipment (UE) only match in CS (compete slot), according as delay feedback channel infor-mation, AP broadcast the sending probability which all UE send packet in conformity to it. The competing success UE can transmit packet through up slot.

2.2 S-ALOHA problem formulation

In a finite user population DSSN, it assume that there are N activated terminate that can send packets to the AP (Access Point). At the beginning of a slot, each activated terminal is either unblocked or blocked, depending on whether its last transmitted packets was successful or not. An unblocked terminal transmits a packet with probability p_n in a slot. Only unblocked terminals can generate new packets. A blocked terminal retransmits its backlogged packet with probability p_r in a slot until successful, at which point it becomes unblocked again. Toward DSSN, We assume that all terminals can receive an immediate feedback carray the message of receiveing the their packets successly at the end of each slot.

At slot *K*, the state X_k can change between 0 and *N* where *N* is the number of activated terminals. Then, the time-varying state of system can be described by a Markov Chain where the state represents the number of blocked terminals. The number of blocked terminals at the end of slot depended only on the number of blocked terminals at the beginning of the slot and the events occurring during the time slot. Let *M* denote the number of blocked terminals, then the number of unblocked terminal is *N-M*. Give the state $X_k = M$, *M* and *N-M* are independent Bernoulli random variables with distribution [2]. Let $Q_r(i,M)$ denote the probability of *i* in *M* terminals of blocked retransmit, and $Q_a(i,M)$ denote the probability *i* in *N-M* terminals of unblocked transmit. Therefore,

(1)
$$Q_r(i,M) = \binom{M}{i}\left(1-p_r\right)^{M-i} p_r^i$$
$$Q_a(i,M) = \binom{N-M}{i}\left(1-p_n\right)^{N-M-i} p_n^i$$

The transfer probability from state k to state $k+i$ denote

(2)
$$P_{k,k+i} = \begin{cases} Q_a(i,k), & 2 \le i \le N-k \\ Q_a(1,k)[1-Q_r(0,k)] & i=1 \\ Q_a(1,k)Q_r(0,k)+Q_a(0,k)[1-Q_r(1,k)] & i=0 \\ Q_a(0,k)Q_r(1,k) & i=-1 \end{cases}$$

It also assumes that $p = p_a = p_n$ .The probability of i terminals (re)transmitting in a slot is denoted:

(3)
$$Q_s(i,N) = \binom{N}{i}\left(1-p\right)^{N-i} p^i$$

The channel transmission wills success when there is only one terminal sending the data in a slotted time, in other words, when $i=1$, the channel gain effective throughput. Let S denoted throughput, it is a geometrical stochastic variable, then:

(4)
$$S = \binom{N}{1}\left(1-p\right)^{N-1} p = Np\left(1-p\right)^{N-1}$$

From (4), we can get that S increases initially with increasing aggregate traffic generation rate Np . The throughput reaches its maximum value at a certain point of the aggregate traffic generation rate $Np=1$ and it starts decreasing with a further increase in the aggregate traffic generation rate. Excessive collisions occur if the offered traffic load crosses the capacity or the maximum throughput of the channel. Repeated collisions waste the bandwidth of the channel. Reducing the retransmission probability in order to randomize the retransmission attempt over a long time interval is the general solution to this problem.

3 Stabilization enhanced for S-ALOHA

In order to guarantee the stability of slotted ALOHA, it is necessary to introduce transmission control mechanisms in the ALOHA channel. The objectives of the controls are to adjust the channel parameters so that the channel operates at optimal performance for the offered (time varying) traffic pattern. The functions of the control procedures are monitoring of channel status; and adjustment of the transmission parameters based on channel observations. Control procedures may be centralized or distributed.

3.1 p-Persistent Control Algorithm

We assume that there are N terminals having packet want to send, and every terminal generating new packet regard as blocked terminal. In slot k , the system estimate it has N_k activated terminal, then every terminal send packet with probability $p_k = 1/N_k$ or not with $1-p_k$ in slot k .The number of send in a slotted time are Bernoulli random variables; therefore, the probability of a slotted time being idle and successful define as follow:

(5)
$$P_{idle} = \binom{N}{0}\left(1-\frac{1}{N_k}\right)^N = \left(1-\frac{1}{N_k}\right)^N = \left(1-\frac{1}{N_k}\right)^{N_k \frac{N}{N_k}}$$
$$P_{succ} = \binom{N}{1}\frac{1}{N_k}\left(1-\frac{1}{N_k}\right)^{N-1} = \frac{N}{N_k}\left(1-\frac{1}{N_k}\right)^{N-1} = \frac{N}{N_k}\left(1-\frac{1}{N_k}\right)^{N_k \frac{N-1}{N_k}}$$

Natural logarithmic on both sides of the (5), get

$$\log\left(P_{idle}\right) = \log\left(\left(1-\frac{1}{N_k}\right)^N\right) = N\log\left(1-\frac{1}{N_k}\right) \quad (1)$$

(6)
$$N = \frac{\log\left(P_{idle}\right)}{\log\left(1-\frac{1}{N_k}\right)}$$

When the variable m is bigger(generally $m \ge 5$), then $\left(1-\frac{1}{m}\right)^m \approx e^{-1}$ .We rewrite (5) as

(7)
$$p_{idle} = \left(1-\frac{1}{N_k}\right)^{N_k \frac{N}{N_k}} \approx e^{-\frac{N}{N_k}}$$
$$p_{succ} = \frac{N}{N_k}\left(1-\frac{1}{N_k}\right)^{N_k \frac{N-1}{N_k}} \approx \frac{N}{N_k} e^{-\frac{N}{N_k}}$$

Hence, natural logarithmic on both sides of the (8) get

(8)
$$\log(P_{idle}) = \log\left(e^{-\frac{N}{N_k}}\right) = -\frac{N}{N_k}$$
$$N = -N_k \log(P_{idel})$$

In slot $k+1$, we use N_{K+1} denote the number of terminal in system, so $N_{k+1} = N$. Otherwise, we taking into account the correlation of the number of node in updated prior and behind; and introduce the scheme of Smooth, modify N_{k+1} as:

(9) $N_{k+1} = \alpha N_k - (1-\alpha) N_k \log(P_{idel})$

When $p_{idle} = 1$, we can set $N_{k+1} = 0.5 N_k$, so let $\alpha = 0.5$. Therefore

(10) $N_{k+1} = 0.5 N_k - 0.5 N_k \log(P_{idel})$

Get countdown on both sides of the (10) get

(2) $P_{k+1} = 2P_k / (1 - \ln(P_{idel}))$

We introduce a variable of SWI (slot windows interval) in algorithm. If system stat idle slot number is N_{idle}, then $P_{idle} = N_{idle} / SWI$.

3.2 Multiple Factor p-Persistent Control Algorithm

We pay attention to (11) being no meaning when p_{idle} is 0, it expresses that the system come forth large collision. Therefore, there is a more idle slot in a statistical window when $p_{idle} \to 0$. In order to solve this question, the usually method is dynamic adjusting the size of statistical window. Nevertheless we introduce a multiple factor to solve this question.

When $\beta <= 1$, idle state of slot is more than collision state. We introduce the idea of run-length, it denote the maximum length of consecutive idle, let L_{idle}.

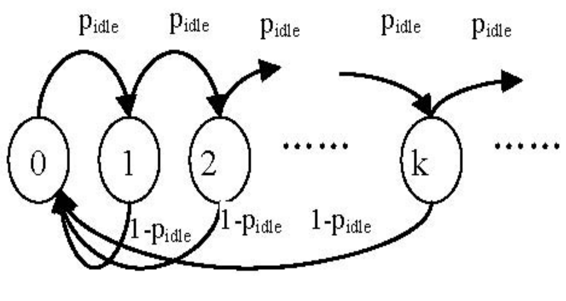

Fig.3. Run-Length of idle

Fig.3 show this structure; k denote the size of run-length. Thus the probability of $L_{idle} = k$ is

(12) $P\{L_{idle}=\text{k}\} = p_{idle}^k \cdot (1 - p_{idle})$

The mean of L_{idle} is

(13) $EV(L_{idle}) = \overline{L_{idle}} = \sum_{k=1}^{\infty} k p_{idel}^k (1 - p_{idle}) = \frac{p_{idle}}{1 - p_{idle}}$

Let $D(L_{idle})$ denote the mean-squared error of L_{idle} ,then

(14)
$$D(L_{idle}) = E(L_{idle}^2) - E^2(L_{idle}) = \sum_{k=1}^{\infty} k^2 p_{idle}^k (1 - p_{idle}) - E^2(L_{idle})$$
$$= \frac{2p_{idle}^2}{(1-p_{idle})^2} - \frac{p_{idle}^2}{(1-p_{idle})^2} = \frac{p_{idle}^2}{(1-p_{idle})^2}$$

Let $\beta = N/N_k$. When $\beta = 0.5$, the probability of slot being idle state is $p_{idle} = e^{-0.5}$, substituted p_{idle} into (13) and (14), we get

(15)
$$EV(L_{idle}) = \frac{e^{-0.5}}{1-e^{-0.5}} = 1.55$$
$$D(L_{idle}) = \left(\frac{e^{-0.5}}{1-e^{-0.5}}\right)^2 = 1.55^2$$
$$\sigma = \sqrt{D(L_{idle})} = 1.55$$

According as the central limit theorem,

(16)
$$P\left\{\left|X - \overline{L_{\text{idle}}}\right| < \varepsilon\right\} \ge 1 - \frac{\sigma^2}{\varepsilon^2}$$
$$P\left\{\left|X - \overline{L_{idle}}\right| < 4\sigma\right\} \ge 0.9375$$

Therefore,

(17) $P\left\{X \ge \overline{L_{idle}} + 4\sigma = 1.55 + 4*1.55 = 7.75\right\} \ge 0.9375$

We take the regulation threshold $L_{idleth} = 8$ .when the system detects 8 consecutive idle slots, we update the probability of terminal sending redouble; namely, let $p_{k+1} = 2p_k$.

Similarly, when $\beta > 1$, it indicates that the estimative terminal number is littler than the actual terminal number. Let L_{coll} denote the collision run-length, thus the probability of $L_{coll} = k$ is

(18)
$$P\{L_{coll}=\text{k}\} = p_{coll}^k \cdot (1 - p_{coll})$$
$$EV(L_{coll}) = \overline{L_{idle}} = \sum_{k=1}^{\infty} k p_{coll}^k (1 - p_{coll}) = \frac{p_{coll}}{1 - p_{coll}}$$
$$D(L_{coll}) = \frac{p_{coll}^2}{(1 - p_{coll})^2}$$

When $\beta = 2$, $p_{coll} = 1 - (p_{idel} + p_{succ}) = 0.594$, substituted the p_{idle} of (18),we have

(19)
$$EV(L_{coll}) = \frac{0.594}{1-0.594} = \frac{0.594}{0.406} = 1.46$$
$$D(L_{coll}) = \left(\frac{0.594}{1-0.594}\right)^2 = 1.46^2$$
$$\sigma = \sqrt{D(L_{coll})} = 1.46$$

We use the result of (16), therefore,

(20) $P\left\{X \ge \overline{L_{coll}} + 4\sigma = 1.46 + 4*1.46 = 7.3\right\} \ge 0.9375$

We take the regulation threshold $L_{collth} = 8$ too. When the system detects 8 consecutive collision slots, we update the probability of terminal as $p_{k+1} = p_k / 2$.

4. Simulation Results

In this section, the throughput is compared between pPCA and MF-pPCA scheme through simulations which are carried out using the NS-2 tool. It assumes that the system work at steady state before slot j which time number of UE suddenly change N_0 to N. The j slot denotes initial slot (0^{th} slot).

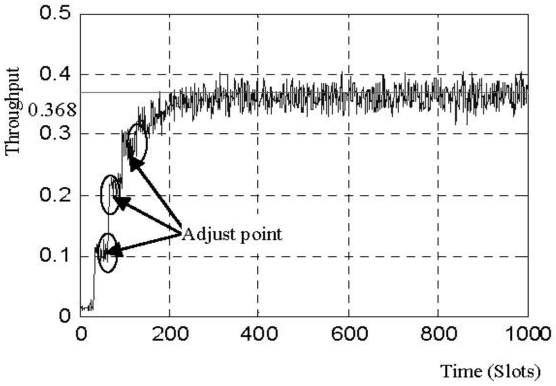

Fig .4. Throughput against pPCA

It base upon the control strategy of pPCA in which the control parameters are chosen as $N = 300, N_0 = 50$, $SWI = 32$. Fig. 4 shows the process of system adjusting. The simulation results indicate that the system can arrives at steady state in approximately 300 slotted times, and then it get the maximal throughput for slotted ALOHA. Because the probability is measured within a certain time, the system needs to go through several adjustments to achieve maximum throughput and stability.

The control parameters are chosen as *N0*=20,*SWI*=32, *N* Values are 2, 5, 20, 50, 100, and system is based upon the control algorithm of pPCA. Fig.5 shows the simulation results, from it we can see that the pPCA can get the steady throughput approximate maximum throughput of slotted ALOHA after definite adjusting time. In the regulation of the former, the system throughput is very little When UE change from $N_0 = 20$ to $N = 2,5,20,50,100$; after SWI slot, they have greatly increased the throughput. But, the adjust time of steady would change according as the ratio $\beta = N / N_0$. The adjust time is shorter when β is in close proximity to 1; and the adjust time is longer when the β is far away from 1. Corresponding, the throughput of system is closed to the maximum theoretic value when $\beta \to 1$. Otherwise, the throughput of system is littler than maximum theoretic throughput when actual current number N apart from the terminal number of previous SWI. On a same β , Fig.5 also show that the conflict is more likely to cause a decline in system throughput comparing with the free case.

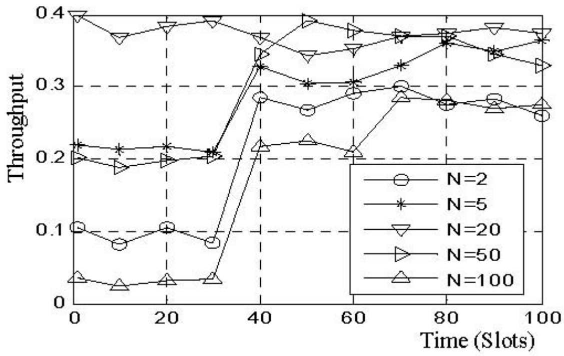

Fig.5. Throughput of pPCA

From Fig.5, it can see that system need longer time to gain the maximum steady throughput as $\beta \geq 2$. To this end, we introduce the multiplying factor into pPCA in order to accelerate the adjust process of pPCA.

Fig.6 shows the compared result of adjust process MF-pPCA with pPCA. The control parameters are chosen as $N = 300$, $N_0 = 50$ and $SWI = 32$, $\beta = 6$ both in two control algorithm. It can observe from Fig.6 that MF-pPCA can rapidly gain the steady maximum throughput than pPCA. The Multiplying Factor p-Persistent Control Algorithm (MF-pPCA) need about 64 slots to get the maximum stable throughput, while pPCA need more than 500 time slots. Comparing to pPCA, the adjusting velocity of MF-pPCA increases about 7 times.

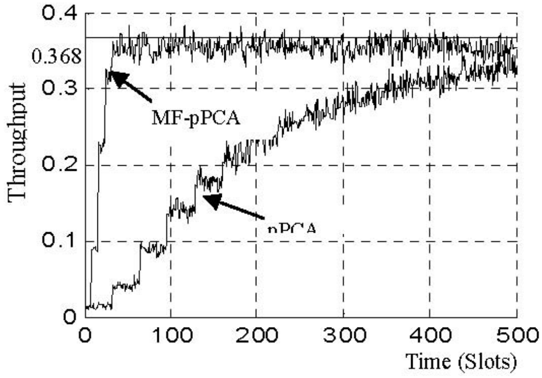

Fig.6. Throughput against MF-pPCA to pPCA

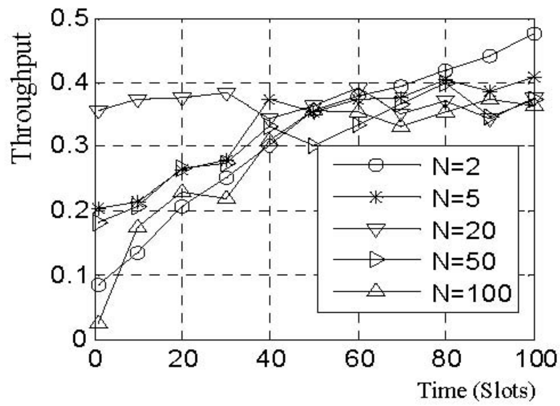

Fig.7. Throughput against MF-pPCA to pPCA

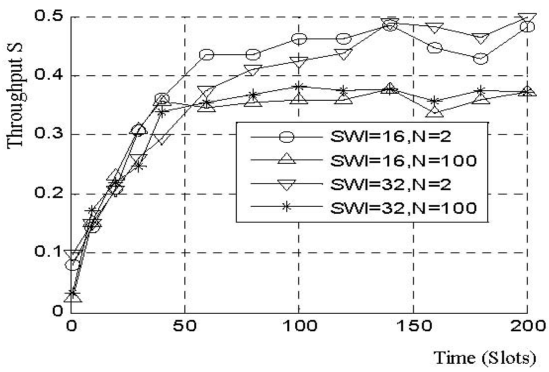

Fig.8. the throughput of MF-pPCA

Fig.7 shows the throughput of MF-pPCA and pPCA in which parameter are chosen as initial estimate terminal number $N_0 = 20$, $SWI = 16$ and simulation time being 100 slots. Fig.7 shows the average throughput of MF-pPCA and pPCA. The performance almost is same MF-pPCA to pPCA when the difference between N and N_0 is small. As the difference increases, the performance difference goes into more obvious between MF-pPCA and pPCA. Comparing to the ordinary p-PCA, the system throughput can increase 10% to 300% when the offered load change between 2~5 times. From Fig 7., it can see that MF-pPCA can quickly get the larger throughput than pPCA; furthermore, the more odds between N and N_0 , the more difference is between of MF-pPCA and pPCA.

Fig8. is based upon the control strategy of MF-pPCA in which the control parameters are chosen as the initial estimate terminal $N_0 = 20$, $SWI = 16$, the actual terminal $N = 2,5,20,50,100$ five case. The simulation results show that after definite adjusts slotted times, the system can gain the maximum throughput rapidly in various environments.

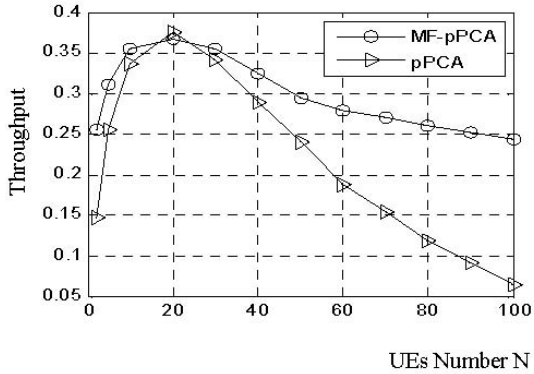

Fig.9. Throughput against two SWI of MF-pPCA

Fig.9 shows the throughput in which parameter are chosen as $N_0 = 20$, initial estimate terminal N_0 use 2 or100, *SWI* is 16 or 32 two case. The simulation results derive MF-pPCA can guarantee the steady of system, and the smaller is SWI, the shorter is time adjusting.

5 Conclusions

In this paper, It assume the terminal can get the information of channel slot state fell back on cognize channel timely. It has proposed two dynamic control strategy for slotted ALOHA aiming at the design of dynamic spectrum sharing access system. Specifically, It apply multiple factor algorithms, It transmission packet with double probability when system detects consecutive 8 idle slots; on the contrary, It halve the probability of transmission when system detect consecutive 8 collisional slots. This auto-control algorithm can reach the maximal steady throughput faster than preceding method when the traffic of system changes acutely. It is effective in control elastic traffic for radio communication system.

ACKNOWLEDGMENT

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REFERENCES

[1] Zhuo Yang, Y.-D. Y., Sheng Chen, et al. MAC protocol classification in a cognitive radio network. Proc of WOCC, 2010.

[2]L.Ma,X.Han,C.Shen. Dynamic open spectrum sharing MAC protocol for wireless ad hoc network. IEEE Int. Symp. New Front. Dynamic Spect. Netw. DySPAN (DySPAN'05). 2005, 203-213.

[3] HU YingBo, YANG WeiWei.Throughput analysis of slotted ALOHA with cooperative transmission using successive interference cancellation. Science in China Series F-Information Sciences. 2009, 52(12):2354-2359.

[4] Clare.L.P. Control procedures for slotted Aloha systems that achieve stability. ACM SIGCOMM Computer Communication Review .1986, 16(3): 302 -309.

[5] Wang S.H., Lin C.K., Hong Y.W. On the stability and delay of channel-aware slotted ALOHA with imperfect CSI. //Proc of ICC 2008, 4830-4834.

[6] Wang S.H., Lin C.K., Hong Y.W. Transmission control with imperfect CSI in channel-aware slotted ALOHA networks. IEEE Transactions on Wireless Communications. 2009, 8(10): 5214-5224.

[7]Liu X., Kountouriotis J., Petropulu A. P.,et al. ALOHA With Collision Resolution (ALOHA-CR) Theory and Software Defined Radio Implementation. IEEE Tran. Sig. Proc.2010,58(8): 4396 - 4410

[8]J.H. Sarker, S.J.Halme. Auto-controlled algorithm for slotted ALOHA. IEEE Proc Commun. 2003, 150 (1):53-58.

[9] Erickson Trejo-Reyes, D. M., Tim O'Farrell. Stabilization of slotted ALOHA using a modified stochastic gradient algorithm. The 14' IEEE 2003 International Symposium on Persona1, Indoor and Mobile Radio Communication Proceedings. 2003, 14(2): 1375-1379.

[10] Xiao Y.,Zhang Y.P.,Gibson J.H.,Xie G.F,et al. Performance analysis of ALOHA and p-persistent ALOHA for multi-hop underwater acoustic sensor networks. //Proc of ICESS '09, 305 - 311

[11]Park J, van der Schaar M. Medium Access Control Protocols with Memory. IEEE/ACM transactions on networking 2010, 18(99): 1-14.

[12]Lin Chun-Kuang, Hong Y.-W. Peter. On the finite-user stability region of slotted ALOHA with cooperative users. //Proc of ICC 2008, 1082-1086.

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