Transmission power control strategy based on partially observable Markov processes for IEEE802.11 WLAN

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Abstract

With the limitation of independent channels in IEEE802.11 WLAN, co-channel AP interferes with each other in repeat coverage area. As traditional AP launched a fixed power in sending data packages, which ignores the differences and mobility of STA. According to the mobility of STA and the partially observable feature of AP-STA link, this paper analyses the internal relations among the link state, transmission power and channel interference of co-channel AP, and proposes a single-link transmission power control (TPC) algorithm based on the Partially Observable Markov Decision Processes (POMDP). Firstly, the single AP-STA link POMDP-TPC model is constructed, and the neural network learning model is established to describe the observation function of POMDP-TPC. Secondly, the algorithm constructs reachable belief searching trees to obtain the approximate optimization, which implements the dynamic creating and on-line updating of the power consumption policy. Finally, under the experiment environment in OPNET and IEEE802.11b, the results demonstrate the algorithm can reduce the AP power consumption efficiently and improve the network throughput greatly.

Keywords: wireless local area networks, access point, POMDP, transmission power control, anti-interference

1 Introduction

The rapid rise of wireless LAN makes the deployment of wireless access point (AP) become increasingly intensive; however, WLAN has limited non-interfering channels, especially the 2.4GHz band only uses three non-overlapping channels (1, 6 & 11). Same channel used by different APs may cause hidden nodes, making channel interference and transmission conflict become the main issues that limit network throughput [1,2]. Thus, the link transmission power control (TPC) is becoming one of the key technologies to solve this problem [3]. It ensures AP coverage, reduces the channel interference and improves the network throughput.

Accordingly, Javier del Prado Pavon took 802.11b as the object of study and proposed a link-based power control algorithm, which calculated packet loss rate through SNR and BER, increased AP throughput [4] and lowered energy consumption. However, the algorithm involved changes in protocols and physical layer, so that it is difficult to promote in large scale. Daji Qiao took 802.11a/h as the object of study, and proposed an optimal energy transfer policy (miser strategy) [5]. This method can effecttively conserve AP power, but it is difficult to handle changes in STA position. Wei Li proposed a PCAP (Power Control for AP Performance enhancement) algorithm [6], which used heuristic method to achieve balance between network throughput and AP proportional fairness. Jing Nie proposed a pccf protocol [7]. RTS transmission power is based on the carrier sensing threshold, reception threshold and the maximum transmission power, and the data transmission power is calculated according to the SINR (signal to interference noise ratio) threshold. The above-mentioned algorithms have effectively promoted the development of TPC algorithm, but still have the following problems:

1) The existing algorithms mainly take AP reference transmission power as the control object, and control AP coverage by adjusting the transmission power of beacon frame to achieve the purpose of reducing interference; however, the differences between STA position and performance are not considered. It is like "talking with many people in a place". If talking with all persons with the same volume, the objects far away or with weak hearing could not hear clearly, while the objects in near place or with good hearing will feel deafening.

2) The existing algorithms lack consideration of uncertainty in wireless environment. Most algorithms assume that the environment is known and unchanging, but the transmission environment has a great deal of uncertainty in practice due to multiple-operator deployment and illegal AP structure.

To solve the above-mentioned problems, this paper introduces the thinking of probability theory, proposes Partly Observable Markov [8] Decision Processing – Transmission Power Control (POMDP-TPC), takes single-link data packet transmission power as the control object and builds POMDP six-tuple model to analyze the correlation of the strength, SNR, BER and link status of received signals, establish the observation function learning model based on neural network and use reachable belief state online search to achieve dynamic planning and real-time decision-making of strategies, and achieve the

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purposes of reducing AP energy consumption and improving network throughput.

2 TPC model based on partly observable Markov

2.1 SYSTEM MODEL

WLAN operating frequencies are 2.4GHz and 5GHz. At present, most operators only support 2.4GHz. For large WLAN network of high-density, although the channels are arranged alternately, the same channel still needs to be used by different APs, and an AP of the same channel can't detect the AP of the opposite end; however, STA in overlapping coverage areas will encounter the risk of conflict (i.e. hidden nodes) in the process of data transmission and reception. Therefore, the link transmission power should be controlled to ensure AP coverage, reduce channel interference and improve the network throughput.

In this paper, co-channel AP interference is the object of study, and the following assumptions are made:

1) AP physical layout and channel planning are basically reasonable, and there is no complete coverage or blind zone;
2) STA has been connected to AP, and this algorithm only controls data transmission power.

If AP and STA can exchange data at a high rate after connecting, they have better wireless channel. Under the premise of high-speed transmission, AP should gradually reduce the transmission power of STA to reduce energy consumption and reduce the interference range of other transmission links. Conversely, if the wireless channel becomes worse and results in speed reduction or packet loss, AP should increase its transmission power. Therefore, the power control algorithm should be specific to each AP-STA link, adjust transmission power in real-time according to the link status and achieve the optimal balance between transfer rate and transmission power.

2.2 SYSTEM FRAMEWORK

The wireless transmission environment has randomness and uncertainty. On the one hand, there are differences between different STAs, including the location of AP from STA and STA sensitivity; on the other hand, the same STA has mobility. Therefore, the transmission power control requires link status observation and assessment for each AP-STA link and then selecting the optimal power adjustment strategy. Its essence is the optimal decision in a random environment. POMDP is an ideal mathematical model to solve such problems. The structure of single link POMDP-TPC is shown in Figure 1.

POMDP allows describing $<S,A,T,R,Z,O>$ with a six-tuple. *S*, *A* and *E* represent state set, action set and observation set respectively; $T: S\times A \rightarrow \prod(S)$ is state transition function, which represents the probability of executing a under the state s to state s', recorded as $T(s,a,s')$; $R: S\times A \rightarrow R$ represents the strategy evaluation function; $O: S\times A \rightarrow \prod(Z)$ is an observation function, which represents the probability of getting observation z when executing a to state s', recorded as $O(s',a,z)$. Evaluate the current link status through six-tuple to get the belief state b. Due to the partial observability and randomness of the link, belief state is actually a probability distribution of state set. The belief state search and value iteration method are used to obtain the optimal strategy, i.e. the optimal transmission power of single link.

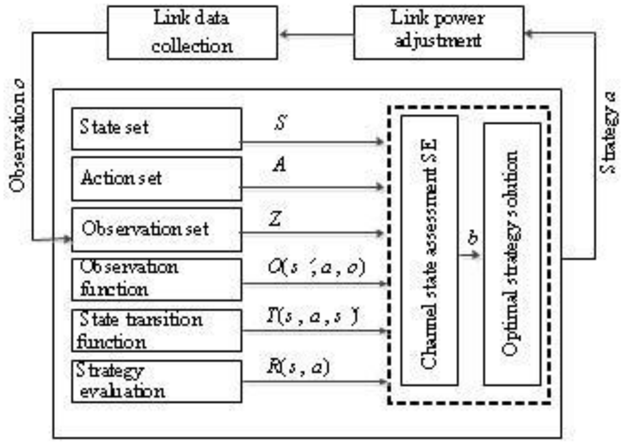

FIGURE 1 POMDP-TPC system framework

POMDP-TPC controller is the core of the system. It takes single AP-STA link as the object. To achieve self-adaption of AP to STA in the data transmission process, a POMDP decision model should be established for each link to obtain the optimal transmission power of the link in real-time and achieve high throughput and low power consumption of the AP.

3 Establishment of POMDP-TPC model

3.1 DEFINITION OF STATE SET, ACTION SET AND OBSERVATION SET

In POMDP-TPC model, the settings of state set, action set and observation set directly affect the effectiveness of control strategies and the complexity of strategy solution. In this paper, the state set, action set and observation set are set as follows through a large number of experiments and correlation analysis:

1) Single AP-STA link status $S_l = S_{ack}\times S_p \times S_{sta}$. S_{ack} indicates whether the message is sent successfully. In IEEE802.11, each packet transmission requires ACK response, and therefore, whether correct ACK packet is received indicates whether the message is sent successfully. S_p indicates the transmission power of the link, $s_p = p_{link} \cdot S_{sta}$ includes STA state, which includes two factors: the distance of the region from AP and whether there is interference in the region. Therefore, the AP transmission power is increased in increments of 0.5 dBm, and its coverage is divided into m regions. Assume that

the maximum transmission power and minimum transmission power of AP are $P_{\max}$ and $P_{\min}$ respectively, then $m=(P_{\max}-P_{\min})/0.5$. In an unknown environment, each region has the possibilities of interference and non-interference, and therefore AP coverage area contains 2m cases, and STA state can be expressed by a two-tuple: $\{(s_{sta\_area}, s_{sta\_inter}) \mid s_{sta\_area} \in (1,m), s_{sta\_inter} \in (0,1)\}$, of which s_{sta_area} indicates the region that STA locates and s_{sta_inter} indicates whether there is interference in this region.

2) The action set A represents a set of power adjustment actions that can be executed by AP. Theoretically, the power adjustment may be any value within the limited range. In fact, AP power adjustment needs to be able to quickly respond to the real time changes in the wireless environment, and should meet the adaptation of opposite end STA to the changes in transmission power. Therefore, the adjustment of transmission power is set to four levels: $\{0.5dBm, 1dBm, 2dBm, 4dBm\}$, so that the power is adjusted to variable step size, which can respond quickly to changes in the environment and can be tuned according to the link status. Depending on the STA, AP transmission power can be increased, reduced or remained unchanged.

3) Observation set Z represents the set of link parameters that can be obtained by AP. STA varies in sensitivity and position and is variable in real time, S_{link} can't be obtained directly, and thus should be inferred by measurable link parameters. The selected parameters should reflect the environment of the reaction medium and the link quality and analyze the association of each parameter and the link state. The calculation is as shown in Equation (1).

$$Correl(X,Y)=\frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\overline{x})^2(y_i-\overline{y})^2}};i,j=1,2,...,10 \quad (1)$$

where n represents the number of samples, $\overline{x}$ and $\overline{y}$ represent the sample mean.

By analyzing the correlation of wireless communication data in January of a district of Shenzhen, Guangdong Province, the strength q, signal-to-noise ratio (SNR), bit error rate b and transmission rate (DTR) of the signals of the correlation coefficient greater than 0.7 are selected as the members of observation set.

3.2 STATE TRANSITION FUNCTION

For each AP-STA link, the state transition function represents the changes of link status in two adjacent time slices. Status s includes s_{ack}, s_p and s_l, which are independent of the conditions, and therefore the state transition function can be written in the form of conditional probability:

$$\begin{aligned}T(s,a,s') &= Pr(s'_{ack},s'_p,s'_l \mid a,s) = \\ &Pr(s'_{ack}\mid a,s)Pr(s'_p\mid a,s)Pr(s'_l\mid a,s)\end{aligned}, \quad (2)$$

s_l only associates with the transmission medium and STA position, and doesn't change with the AP transmission power, so that the Equation (2) can be rewritten as:

$$T(s,a,s')=\begin{cases}0 & s'_l \neq s_l \\ 0 & s'_p \neq s_p+\Delta p \\ Pr(s'_{ack}\mid a,s_{ack},s_l,s_p) & \text{others}\end{cases}, \quad (3)$$

$Pr(s'_{ack}\mid a,s_{ack},s_l,s_p)$ is obtained from historical data.

3.3 OBSERVATION MODEL

Under different link status, executing different power adjustment strategies will obtain different observations, namely to observe the model in different states, the possibility of obtaining the corresponding observation under different statuses and policies, which is expressed as follows with probability:

$$O(s',a,o)=Pr(o\mid s',a). \quad (4)$$

It is inferred from Bayesian rule that:

$$\begin{aligned}Pr(o\mid s',a)&=\frac{Pr(s'\mid o,a)Pr(o\mid a)}{Pr(s'\mid a)}= \\ \frac{Pr(s'\mid o,a)Pr(o\mid a)}{Pr(s'\mid a,s)}&=\frac{Pr(s'\mid o,a)Pr(o\mid a)}{T(s,a,s')}\end{aligned}, \quad (5)$$

where the denominator is the state transition function, which is obtained from Equation (3); in the numerator, $Pr(o\mid a)$ can be regarded as a normalization factor; $Pr(s'\mid o,a)$ represents the probability to obtain status s_{ack} by executing policy a under current observation. As s_{ack}, s_p and s_l are independent of the conditions, so that:

$$Pr(s'\mid o,a)=Pr(s'_{ack}\mid o,a)Pr(s'_p\mid o,a)Pr(s'_l\mid o,a). \quad (6)$$

Obtain $Pr(s'_{ack}\mid o,a)$, $Pr(s'_p\mid o,a)$ and $Pr(s'_l\mid o,a)$ as follows:

1) For $Pr(s'_{ack}\mid o,a)$, whether each data packet is transmitted successfully is determined by whether ACK packet is received. Therefore, the probability of successful transmission of a single packet = probability of data transmission failure * probability of ACK packet transmission failure, as shown below:

$$Pr(s'_{ack}=1\,|\,o,a)=(1-Pr(e\_data\,|\,o,a))\times (1-Pr(e\_ack\,|\,o,a)) . \quad (7)$$

The study of the [3] shows that the probability of packet transmission failure can be calculated through BER, SNR and transmission rate:

$$Pr(e\_data\,|\,o,a)=1-(1-Pr(b\,|\,snr,dtr))^{8L} , \quad (8)$$

where L indicates the packet length. The length of ACK packet is fixed at 14bytes, so

$$Pr(e\_ack\,|\,o,a)=1-(1-Pr(b\,|\,snr,dtr))^{112} . \quad (9)$$

2) For $Pr(s'_p\,|\,o,a)$, assume that the AP power transmitting module always can specify the transmission power, that is, $Pr(s'_p\,|\,o,a)$ is independent of the observation and strategies. For all observations, $Pr(s'_p\,|\,o,a)=1$.

3) For $Pr(s'_l\,|\,o,a)$, link status is strongly correlated to signal strength, SNR, bit error rate and transmission rate strongly correlated. However, the parameters have complex nonlinear relationship, and it is difficult to derive through a simple mathematical model. In this paper, we propose a link status inference model based on BP neural networks, and obtain s' of corresponding observation and strategies through network training and inference.

With three layers BPNN structure, the neurons of input layer and output layer are 4 and 2 respectively. Through the correlation analysis in section 3.1, the link status neural network model inputs are determined as follows: signal strength *q*, SNR, DTR and transmission power *p*. The model output is link status s_l. The number of neurons in the hidden layer calculated in accordance with the empirical equation is identified as 10, and the inference model neural network structure:

$$s_l=\sum_{i=1}^{10} w_{i,o}^{ack}\ \mathrm{tansig}(w_{i,1}^{ack}q+w_{i,2}^{ack}snr+w_{i,3}^{ack}lt+w_{i,4}^{ack}dtr) , \quad (10)$$

$w_{i,o}^{ack}$ is the corresponding weight of the *i*-th neuron of the hidden layer to the output neuron, $w_{i,j}^{ack}$ is the corresponding weight of the *j*-th neuron of the input layer to the *i*-th neuron of the hidden layer, and $\mathrm{tansig}(\cdot)$ nonlinear Sigmoid activation function is used.

3.4 POLICY-RETURN FUNCTION

If the current link is free of interference and the packet transmission is successful in the process of AP packet transmission, the transmission power should be reduced to the power of STA minimum coverage as soon as possible, which can not only ensure successful data transmission, but also reduce energy consumption of AP; conversely, if the current link is free of interference but the packet isn't sent successfully, the transmission power should be increased to be equal to or slightly greater than the minimum coverage power of STA as soon as possible to increase the probability of success and avoid repeated failures and retransmission:

$$R(s,a)=\begin{cases}\dfrac{1}{|s_p+\Delta p-s_{l\_area}*0.5|} & s_{l\_inter}=0, s_{ack}=1\\[2mm] \dfrac{1}{|s_p+\Delta p-s_{l\_area}*0.5-\eta|} & s_{l\_inter}=0, s_{ack}=0\\[2mm] \dfrac{1}{|\Delta p|} & s_{l\_inter}=1, s_{ack}=1\\[2mm] \dfrac{1}{|s_p+\Delta p-s_{l\_area}*0.5-\mu|} & s_{l\_inter}=1, s_{ack}=0\end{cases} , \quad (11)$$

where Δp is the amount of power change, η and μ are anti-interference margin set according to experience. In particular, when the denominator is zero, $R(s,a)=2(1/0.5)=4$.

4 Optimal control strategy solution of single link POMDP-TPC

4.1 ALGORITHM PROCESS

Traditional Markov solution algorithms usually use offline planning. With the increase in the number of iterations, the complexity of algorithm time and space expands rapidly, which is a typical NP-hard problem. To ensure real-time and dynamic adaptability of TPC algorithm, online algorithm [9] is used to divide the entire strategic planning and policy execution into several small plans and executions, start from the current belief state to build reachable belief status search tree, control the spatial scale of reachable belief state and achieve fast solution, as shown in Figure 2.

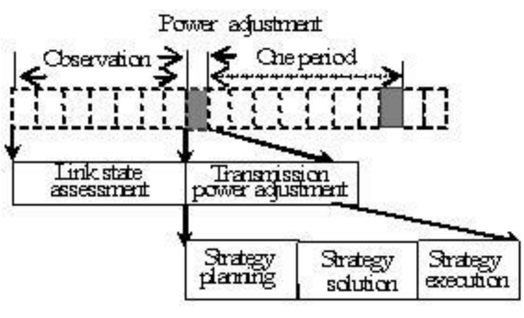

FIGURE 2 Online Solution of AP Link Power Control Algorithm

During system operation, the entire process is run at a fixed period, each period is divided into several small time slices, the former time slices are the observation phase for data collection, filtering and link status assessment, and the power calculation and adjustment are carried out in the last time slice, including strategic planning, strategy solution and strategy execution. After the power is adjusted, repeat observation, assessment of link status and adjustment of transmission power in the new cycle, and thus ensure that the link transmission power can dynamically adapt to the changes in STA and the environment.

4.2 OPTIMAL STRATEGY SOLUTION

The TPC algorithm of the entire link can be divided into off-line training, online strategy planning, online strategy solution, and strategy execution. The objective of offline training is to obtain the corresponding weight of each neuron of the neural network in gradient descent method. The steps of online strategy planning and online strategy solution are as shown in Table 1.

TABLE 1 TPC online planning and solution algorithm

Algorithm: TPC online planning and solution algorithm
Definition: b_c , current belief state; *T*, belief state search tree;
//Online strategic planning
1): Obtain the current belief state b_t according to observation;
2): Build belief state search tree T with current belief point b_t as the root;
// Online strategy solution
3): Calculate the iterative return value function of belief point in *T* through edge node upward propagation algorithm;
4): Obtain the optimal power control strategy a^* under b_t ;
// Online strategy execution
5): Adjust the packet transmission power according to the power control strategy;
6): Collect the link data, and update belief state b_c according to a^* and *z*;
7): Return to 1) and reconstruct belief state search tree;

Here the belief state b is an assessment by observing the current link status. Due to the partial observability and uncertainty of link, it is the probability distribution on a real state set, determined by the action and observation at the moment of 0-t and described:

$$b_t = Pr(s_t \mid a_t, z_t, a_{t-1}, z_{t-1}, ..., a_0, z_0, s_0)\,. \tag{12}$$

To effectively prevent strategy jitter, it is necessary to consider the long-term effects of the current strategy, that is, to construct the reachable belief state search tree according to the current belief state. The root node of the search tree is the current belief state, and the leaf node is the reachable belief state point after one or several steps of power adjustment. Assume that $b(s')$ is the new belief state point, and $b(s')$ can be obtained from the father belief point, observation function and state transition function:

$$b_t(s') = \frac{\sum_{s'\in S} O(s', a^{t-1}, z^t) T(s, a^{t-1}, s') b^{t-1}(s)}{P(z^t \mid b^{t-1}, a^{t-1})}\,. \tag{13}$$

Assume that the depth of search tree is *D*, and obtain to reachable belief state search tree through iteration, which indicates all possible intermediate states and end states starting from the current belief state after power adjustment for *D* times.

Convert partly observable Markov strategy solution process into belief state based Markov solution and strategy evaluation function $\rho(b,a) = \sum_{s\in S} b(s)R(s,a)$. Calculate the function V with Bellman equation; as shown in Equation (15), γ is the discount factor.

$$V^{t+1}(b) = \max_{a\in A}\left[\sum_{s\in S} b(s)R(s,a) + \gamma \sum_{z\in Z} P(z \mid b,a) V^t(b')\right], \tag{14}$$

$$\pi^{t+1}(b) = \arg\max_{a\in A}\left[\sum_{s\in S} b(s)R(s,a) + \gamma \sum_{z\in Z} P(z \mid b,a) V^t(b')\right]. \tag{15}$$

Effectively estimate the long-term impact of different power control strategies on future link status through constructing belief state search tree and value iteration, select the strategy π with the maximum cumulative return value as the optimal strategy to achieve the balance among AP energy consumption, minimum interference and packet transmission success rate, and avoid jitter of control strategies effectively.

5 Experiments and results analysis

Use OPNET simulation platform to build IEEE802.11b wireless network test environment. The simulation parameters are shown in Table 2. FTP traffic flow of normally distributed packet length is used to simulate the STA business environment of each site.

TABLE 2 Parameters of simulation environment

Parameter	Value
Region size	300m*300m
AP number	Four, evenly distributed arrays
STA number	20, randomly and uniformly distributed
AP channel	1
P_{max}	27dBm
P_{min}	5dBm
P_{beacon}	21dBm

The network is shown in Figure 3. Four APs are recorded as AP1-AP4, and 20 STAs are randomly distributed, of which 9 can detect SSID of two or more APs. All STAs establish a connection with AP1, AP2, AP3 and AP4 respectively, of which AP1 has the heaviest load and AP4 is relatively light.

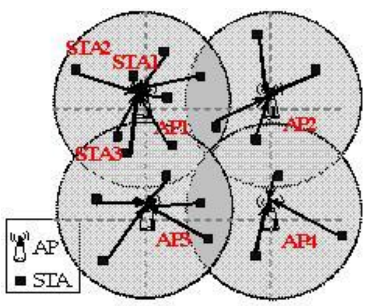

FIGURE 3 Experimental environment network structure

5.1 AP THROUGHPUT AND ENERGY CONSUMPTION

Keep the STA position, and transmission power unchanged and carry out the experiments in three groups: none AP runs this algorithm, AP1 and AP2 run this algorithm, and all APs run this algorithm. Repeat each group of experiments 10 times and evaluate the average. Run each experiment 30 minutes, and compare the average throughput and average energy consumption of AP1, AP2, AP3 and AP4, as shown in Figures 4a and 4b.

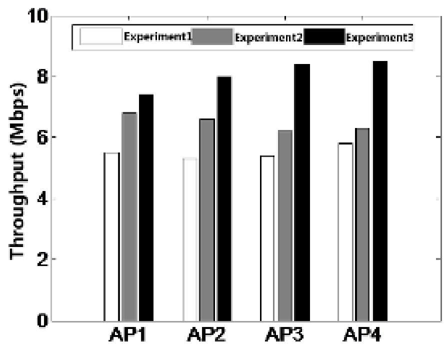

FIGURE 4a Throughput comparison chart

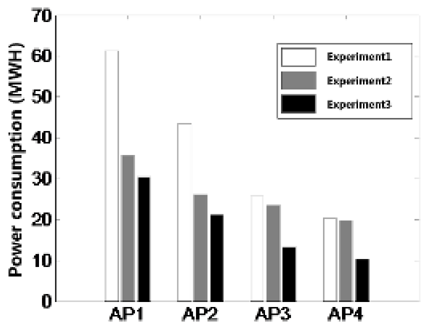

FIGURE 4b Power consumption comparison

Figure 4a shows that the throughputs of four APs have increased when AP1 and AP2 run this algorithm, and AP1 and AP2 are superior to AP3 and AP4, which fully shows that the algorithm can effectively transmit conflict. Although AP3 and AP4 didn't run this algorithm, the throughput was significantly improved because the transmission conflict in repeated coverage region was reduced, and thus the throughput of the entire network was improved effectively; when none AP run the algorithm, all the throughputs were significantly improved, but AP throughputs were the smallest, indicating that although the proposed algorithm can reduce the transmission conflict to some extent, it can't eliminate the conflict. AP1 had the maximum load, so that the possibility of transmission conflict was still greater than other APs, and therefore the throughput was the smallest. Figure 4b well verifies the effectiveness of the algorithm in energy saving. The power consumption of AP is reduced significantly because the algorithm enables AP transmitting data in appropriate power in accordance with the link state.

5.2 DYNAMIC ADAPT ABILITY

Move STA1 position away from 1m from AP1, and move STA2 position close gradually at a distance 80m from AP1. Keep the speed at 5m/s, STA3 position unchanged, and test the transmission power and packet loss rate of these three AP-STA links.

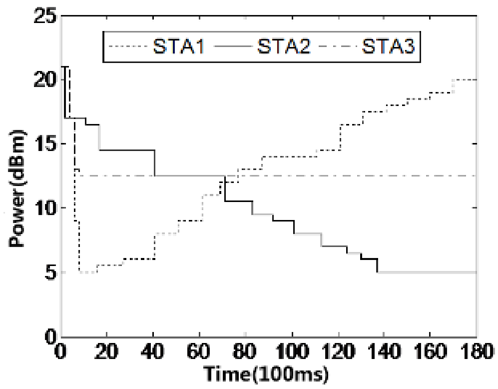

FIGURE 5a Transmission power changes with time

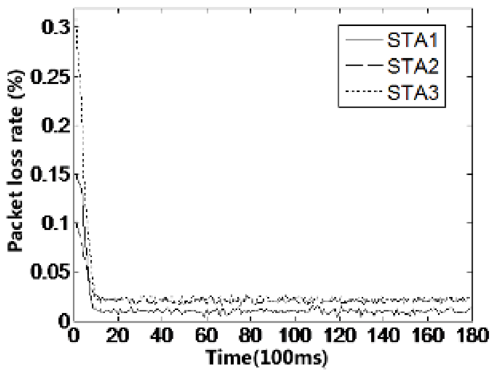

FIGURE 5b Packet loss rate changes with time

Figures 5a and 5b show the relationship of the changes in AP transmission power and packet loss rate. It is known that the adjustment frequency of transmission power is faster in the initial 10 control periods, and the packet loss rate also decreases rapidly. If STA position is unchanged, the transmission power tends to be stabilized and the packet loss rate is reduced to a minimum in the 10^{th} control period; if STA position changes, AP transmission power gradually increases or decreases with the change of STA position, and the packet loss rate can be maintained at a lower level, which fully illustrates that POMDP-TPC has excellent dynamic adaptability.

6 Conclusion

A single link transmission power control method is proposed according to the characteristics that STA position and transmission environment have differences in the control of transmission power. By introducing partly observable Markov theory, establish six-tuple model of single AP-STA link TPC optimal control, construct the observation function and state transition function of link state, obtain the optimal strategy through belief state search and value iteration, achieve maximized expected value of reward function and achieve the objective of reducing power consumption and co-channel interference. The results of OPNET based simulation experiment show that the algorithm can better optimize AP energy consumption and throughput online, and reduce the interference between co-channel APs effectively. At present, the strategy reward function is set according to expert experience, and machine learning method will be studied to optimize the reward strategy function and correct experience setting.

References

[1] Chen J Y, Olafsson S, Yang Y, Gu X Y 2009 Joint Distributed Transmit Power Control and Dynamic Channel Allocation for Scalable WLANs *Wireless Communications and Networking Conference* London 1-6

[2] Douros G D, Polyzos G C2011 Review of some fundamental approaches for power control in wireless networks *Computer Communications* **34**(13) 1580-92

[3] *Deleted by CMNT Editor*

[4] del Prado Pavon J, Choi S 2003 Link Adaptation Strategy for IEEE 802.11 WLAN via Received Signal Strength Measurement *IEEE International Conference on Communications 2003 ICC '03* 1108-13

[5] *Deleted by CMNT Editor*

[6] Li W, Cui Y, Cheng X, Al-Rodhaan M A 2011 Achieving Proportional Fairness via AP Power Control in Multi-Rate WLANs. *IEEE Transactions on Wireless Communications* **10**(11) 3784-92

[7] Nie J, Parr G, McClean S 2011 Power control of control frames in IEEE 802.11 networks *AEU – International Journal of Electronics and Communications* **65**(3) 165-72

[8] *Deleted by CMNT Editor*

[9] Ross S, Pineau J, Paquet S, Chaib-draa B 2008 Online Planning Algorithms for POMDPs. *Journal of Artificial Intelligence Research* **32** 663-704

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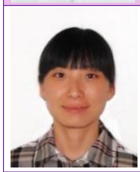

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