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Optimal Ad Hoc Power Control Algorithm Based on Outage Probability

YunLi [1, 2, 3, 4], Shanlin Sun[1, 3, 4], Xunjun Wang[1, 3, 4] and Zhiyan Sun[1, 3]

1. Deparment of Electronic Engineering, Guilin University of Aerospace Technology, Guangxi Guilin 541004;
2. Guangxi Colleges and Universities Key Laboratory of Unmanned Aerial Vehicle (UAV) Telemetry, Guilin University of Aerospace Technology, Guilin 541004, China
3. School of Electronic and Information Engineering, Tianjin University, Tianjin 300072, China
4. Guangxi Experiment Center of Information Science, Guangxi, China
liyun@guat.edu.cn

Abstract

Due to the question about the distribution of the randomness, mobility and mutual interference between nodes in the wireless networks may be difficult to achieve power control accurately. Therefore, propose a power control algorithm based on minimizing interrupt probability. The algorithm which be based on random geometric network model, under ensuring receiving in the receiver by getting the SIR value, adjusts transmit power. Simulation results show that the algorithm not only can solve the problem of the distribution of the nodes in a wireless net- work, can also according to the channel decline, transmitter was adjusted dynamically in real time. Deduce approximate expression of Interrupt probability transmission capacity. Under meet minimum interrupt probability and maximum transmission capacity, deduce power control expression. By this algorithm, the outage probability decreased by 14.8%, the transmission capacity is increased by 15.6%.

***Keywords**: Power control, ALOHA, Outage probability, Transmission capacity, Random geometric*

1. Introduction

In the design of access layer, access layer controls different users who share spectrum. It a- lso in order to insure that data packet is received successfully. Random access of access layer, the common form is ALOHA and CSMA. The one of main functions of access layer which le- ts all the power of the node access channel. The common way of controlling the power of the note is water flooding power control. It is a simple Algorithm of iterative and power control in distributed. The Algorithm of iterative is not adapted to network environment which exists m- any interference sources. Users can only launch in the highest power (the launch which has no power control), therefore, it is possible causes a large number of interrupt, increasing network re-transmission times and increasing total energy consumption of network. So when I design access Layer, I presents the optimal power control algorithm Ad Hoc that is based on interrupt probability. The design principle of the method is to use the theory of random geometry to es- tablish a random SINR mathematical analysis model so that receive port obtains a correct SIR value of the receive data(it is defined as β).Under this condition, transmitter base channel a- ttenuation sends data at less than the maximum transmitted power. Each receive port can

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gain SIR value of receiving data correctly to achieve fairness. According to the channel fading to adjust the transmission power reduce the interrupt probability, then improve the transmission capacity and improve the transmission capacity.

The power control technology is introduced in the literature [13], which can reduce the en- ergy consumption and increase the capacity of the network. At present, the power control tec- hnology is mainly realized by reducing transmission power. However, there is no approximate expression for calculating the transmit power value. Therefore, in this paper, the Ad hoc pow- er control algorithm based on the optimal outage probability is proposed, and the approximate expression of the outage probability is obtained. Based on this expression, the expression of power control is obtained and then achieve more shared channel target.

2. Network Model and Hypothesis

2.1. Network System Model

If assume that there is a large-scale network of ad hoc, the position distribution of the send- ing end node (TX) in a certain time network obeys the homogeneous Poisson distribution, its density in the two-dimensional (R2) plane is λ. When all the nodes are independent and eve- nly distributed in the network plane, and the nodes in the network have the substitution and t- he existence of a lot of mobility, the assumption of the position of the transmitter is reasonab- le with the homogeneous Poisson point process [2].

Consider a pair of reference node (the send end TX_0 to the receiving end RX_0) and accordi- ng to Palm distribution and Slivnyak theorem of random geometry, then the whole Poisson p- oint process is moved, making RX_0 at the origin (as shown in Figure 1-1 network model). Suppose X_i is the distance between the i sending end node TX_0 and receiving node RX_0, and the distance between each sender and its corresponding receiving end is fixed to d, H_{i0} is the channel fading coefficient of the I transmitting terminal node to the origin, H_{ij} is the channel fading coefficient between the I transmitter and its J receiver, the fading index is denoted as $\alpha(\alpha > 2)$ [4]. Thus, the random SINR model at the reference receiver RX_0 is expressed as:

$$SINR_0 = \frac{p_0 H_{00} d^{-\alpha}}{\sum_{i\in\Pi(\lambda)} P_i H_{i0} X_i^{-\alpha} + N_0} \tag{1}$$

In this expression, N_0 is background noise.

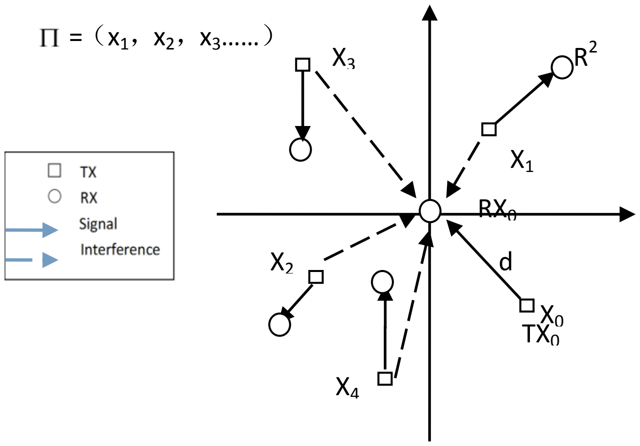

Figure 1. Network Model

From the network model of Figure 1, we can see it cause interference to the other nodes when the transmitter sends the power. If there are too much sending end points, the inter- ference may be greater and power control cannot be controlled by Iterative power control method. At this time, if the transmitter is launched at the maximum power, it is equivalent to no power control and will resulting in more network disruption. The increase of outage probability requires the increase of the total energy consumption. Therefore, under the con- dition of reducing the outage probability and improving the transmission capacity, the transmitting power is calculated according to the channel fading coefficient.

2.2. Outage Probability

The outage probability is defined as the SINR value of the receiving end is lower than a threshold value B, and the sender is not transmitted to the receiving end. Therefore, the outage probability can be expressed as:

$$q(\lambda) = P(SINR_0 < \beta) \tag{2}$$

The $q(\lambda)$ in the formula indicates the outage probability.

2.2.1. The Outage Probability of NPC（No Power Control）

NPC no power control is the maximum of the transmit power to send data, the lower bound of the outage probability is:

$$q_l^{cp}(\lambda) \approx 1 - e^{-\lambda\pi d^2 \beta^\delta E[H^\delta][H^{-\delta}]}, \delta = 2/\alpha \tag{3}$$

When the background noise N_0 is 0, there is no power control (NPC) interrupt expression. The derivation process is as follows: the fading coefficient between the reference nodes (the send end TX_0 and the receiving end RX_0) is defined as the H00, and the fading coefficient of each channel is recorded as $\{H_i\} = H_1, H_2, \ldots$, it is independent and identically distributed [4]. The $S(0)$ in the reference receiver is treated as a random signal in the RX_0, and $\sum(0)$ is a collection of the interference signals:

$$S(0) = PH_0 d^{-\alpha}, \sum(0) = \sum_{i \in \Pi_{R^2,\lambda}} PH_i X_i^{-\alpha} \tag{4}$$

P is sending power. Take (4) into (1), it will get that:

$$SINR_0 = \frac{S(0)}{\sum(0) + \frac{N_0}{P}} \tag{5}$$

To find the complementary cumulative distribution function:

$$\begin{aligned} 1-q(\lambda) &= P(SINR_0 \succ \beta) \\ &= P\{H_0 \succ \beta d^{\alpha}(\sum(0) + N_0 / P)\} \\ &= E[\exp\left\{-\beta d^{\alpha}(\sum(0) + N_0 / P)\right\}] \\ &= e^{-\beta d^{\alpha} N_0/P} E[e^{-\beta d^{\alpha}\sum(0)}] \end{aligned} \tag{6}$$

$SNR = Pd^{-\alpha}/N_0$, $E\left[e^{-\beta d^{\alpha}\sum(0)}\right] = L(\sum(0))(S)|_{S=\beta d^{\alpha}}$, $L(\sum(0))(S)|_{S=\beta d^{\alpha}}$ is the laplace transform of the $S = \beta d^{\alpha}$, so the formula (6) can be expressed as follows:

$$\begin{aligned} 1-q(\lambda) &= e^{-\frac{\beta}{SNR}} L[\sum(0)](S)|_{S=\beta d^{\alpha}} \\ &= e^{-\frac{\beta}{SNR}} \exp\{-\lambda\pi E[H^{\delta}]\Gamma(1-\delta)S^{\delta}\}|_{s=\beta d^{\alpha}} \end{aligned} \tag{7}$$

And because of the following formula:

$$E[H^{\delta}] = \Gamma(1+\delta), E[H^{-\delta}] = \Gamma(1-\delta) \tag{8}$$

So, $q(\lambda)$ can be written as:

$$\begin{aligned} q(\lambda) &= 1 - e^{-\frac{\beta}{SNR}} L[\sum(0)](S)|_{S=\beta d^{\alpha}} \\ &= 1 - e^{-\frac{\beta}{SNR}} \exp\{-\lambda\pi E[H^{\delta}]\Gamma(1-\delta)S^{\delta}\}|_{s=\beta d^{\alpha}} \end{aligned} \tag{9}$$

When $N_0 = 0$,

$$\begin{aligned} q(\lambda) &= 1 - e^{-\frac{\beta}{SNR}} L[\sum(0)](S)|_{S=\beta d^{\alpha}} \\ &= 1 - \exp\{-\lambda\pi E[H^{\delta}]\Gamma(1-\delta)S^{\delta}\}|_{s=\beta d^{\alpha}} \\ &= 1 - e^{-\lambda\pi\beta^{\delta} d^{2} E[H^{\delta}]E[H^{-\delta}]} \end{aligned} \tag{10}$$

Prove is over.

2.2.2 The Outage Probability of Power Control

Assuming that the transmit power is $P_i = P / E[H_{00}^{-k}]H_{00}^{-k}$, H_{ij} indicates the channel fading coefficient between any sender and receiver. When $k = 0$, take it into the expression of transmission power, there will have $P_i = P$, it is expressed as the maximum power transmitted, this is the NPC state. Similarly, when $k = 1$, it corresponds to the channel inversion state. Therefore, when $N_0 = 0$, Outage probability is expressed as:

$$q_l^{scp}(\lambda) \approx 1 - e^{-\lambda\pi d^{2}\beta^{\delta}E[H^{\delta}][H^{-k\delta}]E[H^{-(1-k)\delta}]} \tag{11}$$

The derivation process is as follows:

$$S(0) = \frac{P}{E[H_{00}^{-k}]} H_{00}^{1-k} d^{-\alpha},$$

$$\sum(0) = \frac{P}{E[H_{ii}^{-k}]} \sum_{i \in \Pi_{R^2,\lambda}} H_{ii}^{-k} X_i^{-\alpha}$$

To find the Complementary cumulative distribution function:

$$\begin{aligned}
&1 - q(\lambda) = P(SINR_0 \succ \beta) \\
&= P\{H_0 \succ \beta d^{\alpha} E[H_{00}{}^{-k}] E[H_{00}^{k-1}](\sum(0) + N_0 / P)\} \\
&= e^{-\beta d^{\alpha} E[H_{00}{}^{-k}] E[H_{00}^{k-1}] N_0 / P} \\
&{}^{*}E[e^{-\beta d^{\alpha} E[H_{00}{}^{-k}] E[H_{00}^{k-1}] \sum(0)}]
\end{aligned} \tag{12}$$

$$SNR = \frac{P \dfrac{H_{00}^{1-k}}{E[H_{00}^{-k}]} d^{-\alpha}}{N_0},$$

$$E\left[e^{-\beta d^{\alpha} E[H_{00}{}^{-k}] E[H_{00}^{k-1}] \sum(0)} \right] = L(\sum(0)(S) \,|_{S=\beta d^{\alpha}}$$

So the formula can be expressed as follows:

$$\begin{aligned}
&q(\lambda) = 1 - e^{-\frac{\beta}{SNR}} L[\sum(0)](S) \,|_{S=\beta d^{\alpha}} \\
&= 1 - e^{-\frac{\beta}{SNR}} \exp\{-\lambda \pi E[H^{\delta}] \\
&{}^{*}\Gamma(1 - k\delta)\Gamma(1 - (1-k)\delta) S^{\delta}\} \,|_{s=\beta d^{\alpha}}
\end{aligned}$$

When $N_0 = 0$:

$$q(\lambda) = 1 - e^{-\lambda \pi d^2 \beta^{\delta} E[H^{\delta}] E[H^{-k\delta}] E[H^{-(1-k)\delta}]} \tag{13}$$

Prove is over.

Derivate to the (13), we can draw from Holder's inequality, When k=0.5, $q(\lambda)$ can get the minimum value, and its expression is:

$$q_l^{scp}(\lambda) \approx 1 - e^{-\lambda \pi d^2 \beta^{\delta} E[H^{\delta}] E[H^{-\frac{1}{2}\delta}] E[H^{-(1-\frac{1}{2})\delta}]} \tag{14}$$

According to the adjustment formula of the transmitted power, the expression of the expression after the power adjustment is:

$$P_i = \frac{P}{E[H_{00}^{-\frac{1}{2}}]} H_{00}^{\frac{1}{2}} \tag{15}$$

When the transmission power is adjusted according to the channel fading coefficient and the proportional relationship between the maximum power is shown, the minimum interrupt value can be obtained.

3. Simulation Results and Analysis

3.1. Transmission Capacity

The transmission capacity is defined as the number of common successful communication within the network unit area when the outage probability is limited. The formula is as follows:

$$C(\varepsilon)=\lambda(\varepsilon)(1-\varepsilon) \tag{16}$$

In the formula (16), $\lambda(\varepsilon)(1-\varepsilon)$ is the number of successful communication in the network unit area is limited by the probability of disruption.

①NPC transmission capacity

From the formula (3), when $N_0=0$, the transmission capacity expression is:

$$C(\varepsilon)=-\log(1-\varepsilon)\frac{1}{\pi d^2\beta^\delta}\frac{1}{E[H^\delta]E[H^{-\delta}]} \tag{17}$$

In the formula, $\varepsilon=q(\lambda)$ is the probability of interception, d is the distance between the sender and the receiver, β is SIR value of receiving data at the receiving end, H is the channel fading coefficient, $\delta=2/\alpha$.

②Transmission capacity after power control

From the formula (16), when $N_0=0$, the transmission capacity expression is:

$$C(\varepsilon)=-\log(1-\varepsilon)*\frac{1}{\pi d^2\beta^\delta} * \frac{1}{E[H^\delta]E[H^{-k\delta}]E[H^{-(1-k)\delta}]} \tag{18}$$

When k=0.5, the minimum outage probability is obtained, and its transmission capacity is the largest (as shown in simulation figure 3-4).After the power control, the expression of the maximum transmission capacity is:

$$C(\varepsilon)=-\log(1-\varepsilon)*\frac{1}{\pi d^2\beta^\delta} * \frac{1}{E[H^\delta]E[H^{-\frac{1}{2}\delta}]E[H^{-(1-\frac{1}{2})\delta}]}$$

Slotted ALOHA protocol throughput is the limitation of measurement way, it is described in literature [10] according to the formula $S=Ge^{-G}$. In the formula, S is throughput, G is defined as the load, and the throughput of S is multiplied by the load G each time the probability of successful transmission [12]. When G=1, S gets the maximum, the maximum is e^{-1}, it approximately 0.37, the breaking probability is about 0.63, it means that high throughput will get high break probability. This method can't be well from the perspective of energy saving and outage probability to elaborate network characteristics. So we use the transmission capacity to measure.

In the following simulation process, taking the classical ALOHA protocol as an example, the outage probability and transmission capacity of the two ALOHA protocols of NPC (no power control) and the power control are compared.

3.2. Simulation experiment

The network parameters are set as follows: $\alpha=4$, $\beta=5$, $d=10m$, $\lambda=0.00001$.Through MATLAB simulation, the minimum value of outage probability is obtained, $k = 0.5$. Verify the correctness of the results and analysis of the results.

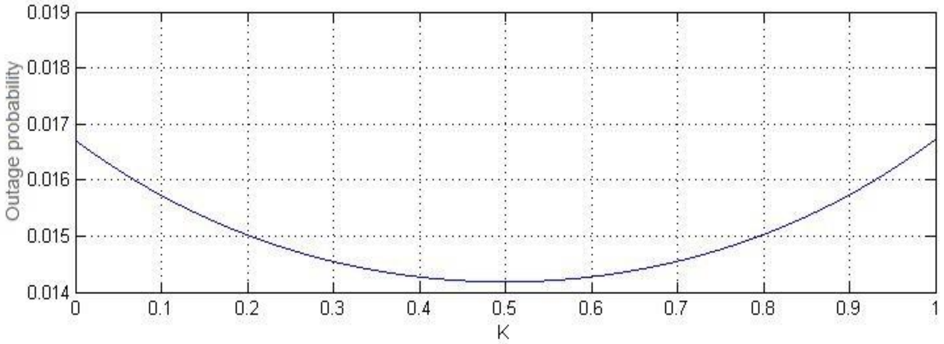

Figure 2. Verify the Value of K

As shown in Figure 2, when the range of K is (0, 1), the minimum value is obtained when k=0.5, the value is 0.0143. It proves the correctness of the derivation of K. The Figure also shows that when k=0 and k=1 (i.e. NPC), the outage probability gets maximum, the value is 0.0168. Thus, the adjusted outage probability has been significantly reduced, and the probability of the adjustment is 14.8%.

In order to verify the effectiveness of the expression, the outage probability of different parameters (the different value of αand the different value ofβ) is simulated, as shown in Table 1.

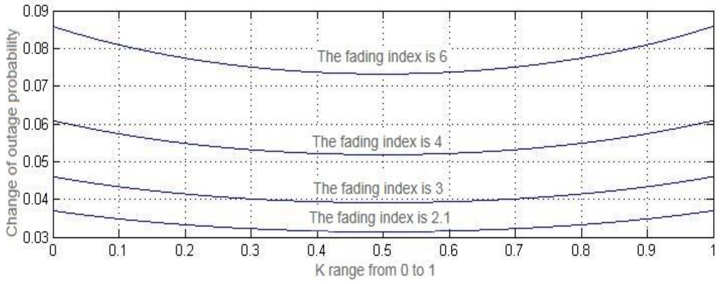

Figure 3. When A=2, Respectively (2.1, 3, 4, 5), the Relationship between the Probability of Disruption and K Value

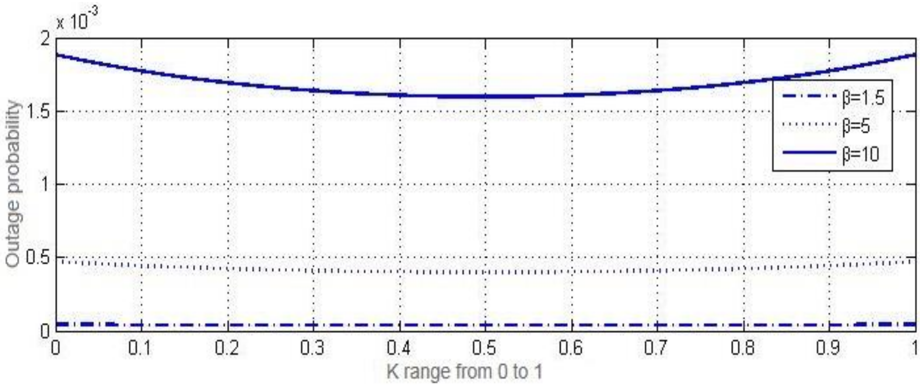

Figure 4. The Outage Probability of a Different Value (1.5, 5, 10)

Table 1. The Outage Probability of Different Parameters (The Different Value of and the Different Value of Ｂ)

Simulation different parameters α and β	K range from 0 to 1
When α>2, α take 2.1, 3, 4, 5, respectively	As shown in Figure 3, when the outage probability is k=0.5, the minimum value is obtained
When β>4 , βtake 1.5, 5, 10, respectively	As shown in Figure 4, when the outage probability is k=0.5, the minimum value is obtained

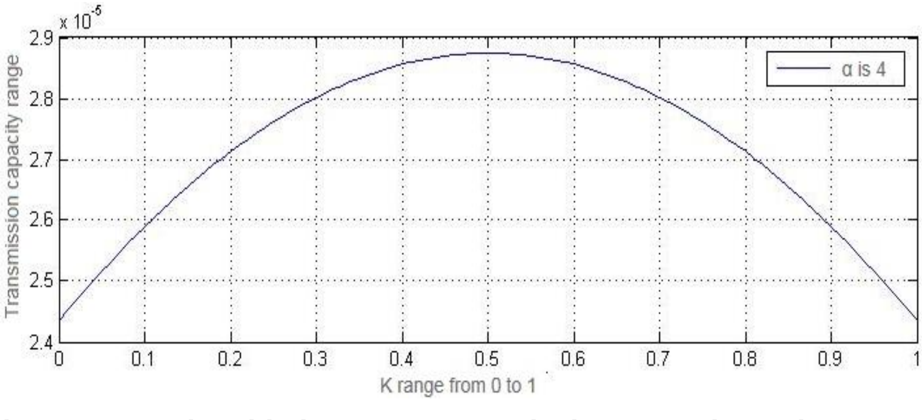

Figure 5. Relationship between Transmission Capacity and K Range

As shown in Figure 5, α=4, according to figure 3, the maximum outage probability is 0.06. When k range is between (0-1), we can get the maximum transmission capacity when $k = 0.5$, the value is 2.88*(10^5), that is to say the minimum outage probability is obtained at k=0.5, at this point you can get the maximum transmission capacity. Without power control, the transmission capacity is 2.43*(10^5). Through power control, the transmission capacity can be improved by 15.6% when the outage probability is limited. The figure shows that when α=4, the boundary value of the outage probability is 0.06

when the maximum value of the transmission capacity can be obtained, the value is 2.8*(10^5) (density values take λ=0.00001). In order to further illustrate the correctness of the expression, simulation transmission capacity in different circumstances (the different value of αand the different value of β), it shows that when k=0.5, the maximum transmission capacity can be obtained with different parameters.As shown in Table 2.

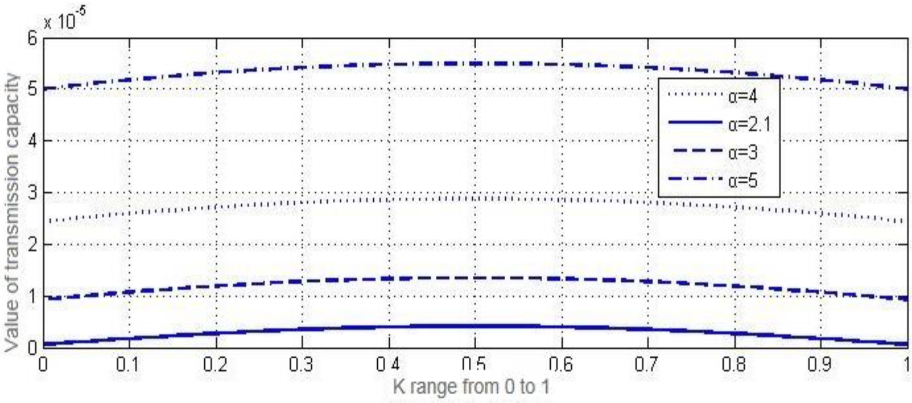

Figure 6. Different Values of A, the Transmission Capacity of the Value Changes

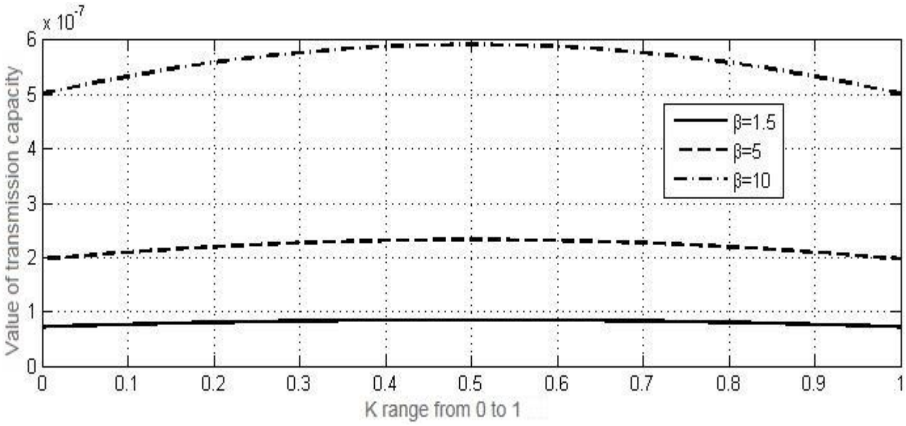

Figure 7. When β takes 1.5, 5, 10, the Value of Transmission Capacity

Table 2. The Transmission Capacity of Different Parameters (The Different Value of A and the Different Value Ofβ)

Simulation different parameters α and β	K range from 0 to 1
When α>2, α take 2.1, 3, 4, 5, respectively	As shown in Figure 6, the transmission capacity when the k=0.5, the maximum value is obtained.
When β>4, βtake 1.5, 5, 10, respectively，the outage probability is 0.1*10-5, 0.5*10-3, 1.8*10-5	As shown in Figure 7, the transmission capacity when the k=0.5, the maximum value is obtained.

4. Conclusion

A power control algorithm based on the minimization of outage probability is designed in this paper. This power control algorithm proposed the network model of mathematical analysis based on stochastic geometry theory. The model solves the random and mobility problems in the design of random access method for wireless network access layer. Under the premise of the approximate expression of the outage probability and the approximate expression of the transmission capacity, to break the probability of a minimum, the maximum transmission capacity, then it needs to adjust the transmission power, and then launch the expression of power. From the expression of the power control, the power control algorithm can adjust the transmission power according to the channel fading. Through the simulation, it is proved that the accuracy of the process is correct, and the power control algorithm can minimize the outage probability and maximize the transmission capacity under different network parameters. The outage probability and transmission capacity of different network parameters are obtained by simulation, which can be applied to the actual Ad hoc network and improve the network performance under different parameters.

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Authors

Yun Li, She was born in Nanning, Guangxi Province, in 1978. She is now an associate professor and currently working toward the Ph.D. degree. She majors in Underwater Wireless Sensor Network.