

## Research Article

# Adaptive Ranging Code Allocation Scheme in IEEE 802.16 Networks

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IEEE 802.16 uses the code division multiple access (CDMA) method as the channel access method to decrease the collision probability of data delivery. However, IEEE 802.16 does not regulate a ranging code allocation scheme in its specification. In this paper, we propose the adaptive ranging code allocation (ARCA) scheme, a novel ranging code allocation scheme for IEEE 802.16. According to the traffic sent to the base station (BS) from the mobile station (MS), the ARCA scheme not only forecasts the traffic quantity of the MS but also finds the optimal ranging code allocation value for the MS to improve the transmission success rate next time. The ARCA scheme is verified with simulation and compared with other schemes in performance differences. According to the simulation results, the ARCA scheme is proved to have better performance than other schemes.

## 1. Introduction

Due to the remarkable advance of networks, people have many requirements in wireless networks. People want wireless networks to support highly mobile, largely covered area and high-data rate communications. Accordingly, IEEE 802.16 [1, 2] is proposed. In IEEE 802.16 network, a base station (BS) uses RF signals to connect mobile stations (MSs). Data transmitted by MSs will go through the BS and the operator backbone network before reaching the Internet. In IEEE 802.16, the BS is in charge of network functionality. When a MS wants to transmit data, it has to send a bandwidth request (BR) to the BS for reserving bandwidth. To decrease the collision probability due to the simultaneous transmissions of BRs, IEEE 802.16 takes the code division multiple access (CDMA) method as the channel access method. The CDMA method uses many different CDMA codes in a CDMA code group; the CDMA code is referred to as the ranging code and the CDMA code group as the ranging code group in the IEEE 802.16 specification. When the MS wants to send a BR, it randomly chooses a ranging code in the ranging code group and then sends the ranging code to the BS. Once the BS receives the ranging code from the MS, it reserves bandwidth in the

next frame for the MS. The CDMA method can have the benefit of avoiding the collision if the MSs choose different ranging codes when they simultaneously send BRs to the BS. Accordingly, the CDMA method can greatly improve the BR transmission success rate.

IEEE 802.16 defines four messages for the use of the CDMA method, that is, Initial Ranging, Periodic Ranging, Handover Ranging, and the aforementioned BR, which are referred to as the Ranging and BR messages in the following text of this paper. IEEE 802.16 regulates 256 ranging codes in a ranging code group and divides the ranging codes into four subgroups corresponding to each type of the Ranging and BR messages. When a MS wants to send any of the Ranging and BR messages, it has to randomly choose a ranging code from the ranging code subgroup corresponding to the message it sends. The BS can use the uplink channel descriptor (UCD) message to dynamically adapt the number of ranging codes allocated to the four ranging code subgroups. However, how to distribute the ranging codes among the four ranging code subgroups is not regulated by the IEEE 802.16 specification but is open to academia and industry. Because there is not much research on the issue, we already propose the DRCA scheme [3] to deal with it on our previous publication. The DRCA scheme allocates more ranging codes to a message

type incurring the high traffic in order to decrease the MSs' chances of choosing the same ranging code and has proved with simulation to have a better total transmission success rate. However, the DRCA scheme has a weakness of failing to guarantee that the system can get the optimal transmission success rate. To overcome the weakness of the DRCA scheme and get the optimal transmission success rate, in this paper we propose an algorithm named the adaptive ranging code allocation (ARCA) scheme, a new ranging code allocation scheme. Although the ARCA scheme works like the DRCA scheme to distribute ranging codes among four ranging subgroups according to the Ranging and BR messages received by a BS, we have a new equation in the ARCA scheme to find the parameters capable of making the system have the optimal total transmission success rate. The ARCA scheme can make the system have a better total transmission success rate than the DRCA scheme.

The paper is organized as follows. Section 2 addresses the ARCA scheme. Section 3 conducts the ARCA scheme with simulation experiments and compares it with other schemes in performance. Section 4 concludes this paper.

## 2. Adaptive Ranging Code Allocation Scheme

The ARCA scheme works in a BS to not only allocate the ranging codes according to the Ranging and BR messages used by the CDMA method, but also to use UCD to notify MSs of the results. The ARCA scheme can decide and distribute the appropriate quantity of ranging codes over four ranging code subgroups according to current network conditions. When MSs begin to move, for example, certain MSs may do the handover from a BS to another BS due to the movements, which will increase the Handover Ranging messages in networks. Against the increase of Handover Ranging messages in networks, the ARCA scheme automatically increases the quantity of ranging codes allocated to the Handover Ranging code subgroup in order to improve successful handover probability and eventually increase the total transmission success rate. The working principle of the ARCA scheme is detailed as follows.

### 2.1. Collecting Statistics about Ranging and BR Messages.

First, the ARCA scheme collects statistics about the Ranging and BR messages per frame received by a BS from MSs in a time period  $t$ . In the Ranging and BR messages, we assume that the numbers of BR, Initial Ranging, Periodic Ranging, and Handover Ranging are  $y_1^t$ ,  $y_2^t$ ,  $y_3^t$ , and  $y_4^t$ . The length of time period  $t$  can be regulated by administrators.

### 2.2. Forecasting Number of Ranging and BR Messages Sent by MS Next Time.

If the BS knows the numbers of BR, Initial Ranging, Periodic Ranging, and Handover Ranging sent by a MS next time, the BS can adjust the allocation of the ranging codes in each ranging code subgroup and improve the transmission success rate of a MS in sending the Ranging and BR messages. In the real world, however, we cannot know the exact number of the Ranging and BR messages sent by a MS next time. As a compromise, we consider

that each network user has the feature of temporal locality [4] in transmitting data, that is, having a high probability to transmit data next time after successfully transmitting data this time. Based on the feature of temporal locality, accordingly, we forecast the numbers of BR, Initial Ranging, Periodic Ranging, and Handover Ranging sent by a MS next time.

The ARCA scheme uses the Single Exponential Smoothing scheme [5] shown in (1) as the forecast algorithm

$$f_i^t = \alpha y_i^{t-1} + (1 - \alpha) f_i^{t-1}, \quad (1)$$

where  $f_i^t$  indicates the forecast value of the  $i$ th message for the time period  $t$ , and  $i$  has a value from 1 to 4 which, respectively, corresponds to BR, Initial Ranging, Periodic Ranging, and Handover Ranging.  $f_i^{t-1}$  indicates the forecast value of the  $i$ th message made for the prior time period  $t - 1$  and  $y_i^{t-1}$  indicates the actual value of the time-series in the prior time period  $t - 1$ .  $\alpha$  is Smoothing Constant that can be from 0 to 1. If administrators want the forecast value to quickly respond to network changes, they can set  $\alpha$  to have a large value. Conversely, they can set  $\alpha$  to have a small value if each type of the Ranging and BR messages does not incur a great change of traffic.

2.3. *Calculating Optimal Number of Ranging Code.* In the previous step, we can get  $f_1^t$ ,  $f_2^t$ ,  $f_3^t$ , and  $f_4^t$  which, respectively, correspond to the forecast numbers of BR, Initial Ranging, Periodical Ranging, and Handover Ranging sent by MSs. Next, we calculate the numbers of ranging codes distributed among the ranging code subgroups. Because IEEE 802.16 uses 256 ranging codes, we can get (2)

$$\sum_{i=1}^4 c_i^t = 256, \quad \text{where } c_i^t > 0. \quad (2)$$

$c_i^t$  is the number of ranging codes allocated to the ranging code subgroup corresponding to the  $i$ th message at the time period  $t$ , while  $c_1^t$ ,  $c_2^t$ ,  $c_3^t$ , and  $c_4^t$ , respectively, correspond to BR, Initial Ranging, Periodical Ranging, and Handover Ranging.

Then, we can use (3) to get probability  $p_i$  that the MS successfully transmits the  $i$ th message

$$p_i = \frac{(c_i^t)!}{\left( (c_i^t - f_i^t)! (c_i^{t-f_i^t}) \right)}. \quad (3)$$

Finally, we can use (4) to find the maximum total transmission success rate  $p_{\max}$  when transmitting the four messages. Besides, we can indirectly locate  $c_1^t$ ,  $c_2^t$ ,  $c_3^t$ , and  $c_4^t$  for achieving  $p_{\max}$ .

$$p_{\max} = \max \left( \frac{\left( \sum_{i=1}^4 p_i f_i^t \right)}{\sum_{i=1}^4 f_i^t} \right). \quad (4)$$

When administrators want to alleviate the overhead of a BS executing the ARCA scheme, they can use (4) to build a table composed of the numbers of the four messages and the

numbers of ranging codes allocated to the four messages for achieving  $p_{\max}$ . Accordingly, the BS can use  $f_i^t$  to look up the table and quickly get  $c_i^t$  capable of making the system have the maximum total transmission success rate.

*2.4. Sending Allocation Result of Ranging Codes to MS.* Finally, the BS gets new  $c_1^t$ ,  $c_2^t$ ,  $c_3^t$ , and  $c_4^t$  via the previous step and uses UCD to transmit them to all MSs. The MS will choose a ranging code from the ranging codes which are allocated to the four ranging code subgroups according to  $c_1^t$ ,  $c_2^t$ ,  $c_3^t$ , and  $c_4^t$  given by the BS. Then, the BS goes back to collect statistics about Ranging and BR Messages and repeats the steps of the ARCA scheme again.

### 3. Simulation and Discussions

In the section, we use MATLAB to simulate the ARCA scheme and compare it with other schemes in different environments in order to observe performance differences.

*3.1. Simulation Environment.* We deploy 200 MSs in a network. We simulate 200 frames and set the time period  $t$  to 10. In other words, we make the BS execute the ranging code allocation one time per 10 frames and calculate the numbers of ranging codes distributed among four ranging code subgroups. Accordingly, we can observe that the BS runs the ranging code allocation 20 times in the entire simulation process. Besides, we follow the recommendation in [5] to set smoothing constant  $\alpha$  to 0.3 for both DRCA and ARCA schemes.

In this simulation, we compare the ARCA scheme and three ranging code allocation schemes in performance differences. We list the three schemes as follows.

- (1) Average allocation (AA) scheme: the BS distributes 256 ranging codes averagely among four ranging code subgroups. In other words, each ranging code subgroup has 64 ranging codes.
- (2) DRCA scheme: it allocates ranging codes according to current traffic of the Ranging and BR messages. If the traffic of the BR increases, it allocates more ranging codes to the BR ranging code subgroup to increase the transmission success rate. The difference between the DRCA scheme and the ARCA scheme is that they use different forecast algorithms and the ARCA scheme can forecast optimal numbers of ranging codes distributed among four ranging code subgroups.
- (3) Optimal scheme: because the BS cannot know the exact number of messages sent by the MS next time in the real world, the ARCA scheme only can forecast the behavior of the MS next time according to current traffic. The optimal scheme assumes that the BS knows the exact number of messages sent by the MS next time and distributes the ranging codes among four ranging code subgroups accordingly. The optimal scheme can get the optimal total transmission success rate. The total transmission success rate

of the optimal scheme can be used as the baseline and compared by that of other schemes in order to identify their performance differences.

The simulation designs five cases to evaluate performance differences of the schemes in different environments. We introduce the five cases as follows.

*Case 1.* When an IEEE 802.16 network is started up, the MSs will send many Initial Ranging messages to the BS for registration. However, the number of Initial Ranging messages eventually will decrease and the number of BR messages will increase when the MSs begin to make the bandwidth requests. For investigating performances of different schemes in the case, we assume that the MS has 10% probability of transmitting Periodic Rangings and Handover Rangings, respectively. The MS has initially 70% probability of transmitting Initial Rangings but gradually decreases probability of transmitting Initial Rangings to 10% at the end of simulation. Conversely, the MS gradually increases probability of transmitting BRs from 10% at the beginning of simulation to 70% at the end of simulation.

*Case 2.* While MSs join the network, their MSs are expected to transmit data. At that time, the proportion of BR messages will be higher than that of other messages. For investigating performances of different schemes in the case, we assume that the MS has 70% probability of transmitting BRs and 10% probability of transmitting Initial Rangings, Periodic Rangings, and Handover Rangings, respectively.

*Case 3.* After the network works for a while and the system becomes stable, the proportions of four messages will be different from each other. We assume that the MS has 40% probability of transmitting BRs, 30% probability of transmitting Initial Rangings, 20% probability of transmitting Periodic Rangings, and 10% probability of transmitting Handover Rangings.

*Case 4.* The MS has 25% probability of transmitting BRs, Initial Rangings, Periodic Rangings, and Handover Rangings, respectively. Although the case does not often happen, the AA scheme will get the optimal performance in the case and is worth a comparison with other schemes.

*Case 5.* Each time, the MS randomly chooses probability of transmitting BRs, Initial Rangings, Periodic Rangings, and Handover Rangings. Because the MS randomly generates the proportion of the four messages each time, the transmission of the Ranging and BR messages is not affected by the previous transmission. In the case, the MS transmits messages in random probability. The numbers of BR and Ranging messages sent by the MS this time have no relation with those sent by the MS previous time, so DRAC and ARCA schemes cannot use their forecast algorithms to get many benefits. Considering traffic with the feature of temporal locality in a real network, that is, the behavior of the MS this time affected by the behavior of the MS in the previous time, we think that the environment of Case 5 unlikely appears in the real world. The simulation runs Case 5 just for observing impacts

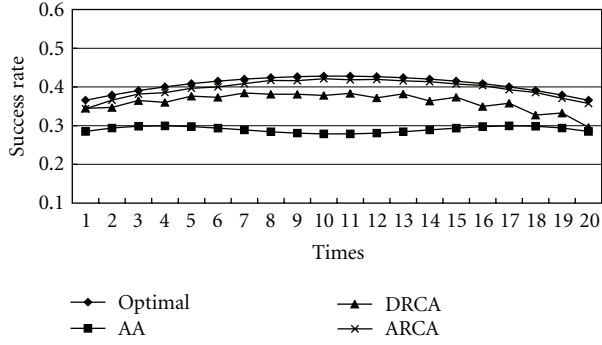


FIGURE 1: Total transmission success rate in Case 1.

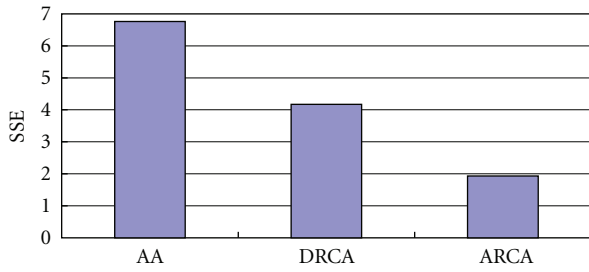


FIGURE 2: Sum of squared errors in Case 1.

on DRAC and ARCA schemes when their forecast algorithms cannot generate accurate forecast values.

The simulation will evaluate the schemes with the following two metrics. First, it will compare their total transmission success rates  $pt$  through (5)

$$pt = \frac{\sum_{i=1}^4 \left( c_i^t! / \left( (c_i^t - n_i^t)! \binom{c_i^t}{n_i^t} \right) n_i^t \right)}{\sum_{i=1}^4 n_i^t}. \quad (5)$$

$n_i^t$  indicates the number of the  $i$ th messages in each frame sent by the MS for the time period  $t$ .  $c_i^t$  is the number of ranging codes allocated to the ranging code subgroup corresponding to the  $i$ th message for the time period  $t$ .  $i$  has a value from 1 to 4 which, respectively, corresponds to BR, Initial Ranging, Periodic Ranging, and Handover Ranging. The more value  $pt$  has, the more transmission success rate the MS has.

Second, the simulation will compare the schemes' sum of the squared errors (SSEs); A SSE expresses the difference between  $pt$  of a scheme and that of the optimal scheme. A SSE can be derived from (6)

$$SSE_j = \sum_{t=1}^{20} \left( pt_j^t - pt_{\text{optimal}}^t \right)^2. \quad (6)$$

$SSE_j$  indicates a SSE of the  $j$ th scheme where  $j$  is 1 for the AA scheme, 2 for the DRCA scheme, and 3 for the ARCA scheme.  $pt_j^t$  indicates  $pt$  of the  $j$ th scheme for the time period  $t$  while  $pt_{\text{optimal}}^t$  is  $pt$  of the optimal scheme. Because the simulation makes the BS execute the ranging code allocation 20 times, we accumulate squared errors 20 times to get SSE. A scheme

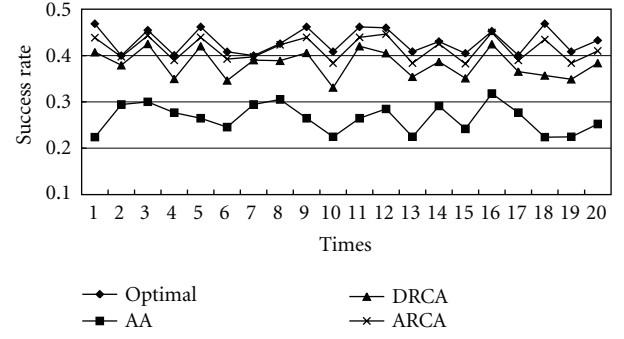


FIGURE 3: Total transmission success rate in Case 2.

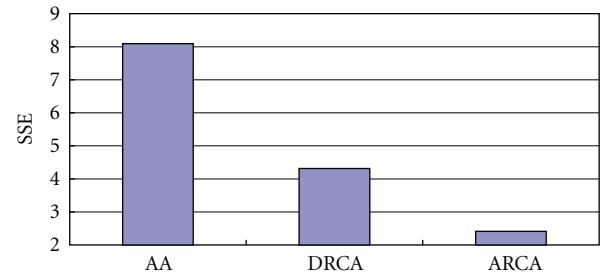


FIGURE 4: Sum of squared errors in Case 2.

has a small SSE meaning that its  $pt$  is close to that of the optimal scheme.

**3.2. Results and Discussions.** We show the simulation results of the aforementioned four schemes in five different cases and have a discussion about the results.

**3.2.1. Case 1.** Figure 1 shows the total transmission success rates of the four schemes in Case 1. According to the figure, we have several points. First, DRCA and ARCA schemes both have their forecast algorithms capable of forecasting traffic quantity sent by the MS next time according to current traffic quantity sent by the MS. If the MS always sends BRs in a transmission more than in the previous transmission, for example, the forecast algorithm will allocate more ranging codes to BRs accordingly. Because of the forecast algorithms, DRCA and ARCA schemes outperform the AA scheme. Second, we compare ARCA and DRAC schemes and note that the ARCA scheme not only outperforms the DRAC scheme but also has results much close to the optimal scheme's results. Figure 2 shows SSEs of AA, DRCA, and ARCA schemes. In the figure, we observe that the ARCA scheme can have performance closer to the Optimal scheme than AA and DRAC schemes when the MS transmits messages in variable probability.

**3.2.2. Case 2.** Figure 3 shows total transmission success rates of the four schemes in Case 2. According to the total transmission success rates, we list the schemes from the scheme having the highest score to the one having the lowest score and then get Optimal, ARCA, DRCA, and AA schemes

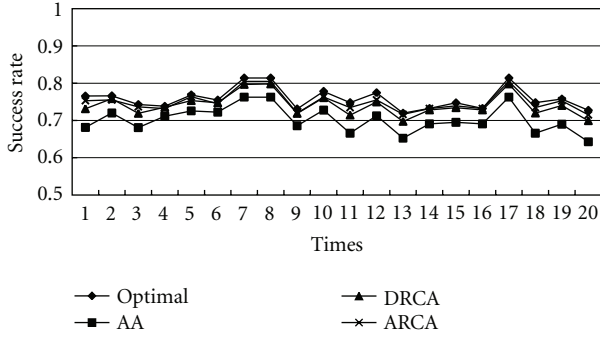


FIGURE 5: Total transmission success rate in Case 3.

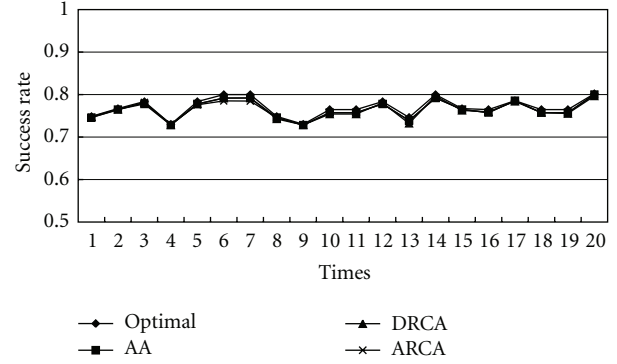


FIGURE 7: Total transmission success rate in Case 4.

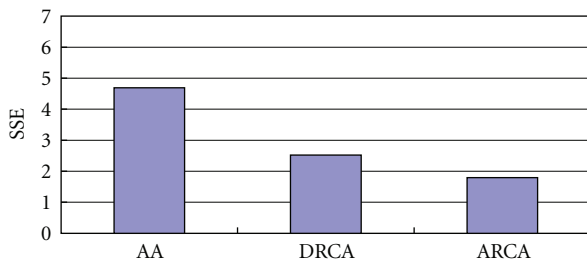


FIGURE 6: Sum of squared errors in Case 3.

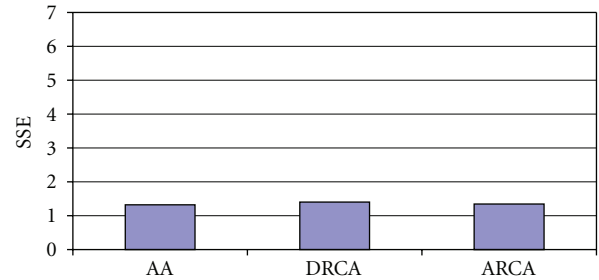


FIGURE 8: Sum of squared errors in Case 4.

in order. The reason of getting the worst performance in the AA scheme is that the BS allocates 64 ranging codes to each of the four messages, which is not enough to BRs transmitted at 70% probability. Accordingly, the MS has many collisions and the degradation of the total transmission success rate when transmitting BRs. ARCA and DRCA schemes allocate the ranging codes according to statistics about Ranging and BR messages collected at the BS, so BR can get more ranging codes without the collision problem in the AA scheme. Figure 4 shows the comparisons between AA, DRCA, and ARCA schemes in SSEs. We observe that the ARCA scheme has better performance than AA and DRCA schemes.

3.2.3. *Case 3.* Figure 5 compares the total transmission success rates of the four schemes in Case 3. We observe that the AA scheme is the worst because many collisions happen to decrease the total transmission success rate when the MSs simultaneously transmit many BRs and Initial Rangings via 64 ranging codes allocated by the BS for each message type. However, DRCA, ARCA, and Optimal schemes do not have many differences in their total transmission success rates. Figure 6 compares SSEs of AA, DRCA, and ARCA schemes. In the figure, we observe that the ARCA scheme outperforms AA and DRCA schemes. Comparing the difference between ARCA and DRCA schemes, we know that the two schemes use different forecast algorithms, and the ARCA scheme can find the number of ranging codes to achieve the maximum total transmission success rate according to the forecast values. Accordingly, the ARCA scheme can have better performance than the DRCA scheme in Case 3.

3.2.4. *Case 4.* Figure 7 shows the total transmission success rates of the four schemes in the Case 4. As we expect that the AA scheme has a good result, but DRCA and ARCA schemes both get results close to the result of the optimal scheme. In Figure 7, the AA scheme has an unstable total transmission success rate because we assume that the real network will not keep traffic intact and we sophisticatedly make a little change in the numbers of the four messages transmitted by the MS to reflect the behavior of a real network. Figure 8 compares SSEs of different schemes. In the figure, we observe that the AA scheme has a small SSE due to the change of traffic generated by the simulator. Besides, other two schemes have SSEs similar to the SSE of the AA scheme. According to Figures 7 and 8, we note that AA, DRCA, and ARCA schemes in the Case 4 can get comparable results.

3.2.5. *Case 5.* Figure 9 shows total transmission success rates of the four schemes in Case 5. The figure has unstable curves because each time the MS transmits BR and Ranging messages in variable probability that may change greatly. Accordingly, the total transmission success rate of each scheme maybe changes greatly. Figure 10 shows SSEs of AA, DRCA, and ARCA schemes. In Figures 9 and 10, we observe that the forecast algorithms do not get many benefits, so SSEs of DRCA and ARCA schemes are much greater than those in previous cases. Although the ARCA scheme has worse performance than AA and DRCA schemes, the difference is slight and can be improved by the adjustment of  $\alpha$  in the forecast algorithm to make the ARCA scheme respond quickly to network changes. Because we want to compare and

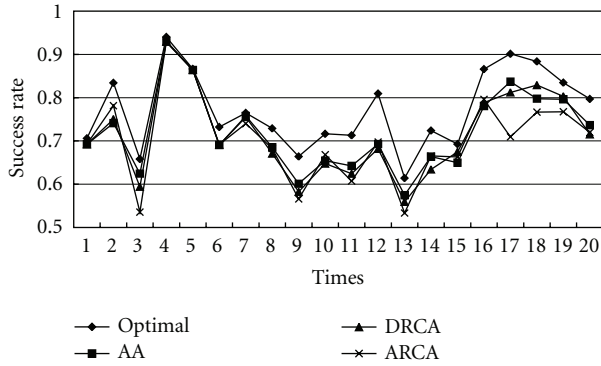


FIGURE 9: Total transmission success rate in Case 5.

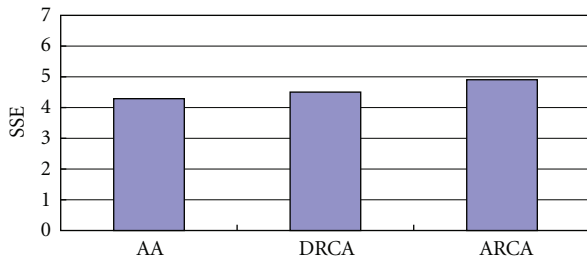


FIGURE 10: Sum of squared errors in Case 5.

analyze the schemes with the identical  $\alpha$  in all cases, we do not adjust  $\alpha$  for the ARCA scheme in this case and use the same  $\alpha$  as the previous cases.

#### 4. Conclusions and Future Works

Because IEEE 802.16 does not regulate a ranging code allocation scheme in its specification, we propose the ARCA scheme in this paper for it. The working principle of the ARCA scheme can be divided into two parts. The first part is the forecast algorithm. The forecast algorithm collects statistics about traffic currently received by the BS and forecasts the numbers of messages sent by the MS next time based on the feature of temporal locality in a real network. The second part is to find the number of ranging codes for achieving the optimal total transmission success rate according to the forecast numbers of messages sent by the MS and then notify the MS of the ranging code allocation result.

The simulation designs five cases to compare ARCA, Optimal, AA, and DRCA schemes in performance differences. Firstly, from Case 1 to Case 3, we observe that the ARCA scheme not only outperforms AA and DRCA schemes but also has performance close to the Optimal scheme. Then, we observe that the four schemes have similar results in Case 4. In Case 5, we observe that the ARCA scheme does not have much performance difference in comparison to AA and DRCA schemes. According to the simulation results, we know that the ARCA scheme is better and more suitable than AA and DRCA schemes to work in 802.16 networks. In the future, we will focus on improving the forecast algorithm

of the ARCA scheme to make it have performance close to the Optimal scheme even when it works in an environment without the feature of temporal locality like Case 5.

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