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Bridging Theory and Practice: A Packet Tracer-Based Simulation Approach to Computer Network Education

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Abstract: Computer network course features abstract concepts and obscure principles, making it difficult for students to form intuitive understanding solely through classroom theoretical instruction. To address the issue, a simulation experiment teaching reform plan based on Packet Tracer is proposed. The core concept is to ensure that each simulation experiment precisely corresponds to the key knowledge points in theoretical teaching, enabling students to see the specific presentation of abstract principles through hands-on operations. A three-in-one teaching system of "theoretical knowledge points - simulation experiments - verification content" was designed, and the case of the switched Ethernet experiment was used to detail how Simulation mode enables students to observe self-learning process of switch, clear forwarding of unicast frames, and collision-free transmission of full-duplex communication. Teaching practice has shown that this "theory-driven, experiment-verified" model effectively reduces students' cognitive load and helps them establish an intuitive connection from concepts to phenomena.

Keywords: Computer Network; Simulation Experiment; Integration of Theory and Practice; MAC Address Learning.

1. Introduction

Computer network is a core course for computer science and communication majors, but its concepts are abstract and their principles are obscure. Students can hardly truly understand them merely through classroom lectures[1]. At the same time, traditional experimental teaching has the problem of a disconnect between theory and practice. Students often perform mechanically without being able to establish a connection between the experimental phenomena and the classroom knowledge[2]. Due to limited equipment, some institutions even complete experiments through teacher demonstrations, leaving students without hands-on opportunities and significantly reducing the teaching effect[3].

Virtual simulation technology offers new solutions to these problems. Cisco Packet Tracer is a powerful network simulation software that can simulate the operation processes of devices such as switches and routers[4]. Its Simulation mode visually represents the transmission process of data frames, and since the software is free, it breaks down the temporal and spatial constraints of laboratory instruction.

To address the teaching challenges of computer network, this paper proposes a reform plan for simulation-based experimental instruction using Packet Tracer. The core concept is to ensure that each simulation experiment precisely corresponds to a key theoretical concept, thereby transforming the experiment into a visual verification tool for theory. Using a switched Ethernet experiment as an example, this paper details the design and implementation process of this teaching model.

2. Design of the Simulation-Based Experimental Teaching System

2.1. Design Philosophy

(1) Theory-practice alignment with precise matching

Each simulation experiment precisely corresponds to one or more core theoretical knowledge points, achieving "practice immediately after lecture, understanding immediately after practice."

(2) Visualization priority to reduce cognitive load

Utilizing the Simulation mode of Packet Tracer, the abstract process is presented intuitively.

(3) Progressive difficulty from basic to advanced

Experimental content progresses from basic verification to comprehensive design and then to exploration and innovation, with abilities gradually improving.

2.2. Theory and Experiment Mapping System

This scheme proposes a three-in-one mapping system of "theoretical knowledge points—simulation experiments—validation content, " ensuring each theory has corresponding experimental validation. Following students' cognitive development, experiments are categorized into three progressive levels.

As shown in Table 1, this plan achieves a deep integration of theory and experiment. Each theoretical knowledge point is paired with an experimental session, allowing students to immediately observe abstract concepts through simulation experiments. This theory-driven and experiment-validated model makes the abstract concepts concrete and tangible.

3. Teaching Case: Building a Switched Ethernet Using the Switch

3.1. Correspondence Between Theoretical Knowledge and the Experiment

Before starting the experiment, students have learned the following content in theoretical lectures[5]:

(1) Switch operates at the data link layer and forwards frames using a forwarding table (MAC addresses and port numbers);

(2) Switch possesses the ability to learn MAC addresses autonomously(self-learning);

(3) Switch can simultaneously connect multiple pairs of ports, enabling collision-free transmission.

Table 1. Mapping of theoretical teaching content to simulation experiments

Chapter	Core Theoretical Knowledge Points	Corresponding Simulation Experiment	Experiment Type
Chapter 1: Introduction to Computer Networks	Network topology, functions of network devices	Getting to Know Packet Tracer	Basic Verification
Chapter 2: Physical Layer	Transmission media, interface standards	Making a Network Cable	Basic Verification
Chapter 3: Data Link Layer	**Switch operation principle, collision domains**	**Building a Switched Ethernet Using a Switch**	**Basic Verification**
Chapter 4: Network Layer	ARP protocol, IP address classification	Principles of ARP Protocol Operation	Comprehensive Design
Chapter 4: Network Layer	Static routing, dynamic routing	Comparison of Static and Dynamic Routing	Comprehensive Design
Chapter 5: Transport Layer	TCP three-way handshake, UDP characteristics	TCP Connection Management	Comprehensive Design
Chapter 6: Application Layer	DNS recursive query, iterative query	DNS Protocol Analysis	Comprehensive Design
Comprehensive Application	Integrated use of multiple protocols	Comprehensive Design of a Small Enterprise Network	Inquiry-Based Innovation

Note: The row in bold represents the detailed case study in this paper. Other experiments can follow the same pattern to form a complete simulation-based experimental teaching system.

3.2. Network Construction and Basic Configuration

This experiment is conducted in the Cisco Packet Tracer v8.2.0 virtual simulation environment on the Windows 10 operating system. A star topology is adopted, consisting of one 2960 switch and three PCs, as shown in Figure 1. The detailed configuration steps are as follows.

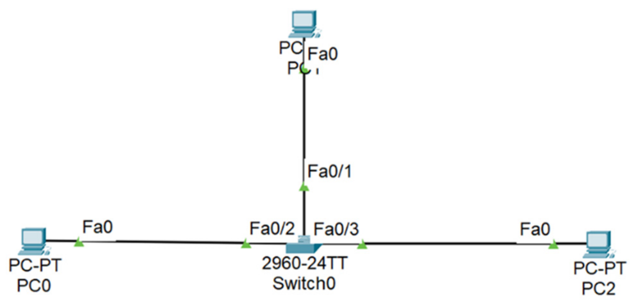

Figure 1. Network topology of the experiment

(1) Build the network topology

Open Packet Tracer and construct the network topology in the Logical workspace according to the topology shown in Figure 1.

(2) Configure IP addresses and subnet masks

Following Table 2, assign IP addresses and subnet masks to PC0, PC1, and PC2 via each computer's graphical user interface. Then, label the IP addresses and subnet masks next to the corresponding PCs using annotations.

Table 2. IP addresses and subnet masks for each computer

Computer Name	IP Address	Subnet Mask
PC0	192.168.0.1	255.255.255.0
PC1	192.168.0.2	255.255.255.0
PC2	192.168.0.3	255.255.255.0

(3) Select the network protocol

This experiment only needs to monitor the Internet Control Message Protocol (ICMP). The setup procedure is as follows: switch to the Simulation mode, use "Edit Filter" in the Simulation Panel to open the protocol selection dialog, and then click ICMP under the IPv4 tab.

3.3. Functional Verification of the Switch

After network configuration is completed, follow the steps below to verify the switch's self-learning capability, explicit forwarding mechanism, and collision-free characteristics.

(1) Test network connectivity

Switch to Realtime mode. Execute ping 192.168.0.2 and ping 192.168.0.3 on PC0 to test connectivity with PC1 and PC2. The objectives are: to verify that the network topology and IP configurations are correct; to allow PC0 to exchange MAC addresses with PC1 and PC2; and to enable the switch to learn the mapping between MAC addresses and ports, thereby preventing subsequent ARP processes from interfering with experimental observations. The test results are shown in Figure 2, indicating that PC0 has successfully established connectivity with both PC1 and PC2.

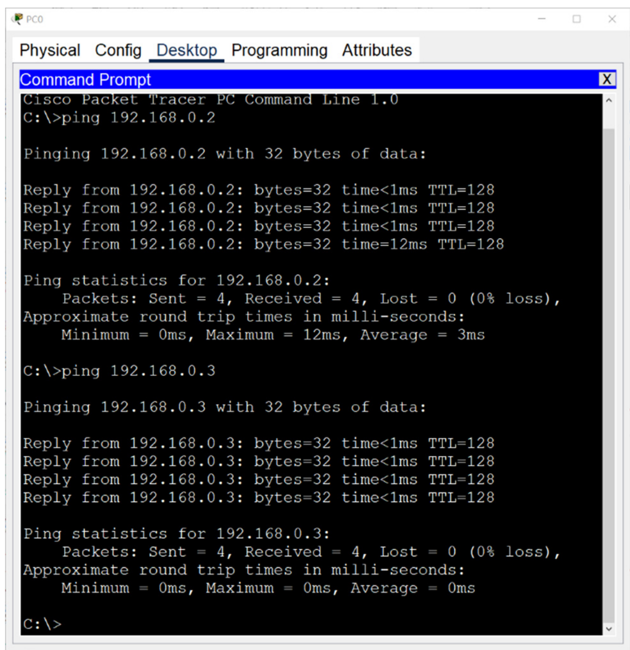

Figure 2. Connectivity test results of PC0, PC1, and PC2

(2) View the switch's forwarding table to verify the self-

learning results

Click on Switch0 and access the CLI to view the MAC address table in privileged mode. The result is shown in Figure 3.

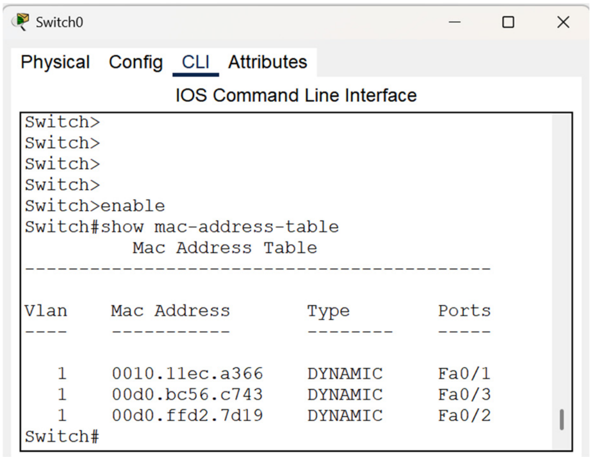

Figure 3. forwarding table of Switch0

At this point, students can clearly see that the switch has learned the MAC addresses of all three PCs and recorded their corresponding port numbers. This serves as a direct visual verification of the theoretical concept that "switch possesses the ability to learn MAC addresses autonomously". Students no longer passively accept conclusions but instead witness the learning outcomes themselves.

(3) Verify that a self-learned switch can forward unicast frames explicitly

Explicit forwarding refers to the switch looking up the destination MAC address in its forwarding table and forwarding the frame through the corresponding port. Blind forwarding refers to the switch forwarding the frame out of all ports except the receiving port when the destination MAC address is not found in the forwarding table.

Switch to Simulation mode. Use the "Add Simple PDU" tool in the workspace toolbox to send a unicast frame from PC0 to PC1. Use the "Capture then Forward" button in the Playback Control bar to perform step-by-step simulation. The data frame transmission process can be observed as follows:

1st click: the unicast frame sent from PC0 to PC1 arrives at Switch0, as shown in Figure 4.

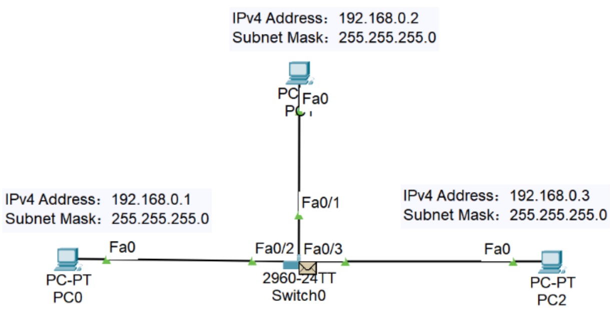

Figure 4. Switch0 receives the unicast frame from PC0

2nd click: the self-learned Switch0 explicitly forwards the unicast frame. Only PC1 receives the unicast frame, while PC2 does not, as shown in Figure 5. This indicates that PC1, upon parsing the frame and recognizing it as an ICMP request from PC0, accepts the frame.

The observation reveals that self-learned Switch0 forwards unicast frames explicitly: only PC1 receives the frame, while PC2 does not. This serves as a direct visual verification of the theoretical concept that "switch looks up the destination MAC address in its table and forwards accordingly." Students can clearly see that the frame is sent only to the target port, rather than to all ports as in the case of the hub.

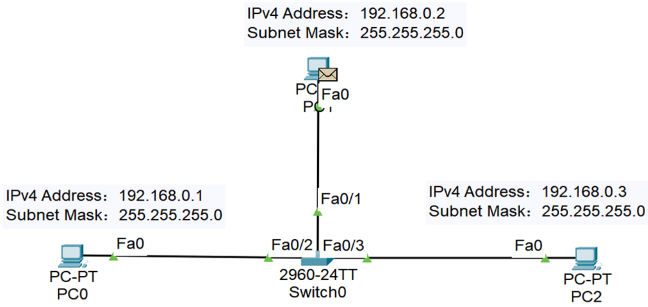

Figure 5. PC1 receives the frame explicitly forwarded by Switch0

Guided teaching questions can be set as follows: How does the switch know which port PC1 is connected to? What happens if the switch's forwarding table contains no record of the destination MAC address?

(4) Verify that no collisions occur in a switched Ethernet.

Have PC1 and PC2 simultaneously send unicast frames to PC0. The two frames are in different colors, as shown in Figure 6. The step-by-step simulation process is as follows:

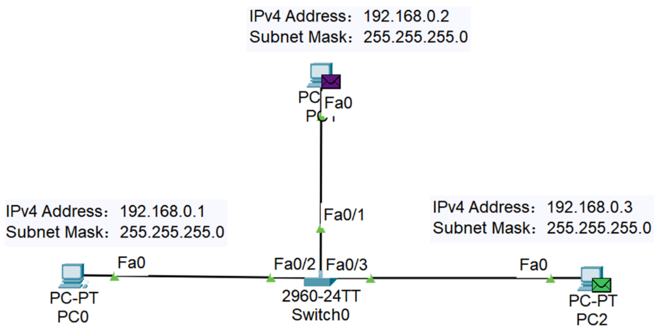

Figure 6. PC1 and PC2 simultaneously sending unicast frames to PC0

1st click: Two unicast frames sent by PC1 and PC2 arrive at Switch0 simultaneously. The simulation effect is shown in Figure 7.

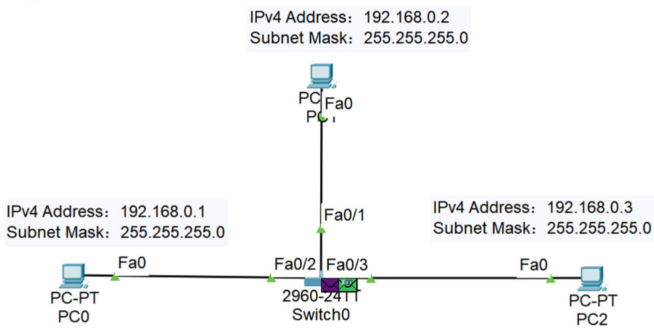

Figure 7. Two unicast frames arrive at Switch0

2nd click: The unicast frame from PC1 is forwarded by Switch0 to PC0. The simulation effect is shown in Figure 8.

3rd click: The unicast frame from PC2 is forwarded by the switch to PC0. Simultaneously, the ICMP acknowledgment frame from PC0 to PC1 arrives at the Switch0. The simulation effect is shown in Figure 9.

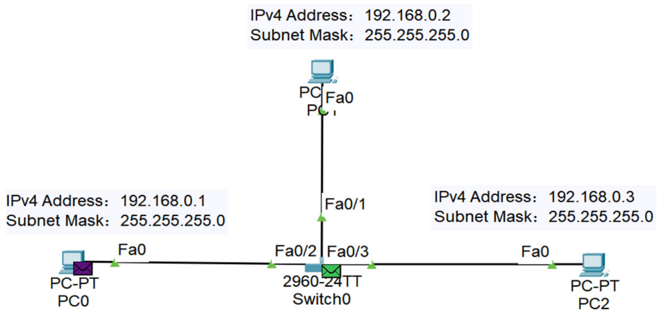

Figure 8. The frame from PC1 delivered to PC0

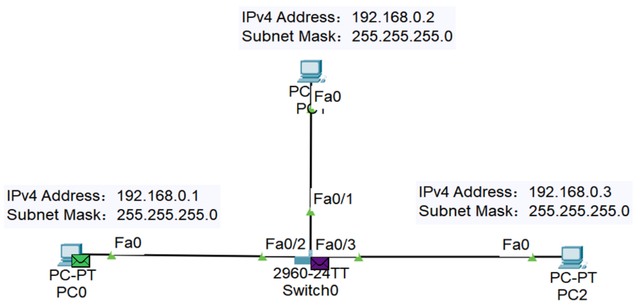

Figure 9. Concurrent frame delivery and acknowledgment

4th click: The ICMP acknowledgment frame from PC0 to PC1 arrives at PC1 via Switch0, while the acknowledgment frame from PC0 to PC2 simultaneously arrives at the switch.

5th click: The ICMP acknowledgment frame from PC0 to PC2 arrives at PC2 via Switch0.

Observations reveal no collisions during transmission, directly verifying the theoretical concept that "switch can isolate collision domains." Students clearly see the switch simultaneously connect multiple port pairs, enabling each pair of computers to transmit without collisions as if exclusively occupying the medium.

Guided teaching questions can be set as follows: Why do no collisions occur in a switched Ethernet? What would happen if the switch were replaced with a hub?

4. Supporting Role of Virtual Simulation Experiments in Theoretical Teaching

(1) Visual transformation of abstract concepts

Through the Simulation mode, the abstract concepts such as MAC address learning and frame forwarding are presented in an animated form step by step. Students can see the transmission path of data frames and the decision-making process of the switch, achieving a cognitive leap from "the abstract" to "the concrete".

(2) Establishing a closed loop of theory and phenomena

This scheme follows the design concept of "each theoretical knowledge point has corresponding experimental verification". After students learn the theory, they immediately see the corresponding phenomenon through experimental commands or simulation mode, forming a "theory → experiment → verification" closed loop. They deepen their understanding through hands-on operation rather than passively accepting conclusions.

(3) Enhancing learning initiative and inquiry interest

Packet Tracer is free software. Students can repeatedly practice without any time or space restrictions. Practice shows that many students will actively try to design more complex topologies and return to the classroom with questions, achieving a transformation from passive completion to active exploration.

5. Conclusion

Computer network course involves many abstract concepts that challenge student understanding. To address this issue, this paper constructs a three-in-one teaching comparison system of "theoretical knowledge points - simulation experiments - verification content", ensuring that each theoretical knowledge point has a corresponding experimental verification stage. Taking the switched Ethernet experiment as an example, after learning how switches work, students immediately reinforce their understanding using Packet Tracer's Simulation mode. This transforms abstract theory into tangible phenomena, facilitating the internalization of knowledge. Teaching practice shows that this mode can effectively reduce students' cognitive load and enhance their learning initiative. Simulation experiments have advantages such as low cost, high flexibility, and good security, and are an effective supplement to computer network experimental teaching. In the future, we will further improve the simulation experiment cases and integrate them deeply with the online teaching platform to continuously improve teaching quality.

Acknowledgments

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