Network Programming

Lecture 02

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- Flow 5
- NAPI
- Flow 6
- Flow 7

How to Process Interrupt and Received Packet

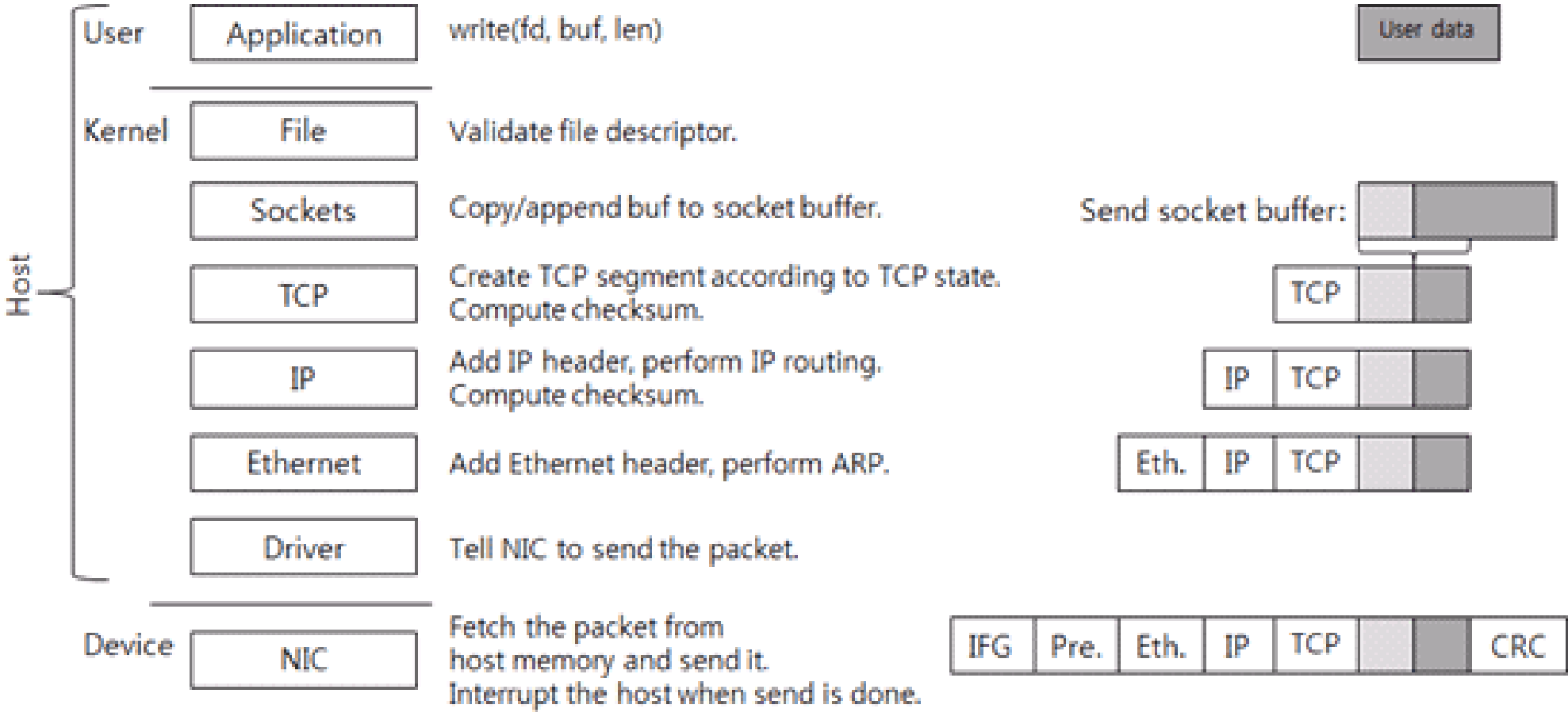
Data Structure

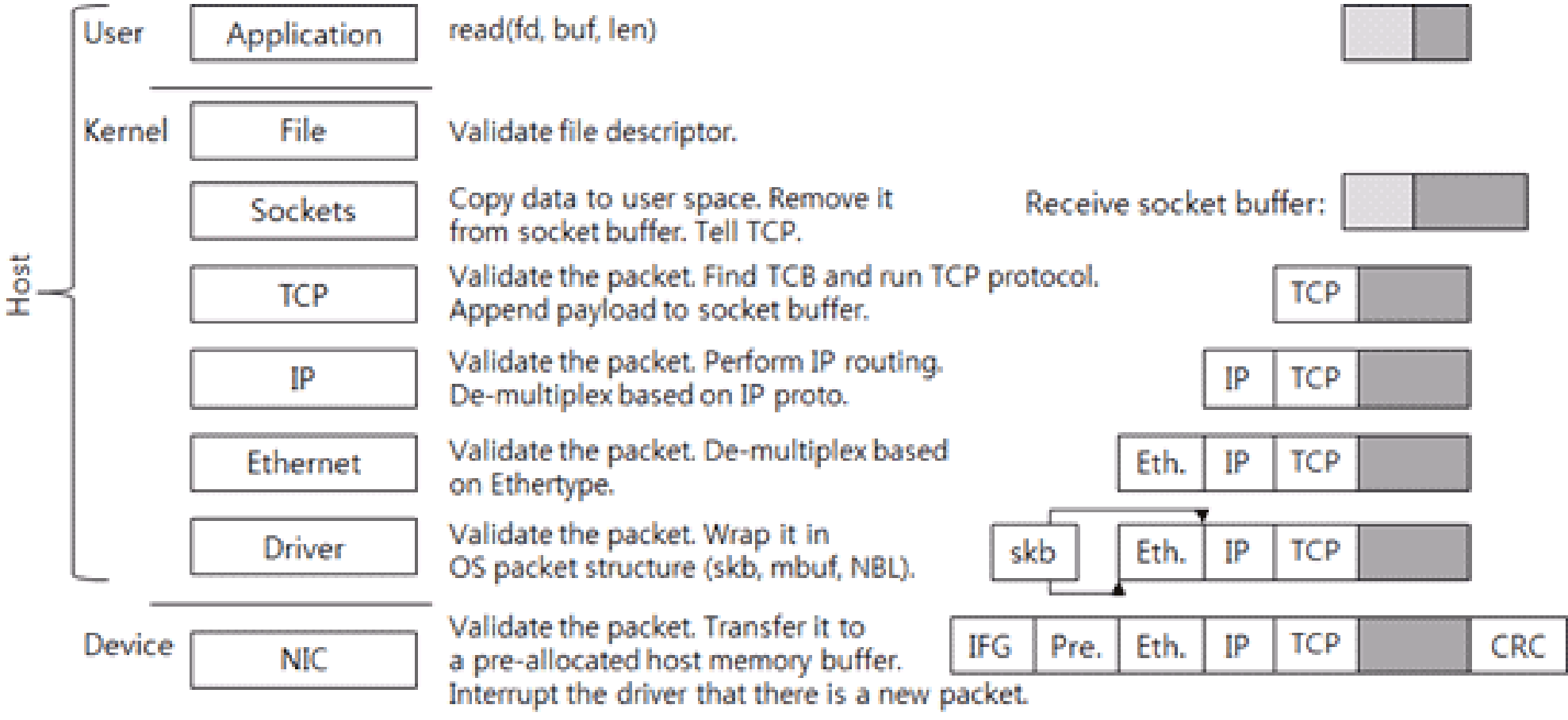
- sk_buff
- TCP Control Block
- TCP Connection Lookup Table

Next Week InchALLAH

Homework

Following content is based on
http://www.cubrid.org/blog/dev-platform/understanding-tcp-ip-network-stack/


Host
User
Application
write(fd, buf, len)
User data
Kernel
File
Validate file descriptor.
Sockets
Copy/append buf to socket buffer.
Send socket buffer:
TCP
Create TCP segment according to TCP state.
Compute checksum.
TCP
IP
Add IP header, perform IP routing.
Compute checksum.
IP
TCP
Ethernet
Add Ethernet header, perform ARP.
Eth.
IP
TCP
Driver
Tell NIC to send the packet.
Device
NIC
Fetch the packet from
host memory and send it.
Interrupt the host when send is done.
IFG
Pre.
Eth.
IP
TCP
CRC


Host
User
Application
read(fd, buf, len)
Kernel
File
Validate file descriptor.
Sockets
Copy data to user space. Remove it from socket buffer. Tell TCP.
Receive socket buffer:
TCP
Validate the packet. Find TCB and run TCP protocol. Append payload to socket buffer.
TCP
IP
Validate the packet. Perform IP routing. De-multiplex based on IP proto.
IP
TCP
Ethernet
Validate the packet. De-multiplex based on Ethertype.
Eth.
IP
TCP
Driver
Validate the packet. Wrap it in OS packet structure (skb, mbuf, NBL).
skb
Eth.
IP
TCP
Device
NIC
Validate the packet. Transfer it to a pre-allocated host memory buffer. Interrupt the driver that there is a new packet.
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- This buffer is a memory that has already been requested by the driver to the kernel and allocated for receiving packets
- After the buffer has been allocated, the driver tells the memory address and size to the NIC.
- When there is no host memory buffer allocated by the driver even though NIC receives a packet, NIC may drop the packet

Device Driver

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- For example, **sk_buff** of **Linux**, **mbuf** of **BSD-series** kernel, and **NET_BUFFER_LIST** of **Microsoft Windows**.

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- According to TCP state, it can send a new TCP packet (ex. ACK).

Now

Now, TCP/IP receiving packet handling has completed.

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- In the past, socket buffer size had been adjusted on the application or the OS configuration.
- Latest network stack has a function to adjust the receive window automatically.

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- TCP increases receive window because there is new space in the socket buffer.
- TCP sends a packet according to protocol status. If no packet is transfered, system call is terminated.

Functions of Network Stack Layers

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- Latest network stack has many more functions and complexity.
- Latest network stack is classified by purpose as follows:
- Packet processing procedure manipulation
- Protocol performance
- Packet processing efficiency

Packet Processing Procedure Manipulation

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- By inserting the user-controllable code to the basic processing flow, the function can work differently according to user configuration.

Protocol Performance

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- Various congestion control algorithms and additional TCP functions can be added

Packet Processing Efficiency

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  - CPU cycle
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  - CPU cycle
  - memory usage
  - memory accesses
- Attempts include
  - stack parallel processing
  - header prediction
  - zero-copy
  - single-copy
  - checksum offload
  - TSO, LRO, RSS
  - etc.

Control Flow in the Stack

More detailed look at the internal flow of the Linux network stack.

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- Like a subsystem which is not a network stack, it basically runs as the event-driven way
- Event-driven way: reacts when the event occurs.
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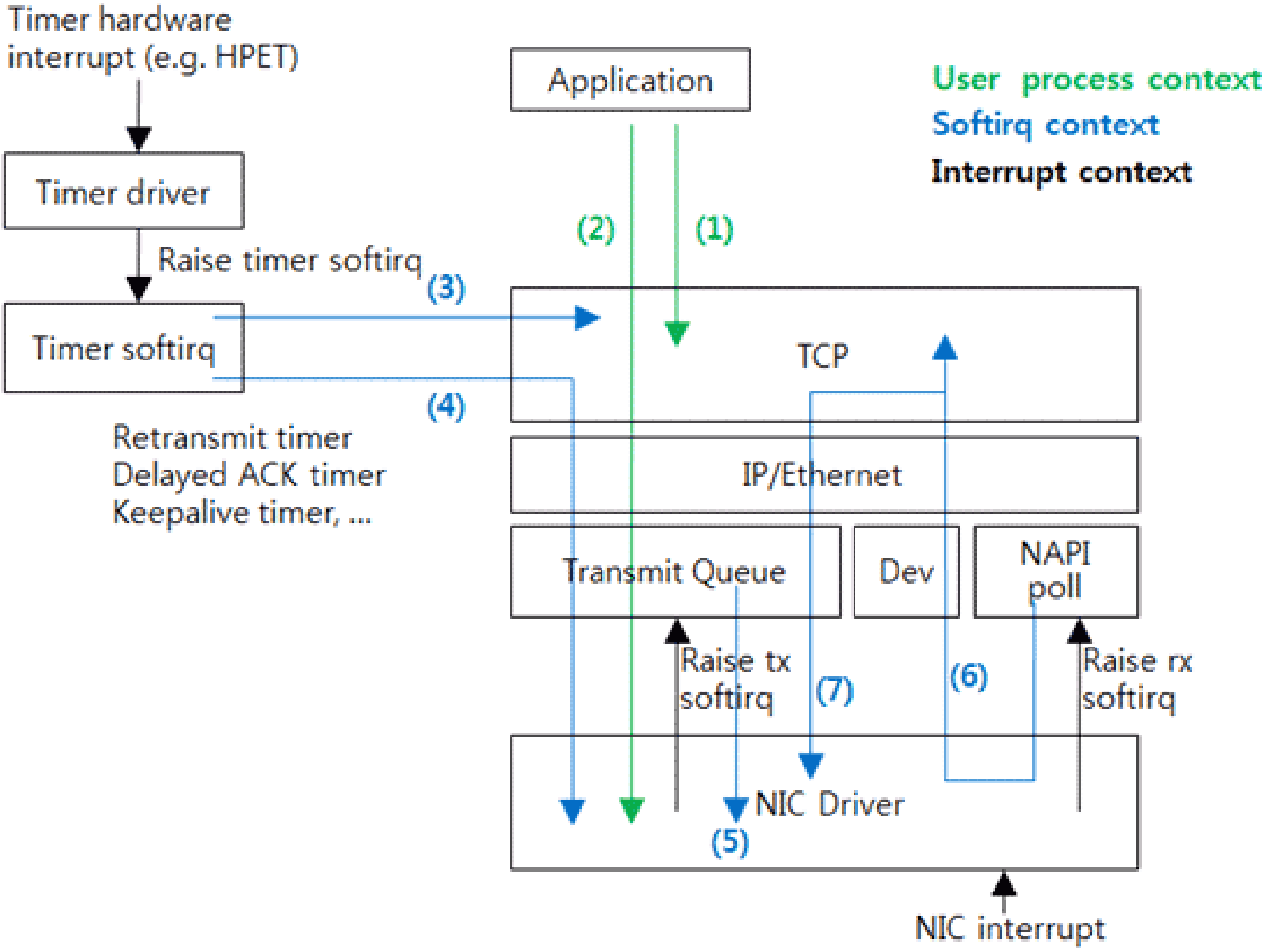
- Previous figures were simplified diagrams of control flow.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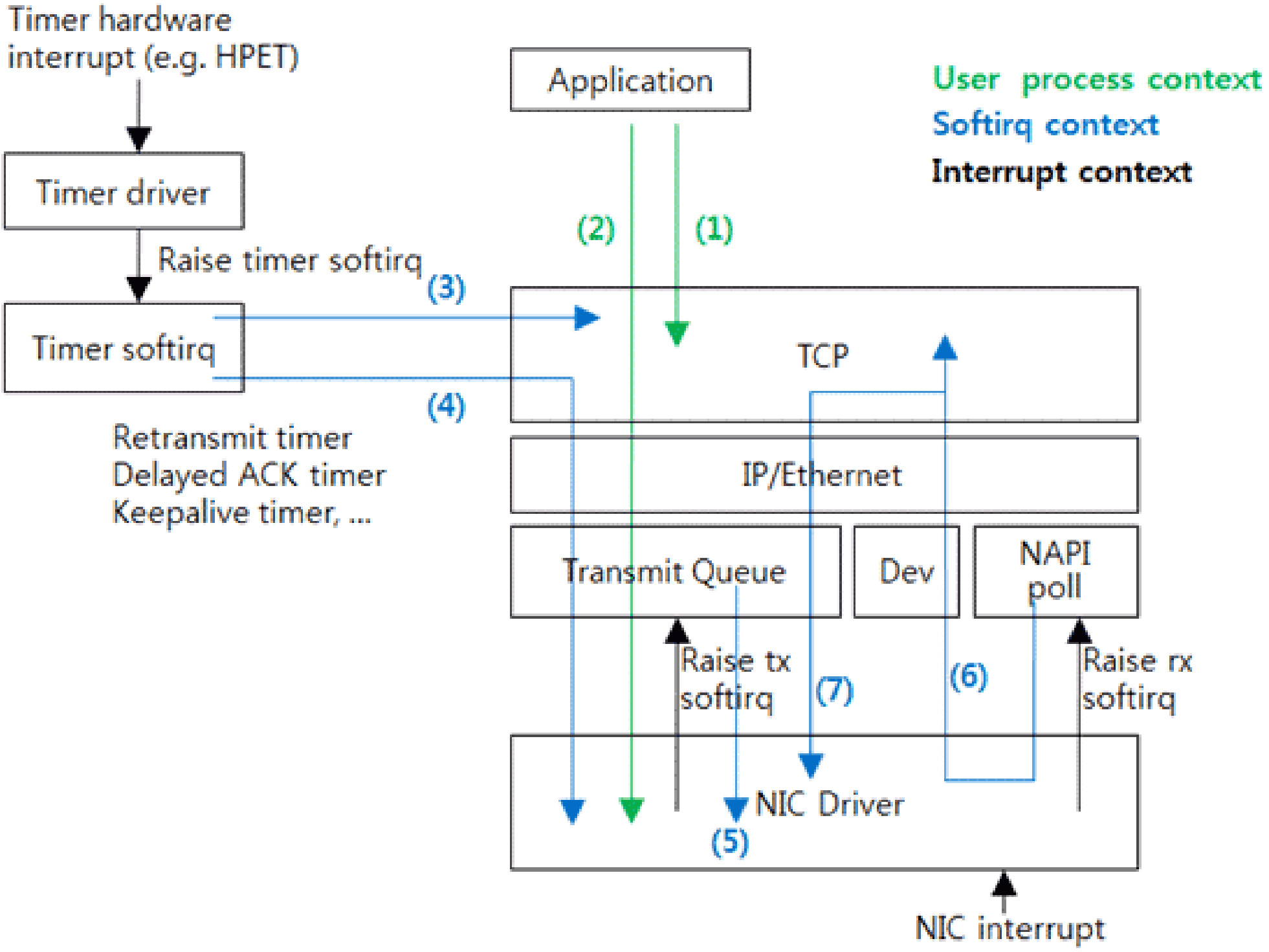
- For example, calls the read system call and the write system call and then executes TCP.
- However, there is no packet transmission.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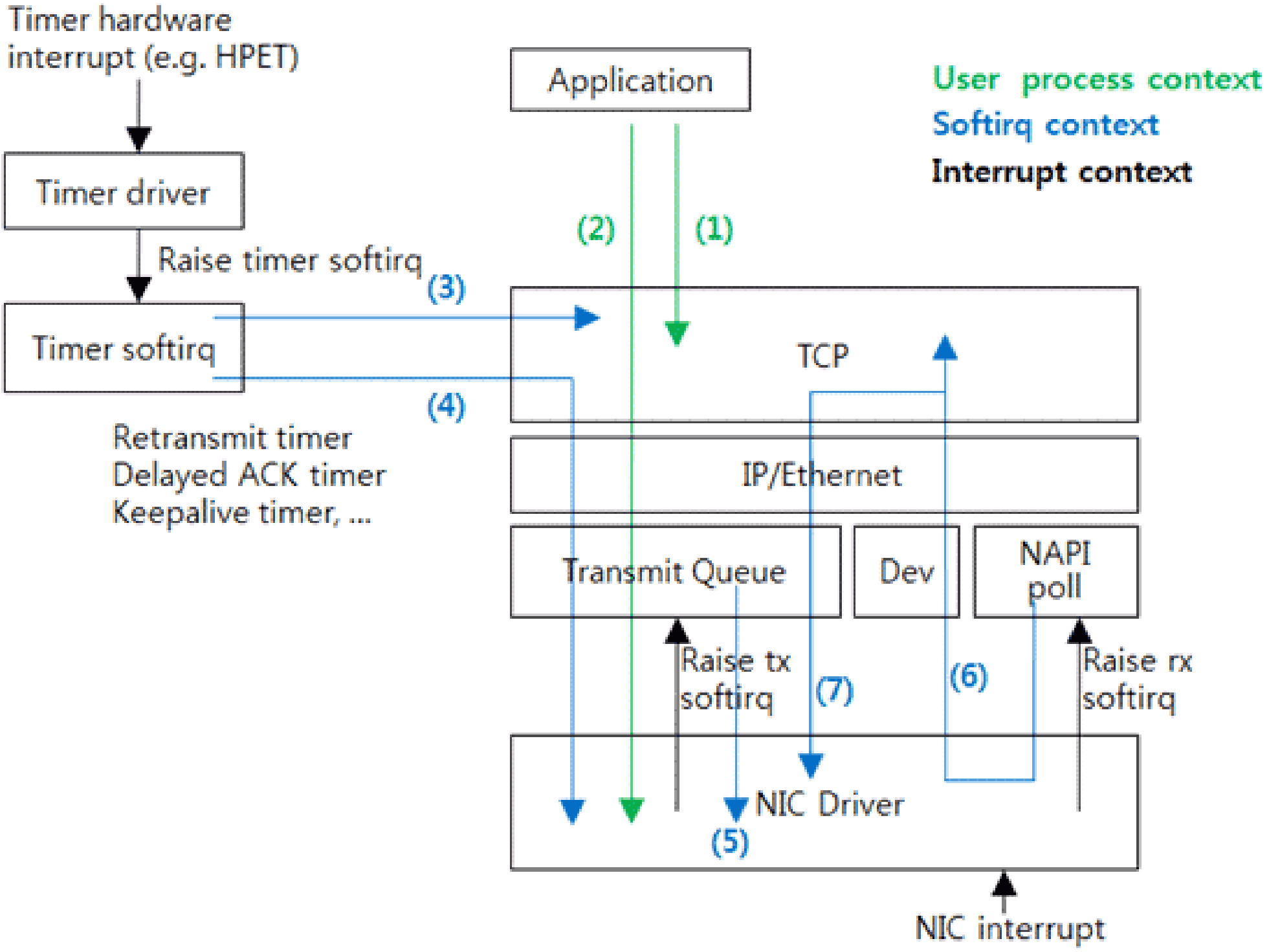
- At Flow 1 and Flow 2, the process thread of the application also executes the driver.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Flow 3

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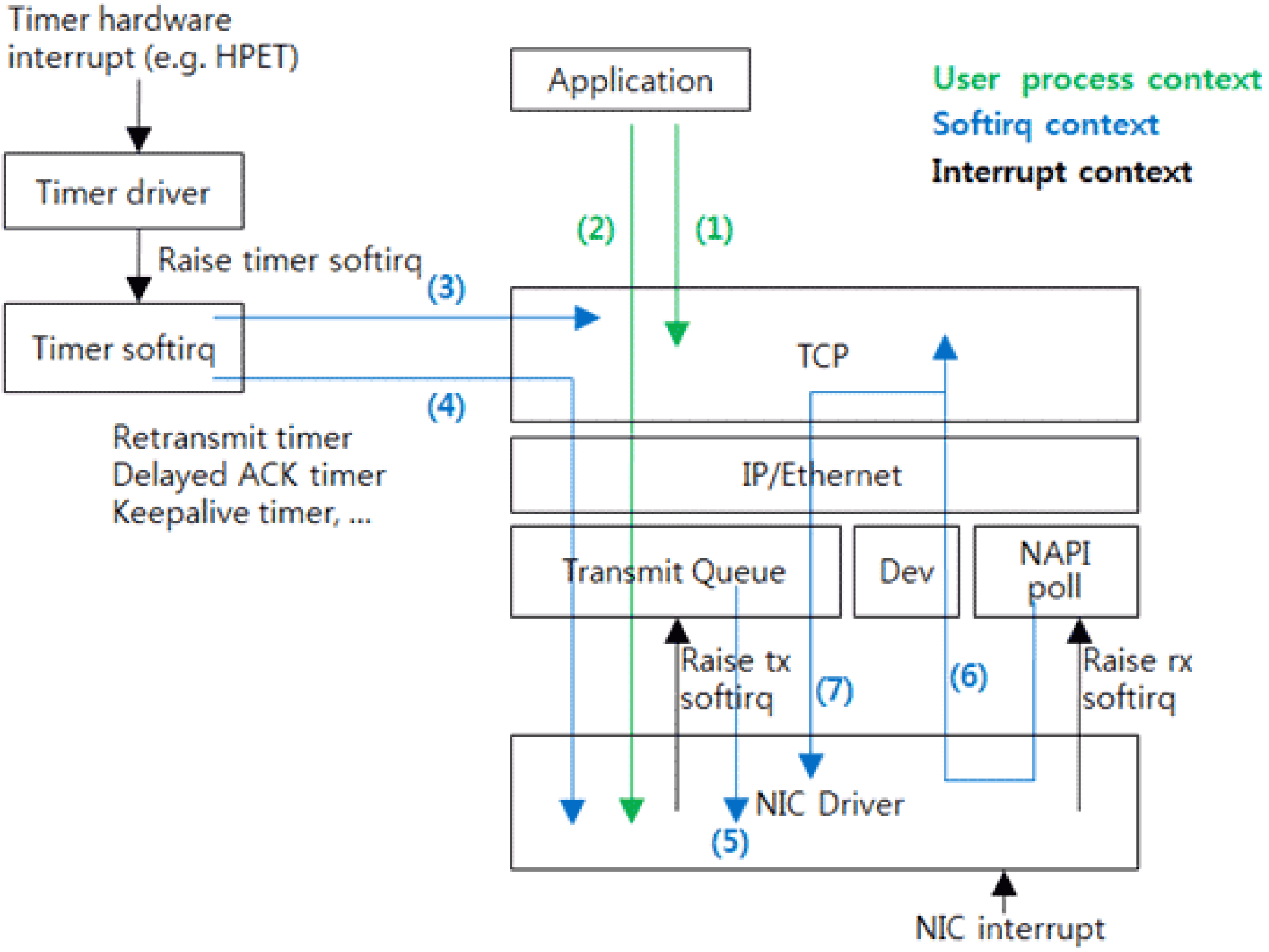
- Example, when **TIME_WAIT** timer has expired, TCP is called to delete the connection.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Flow 4

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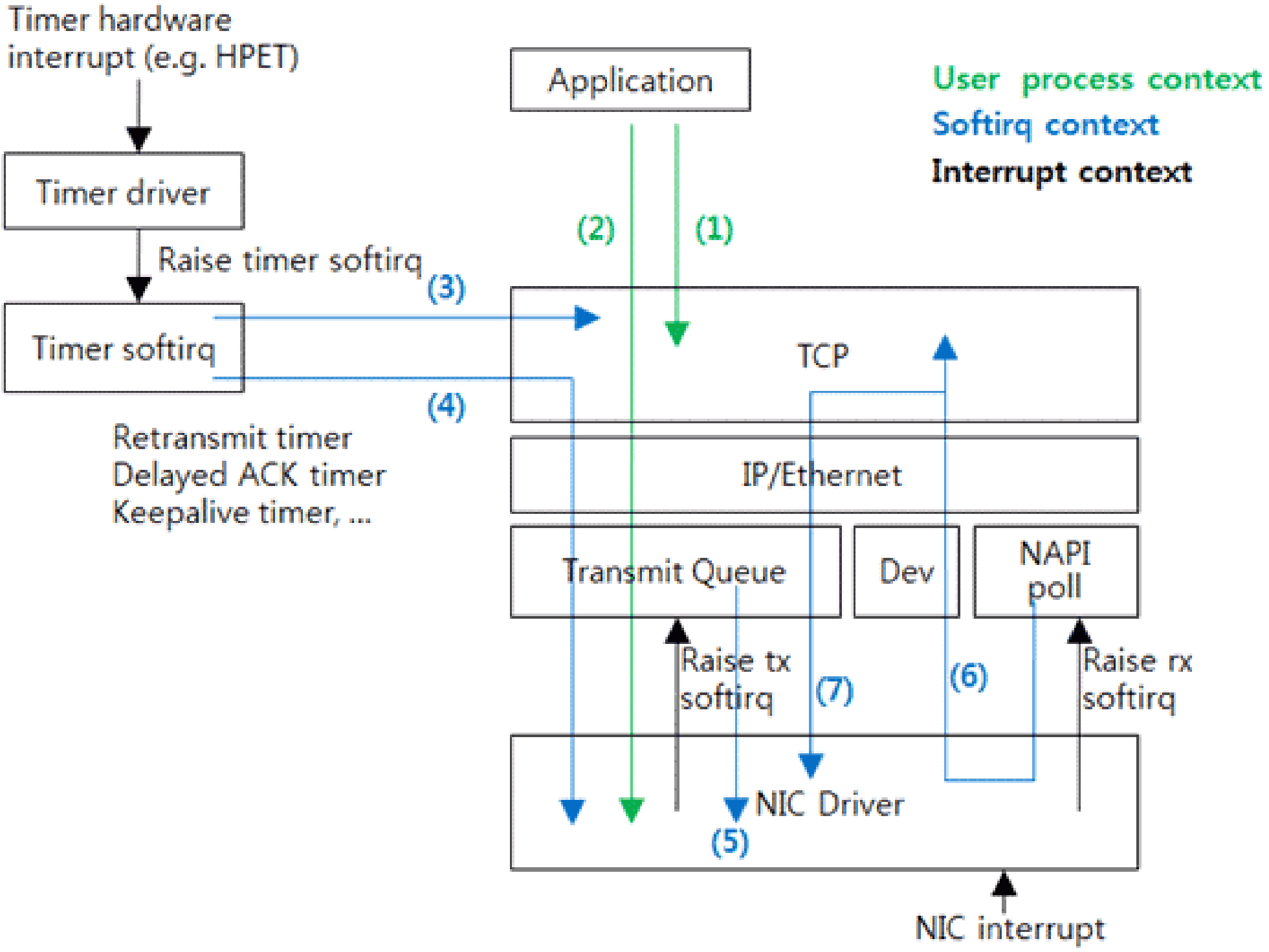
- Example, when the retransmit timer has expired, packet of which ACK has not been received is transmitted.
- **Flow 3** and **Flow 4** show the procedure of executing the timer softirq that has processed the timer interrupt.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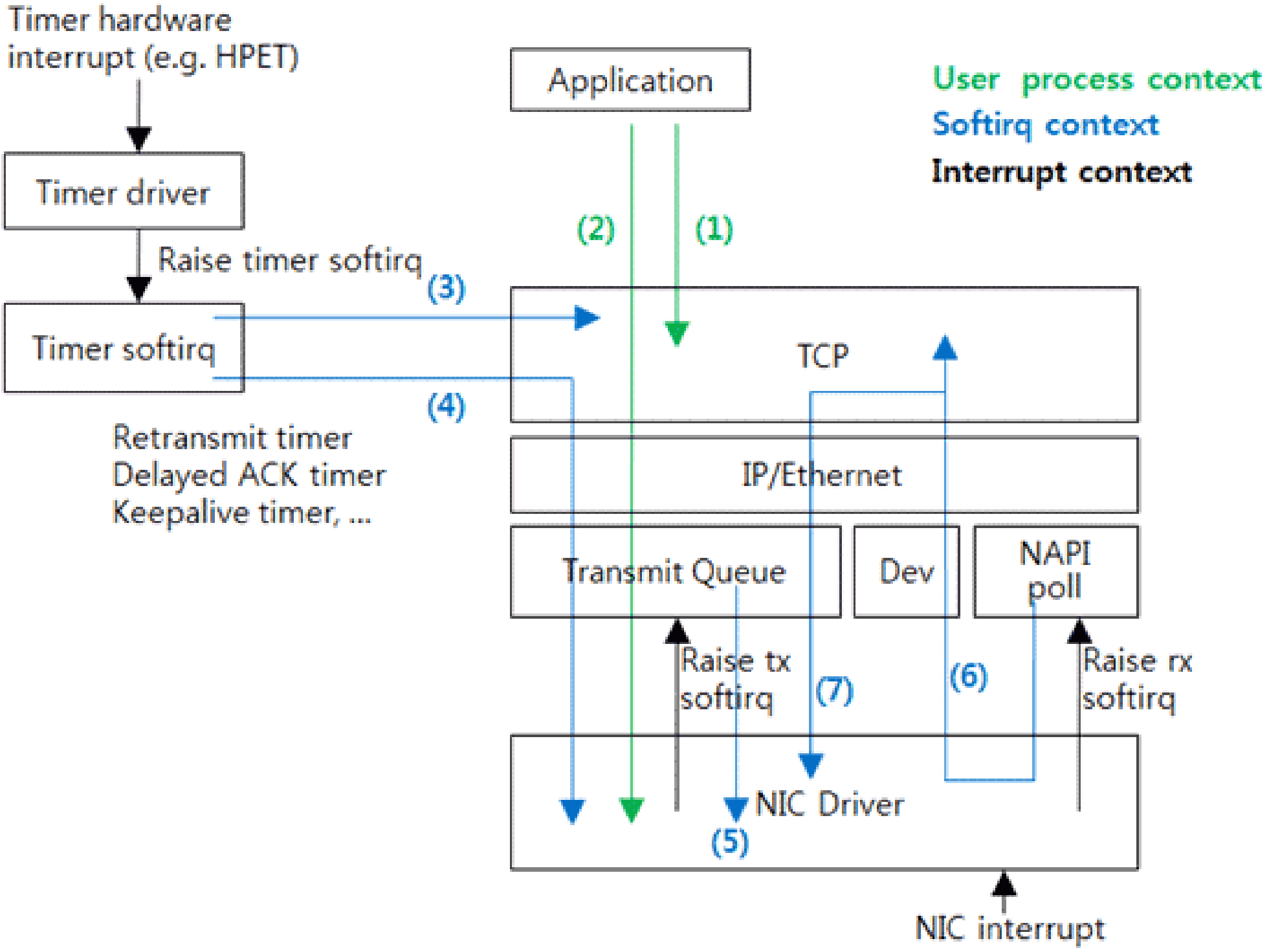
- In most cases, execution of the driver is terminated here.
- **Flow 5** is the case of packet accumulation in the transmit queue.
- The driver requests softirq and the softirq handler executes the transmit queue to send the accumulated packet to the driver.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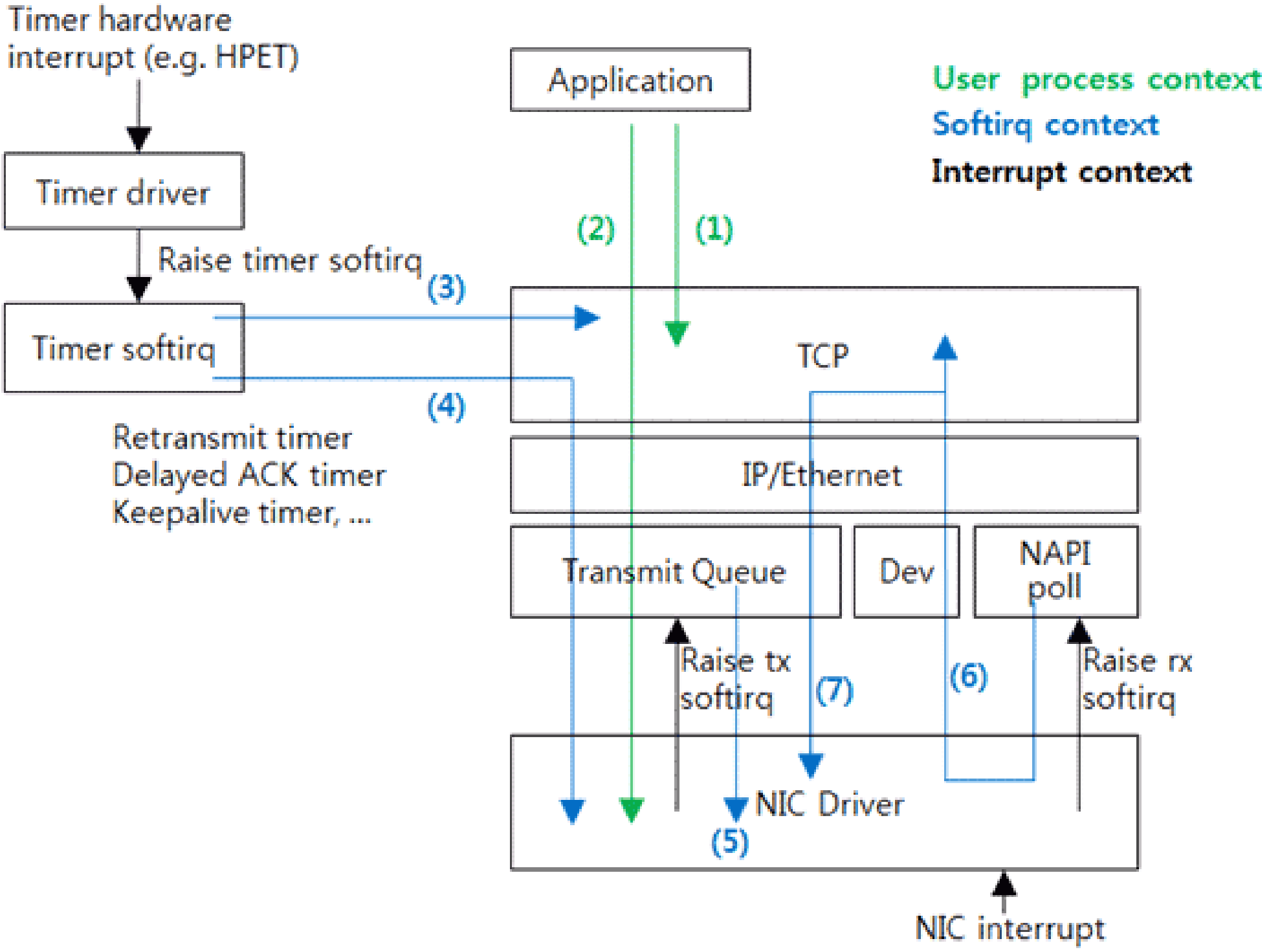
- softirq that processes the received packet, calls the driver, and transmits the received packet to upper layer.
- In Linux, processing the received packet this way is called **New API (NAPI)**.
- It is similar to polling because the driver does not directly transmit the packet to the upper layer, but the upper layer directly gets the packet.
- The actual code is called NAPI poll or poll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Flow 6

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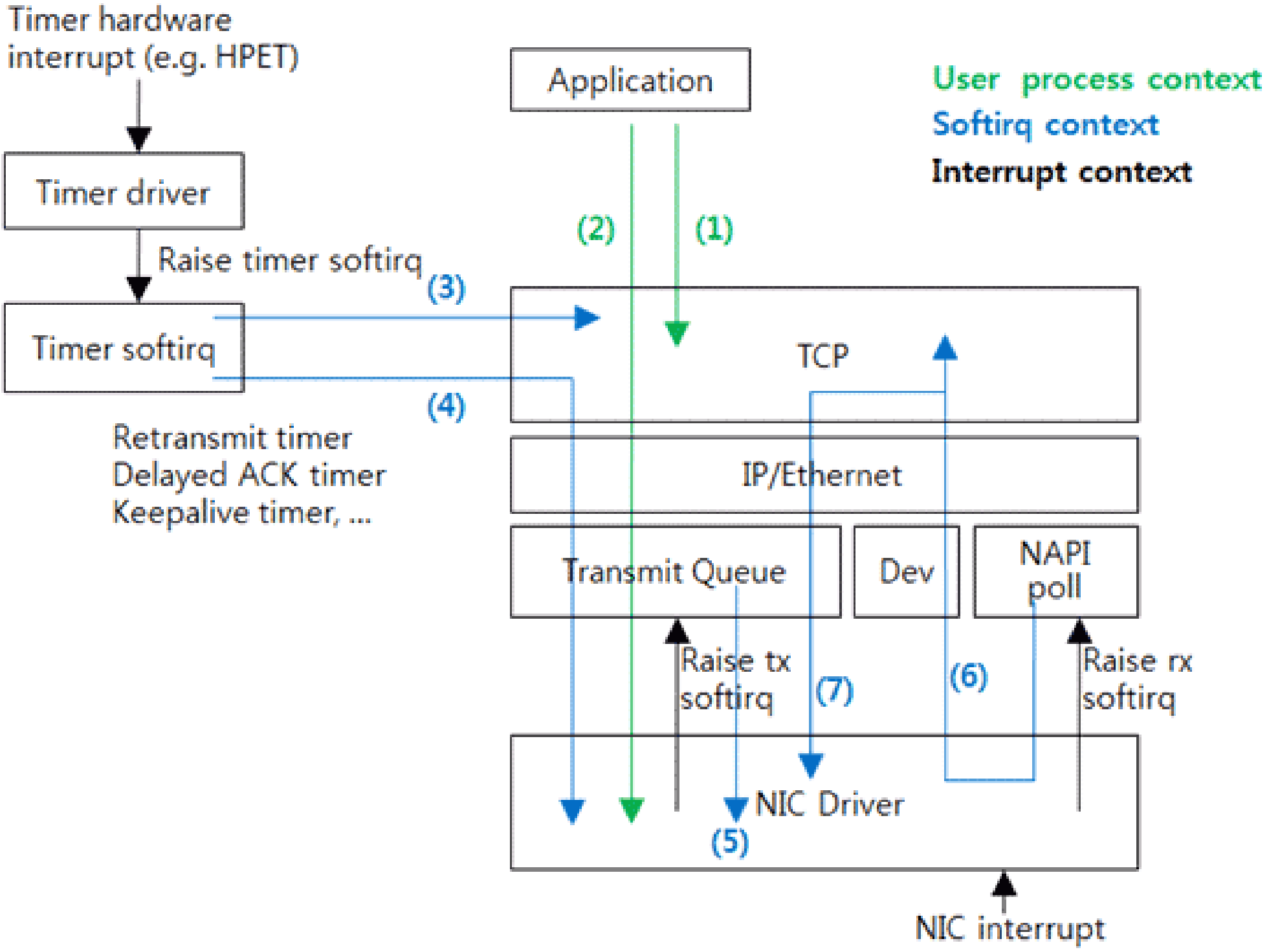
- Shows the case that completes execution of TCP.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Flow 7

Flow 7

- Shows the case that requires additional packet transmission.

Flow 7

- Shows the case that requires additional packet transmission.
- All of **Flow (5), (6), and (7)** are executed by the **softirq** which has processed the NIC interrupt.

How to Process Interrupt and Received Packet - 1

Next slide, shows the procedure of processing an interrupt

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- CPU executes the kernel interrupt (called irq) handler.

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- Driver frees the packet transmitted and then calls the **napi_schedule()** function to process the received packet.

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- This handler refers to the interrupt number and then calls the driver interrupt handler.
- Driver frees the packet transmitted and then calls the **napi_schedule()** function to process the received packet.
- This function requests the softirq (software interrupt).

How to Process Interrupt and Received Packet - 2

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How to Process Interrupt and Received Packet - 2

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- The kernel handler executes the interrupt handler for the softirq.

How to Process Interrupt and Received Packet - 2

- After execution of the driver interrupt handler has been terminated, the control is passed to the kernel handler.
- The kernel handler executes the interrupt handler for the softirq.
- After the interrupt context has been executed, the softirq context will be executed.
- **Note:** Interrupt context and softirq context are executed by identical thread, however they use different stacks.
- **Note:** Interrupt context blocks hardware interrupts, however softirq context allows for hardware interrupts.

How to Process Interrupt and Received Packet - 3

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- The **poll()** function calls the **netif_receive_skb()** function and then sends the received packets one by one to the upper layer.
- After processing the softirq, the application restarts execution from the stopped point in order to request a system call.

How to Process Interrupt and Received Packet - 4

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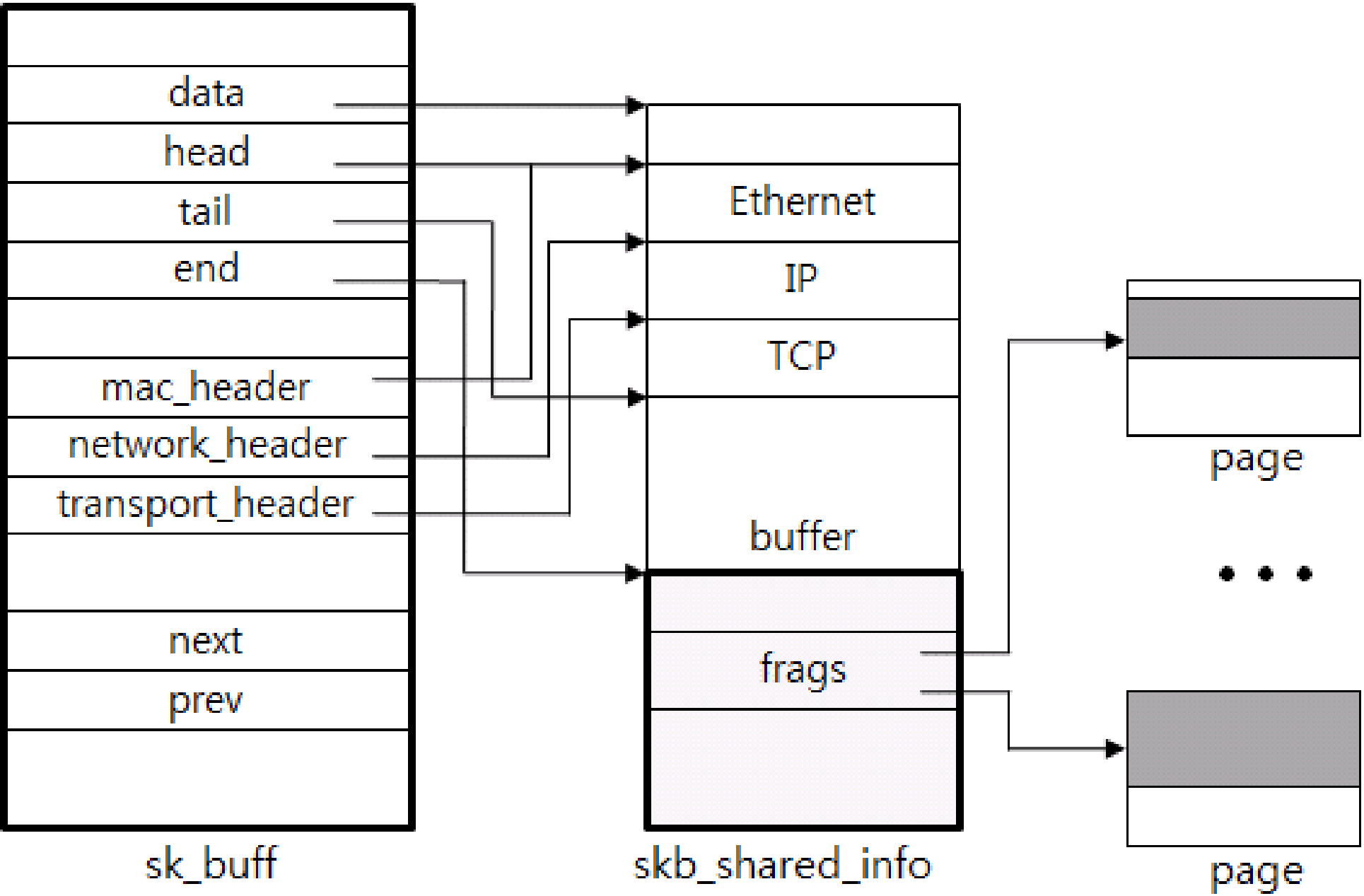
- The phenomenon occurs due to the way of processing received packets explained so far.
- To solve the problem, multi-queue NIC, RSS, and RPS have been developed.

Some Data Structures

The followings are some key data structures:

- sk_buff structure
- TCP Control Block
- net_device structure (NIC - skipped)
- TCP Connection Lookup Table


data
head
tail
end
mac_header
network_header
transport_header
next
prev
sk_buff
Ethernet
IP
TCP
buffer
frags
skb_shared_info
page
page

sk_buff

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- Basic functions are:
  - Including Packet Data and *meta data*
  - How to Add or Delete a Header
  - How to Combine and Divide Packet
  - Quick Allocation and Free

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- Pointers point to the starting position of Ethernet header, IP header, and TCP header respectively.
- This way makes TCP protocol processing easy.

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- For example, to remove the Ethernet header, just increase the head pointer.

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- The next pointer and pre pointer are used for this purpose.

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- For example, if data is transmitted at the speed of 10-Gigabit Ethernet, more than one million packets per second must be created and deleted.

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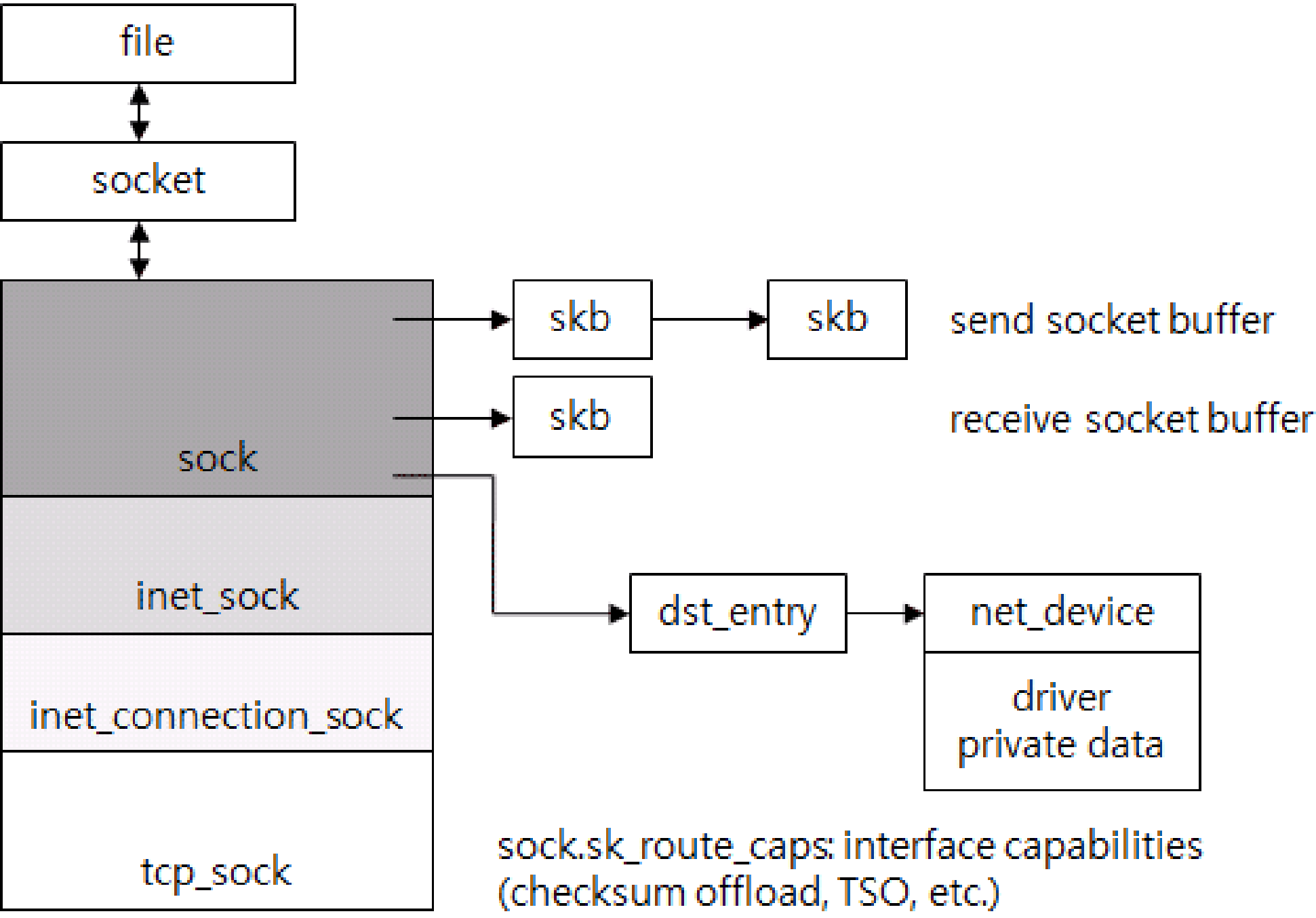
- Here is the relationship among the file, the socket, and the tcp_sock.


file
socket
sock
inet_sock
inet_connection_sock
tcp_sock
skb
skb
skb
send socket buffer
receive socket buffer
dst_entry
net_device
driver
private data
sock.sk_route_caps: interface capabilities
(checksum offload, TSO, etc.)

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- The socket refers to the **tcp_sock** again.
- **tcp_sock** is classified into **sock, inet_sock**, etc. to support various protocols except TCP (kind of polymorphism).

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- NIC is expressed as the **net_device** structure.

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- Hash function has been selected by considering defense against attacks to the hash table.

Next Week InchALLAH

Next Lecture

- Following Code
- Lab setup
- Basic *nix Networking commands
- Socket Programming in C++

Next Lab

- **Continue** Review TCP/IP Suite (Solve selected Qs)
- Qs can be found at `http://technologyeye.weebly.com/uploads/9/6/1/4/9614102/interview_question_networkingrajkumar.pdf`

Homework

- Study this lecture (very well)
- Prepare for the Next Lecture
- Check some Kernel code (mainly Networking Subsystem)
- Study the Lab file
- Check the github Course repository


YOU GO
NOW!