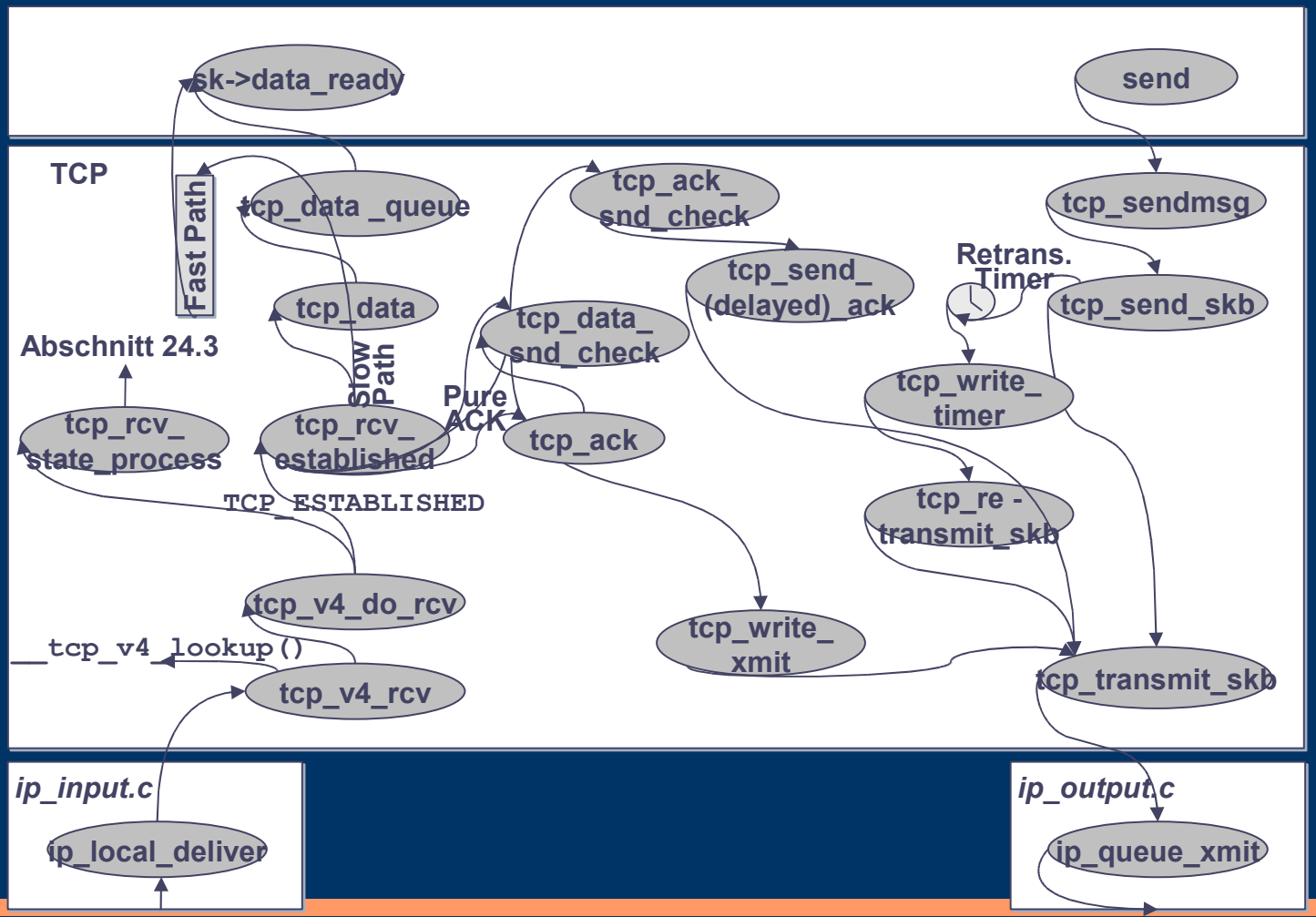
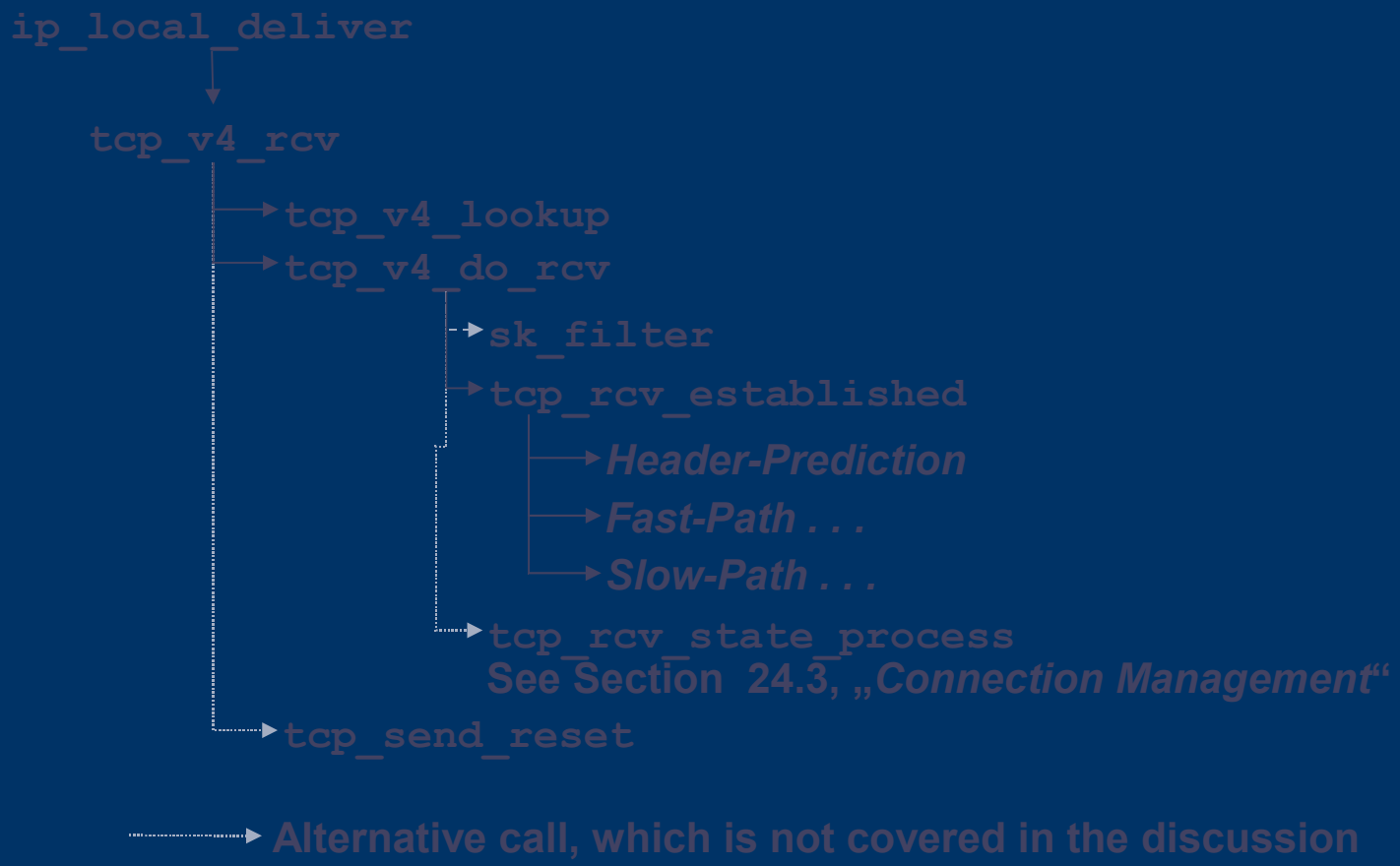
# TCP Implementation in Linux



# *tcp_v4_rcv(skb,len)*

- Checks if the packet is really addressed to the host (*skb→ pkt_type == PACKET_HOST*). If not, the packet is discarded.
- Invokes *tcp_v4_lookup()* to search the hash table of active sockets for the matching sock structure.
  - Source/destination IP addresses and ports and the network device index skb→dst→rt_iif at which the segment arrive are used to index into the hash table.
- If a matched sock structure is located, *tcp_v4_do_rcv()* is invoked; otherwise, *tcp_send_reset()* sends a *RESET* segment.

# *Process of Receiving a Segment*



# *tcp_v4_do_rcv()*

- If the TCP state (sk→state) is
  - TCP_ESTABLISHED, invokes *tcp_rcv_established()*.
  - One of the other states, invokes *tcp_rcv_state_process()*, i.e., the TCP state machine will be examined to determine state transition.

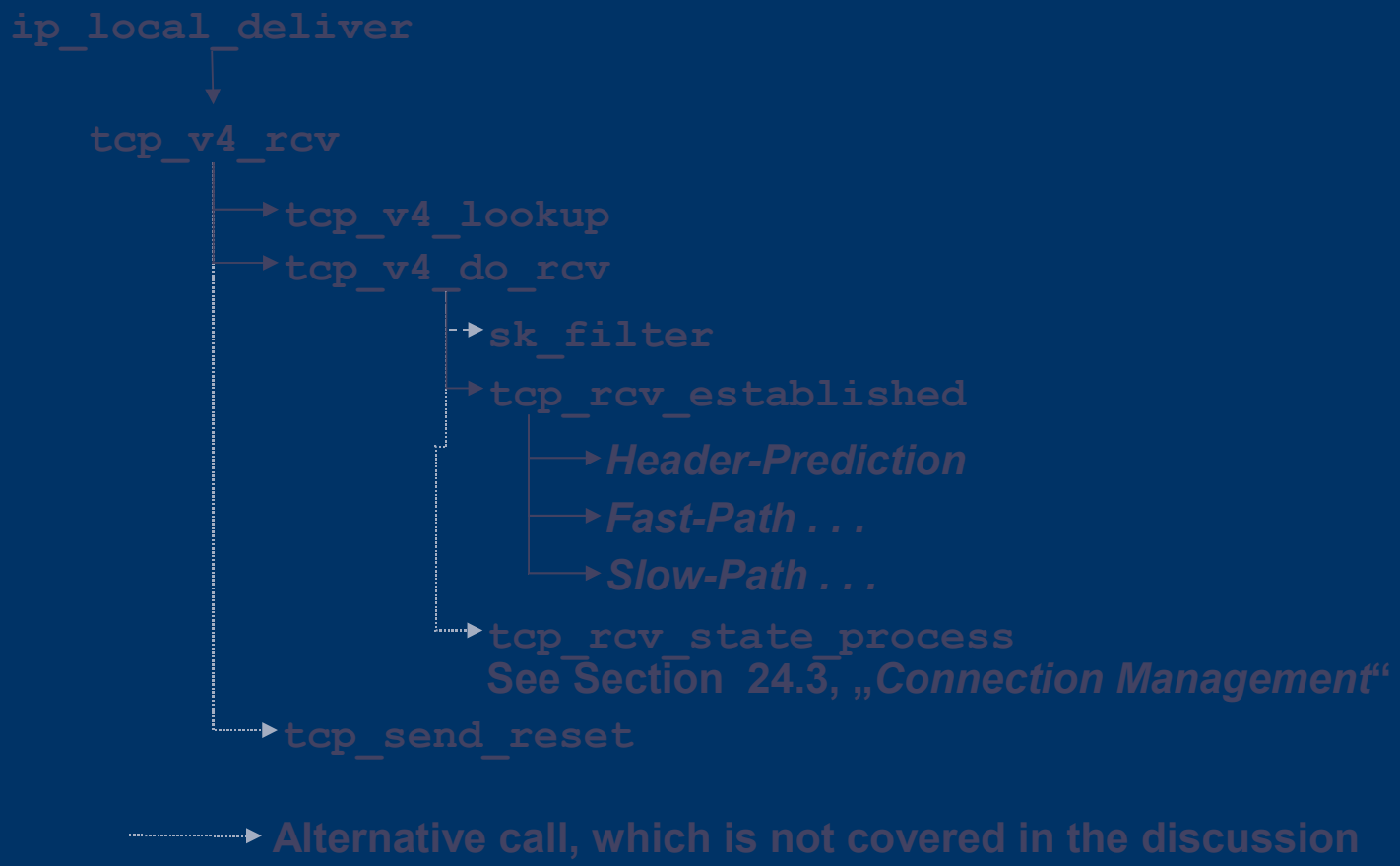
# *tcp_rcv_established(sk,skb,th,len)*

- Dispatches packets to *fast path* or *slow path*
- Packets are processed in fast path if
  - The segment received is a pure ACK segment for the data sent last.
  - The segment received contains the data expected.

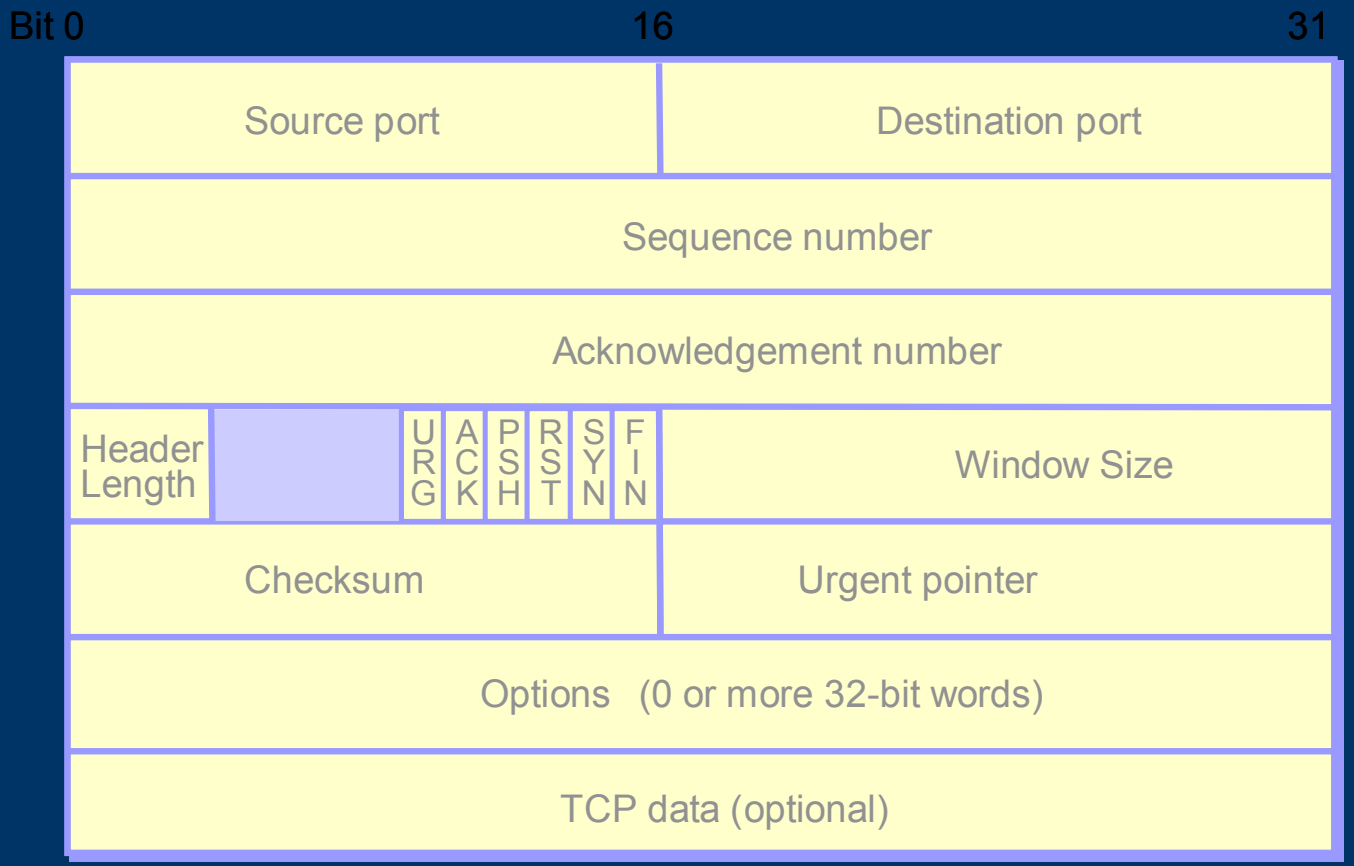
# *tcp_rcv_established(sk,skb,th,len)*

- Packets are processed in slow path if
  - If SYN, URG, FIN, RST flag is set (detected in *Header Prediction*).
  - The SN of the segment does not correspond to *tp→ rcv_nxt*.
  - The communication is two-way.
  - The segment contains a zero window advertisement.
  - The segment contains TCP options other than the timestamp option.

# *Process of Receiving a Segment*



# Header Prediction (TCP Header)



# *Header Prediction*

```
if ((tcp_flag_word(th) & TCP_HP_BITS) == tp->pred_flags &&
        TCP_SKB_CB(skb)->seq == tp->rcv_nxt)
 { (… FAST PATH…) }
Else
{ (… SLOW PATH…) }
```

Note that

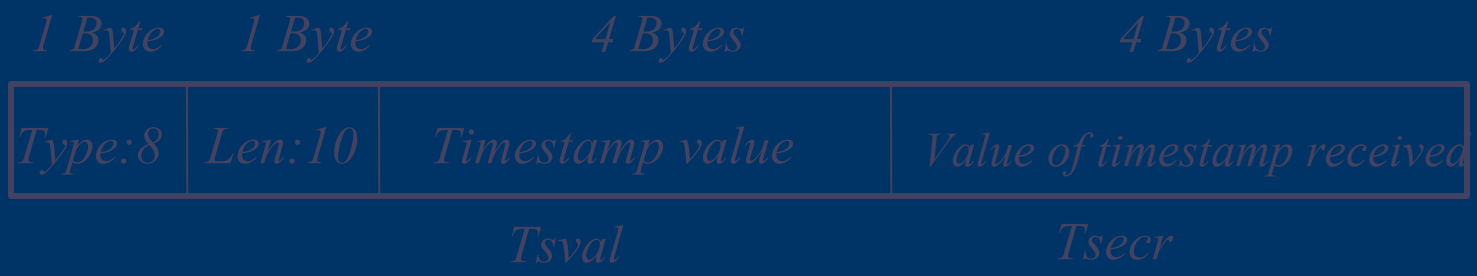
7. #define TCP_HP_BITS (~(TCP_RESERVED_BITS|TCP_FLAG_PSH))
8. tp->pred_flags is set in *tcp_fast_path_on()*

# Header Prediction

```
static __inline__ void __tcp_fast_path_on(struct tcp_opt *
    tp, u32 snd_wnd)
  {
     tp->pred_flags = htonl((tp->tcp_header_len << 26) |
    ntohl(TCP_FLAG_ACK) | snd_wnd);
  }
static __inline__ void tcp_fast_path_on(struct tcp_opt *tp
    )
 {
__tcp_fast_path_on(tp, tp->snd_wnd>>tp->snd_wscale);
 }
```

# Fast Path in tcp_rcv_established()

1. *TCP_SKB_CB(skb)→seq == tp→rcv_nxt?* If so, proceed.
2. Checks if the timestamp option exists. If so,
   - the timestamp value, *Tsval* and *Tsecr* are read.
   - If the condition to update the *tp→ts_recent* timestamp is met (i.e., *tp->rcv_tsval - tp->ts_recent) < 0* ), the values are accepted by *tcp_store_ts_recent()*.



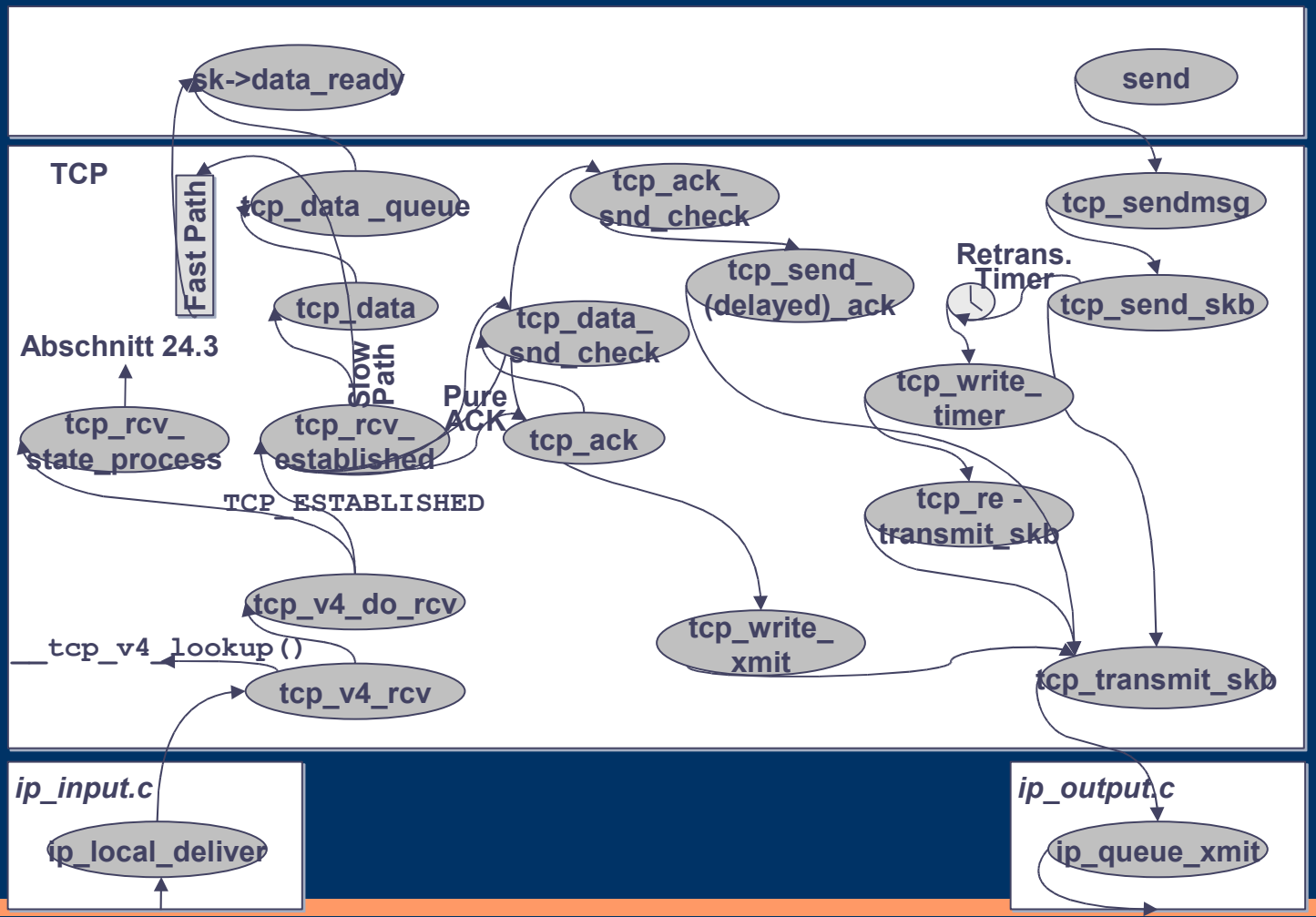
# *Fast Path in tcp_rcv_established()*

1. packet header length == segment length?
2. Yes → ACM segment
   - Invokes *tcp_ack()* to process the ack.
   - Invokes *__kfree_skb()* to release the socket buffer
   - Invokes *tcp_data_snd_check()* to check if local packets can be sent (because of the send quota induced by the ack).

# *Fast Path in tcp_rcv_established()*

1. No → Data segment
   - If the payload can be copied directly into the user space,
     - the statistics of the connection are updated
     - the relevant process is informed
     - the payload is copied into the receive memory of the process
     - The sequence number expected next is updated
   - If the payload *cannot* be copied directly
     - Checks if the receive buffer for the socket is sufficient
     - The statistics of the connection are updated
     - The segment is added to the end of the receive queue of the socket
     - The sequence number expected next is updated.

# TCP Implementation in Linux



# *Fast Path in tcp_rcv_established()*

1. No → Data segment (cont'd)
   - Invokes *tcp_event_data_rcv()* to carry out various management tasks
   - If the segment contains an ack, then invoke *tcp_ack()* to process the ack and *tcp_data_snd_check()* to initiate transmission of waiting local data segments.
   - Checks if an ack has to be sent back in response to receipt of the segment, in the form of Delayed ACK or Quick ACK mode.

# *Helper Function – tcp_ack()*

1. Adapt the receive window (*tcp_ack_update_window()*)
2. Delete acknowledged packets from the retransmission queue (*tcp_clean_rtx_queue()*)
3. Check for zero window probing acknowledgement.
4. Update RTT and RTO.
5. Activate the fast retransmit mode if necessary.

# Helper Function – tcp_data_snd_check()

- *tcp_data_snd_check()* checks if local data in the transmit queue can be transmitted (as allowed by the sliding windows)

```
static __inline__ void tcp_data_snd_check(struct sock *sk)
{
    struct sk_buff *skb = sk->tp_pinfo.af_tcp.send_head;
     struct tcp_opt *tp = &(sk->tp_pinfo.af_tcp);
    if (skb != NULL)
    {
    if (after(TCP_SKB_CB(skb)->end_seq, tp-      >snd_una + tp-
    >snd_wnd) ||            tcp_packets_in_flight(tp) >= tp->snd_cwnd ||
            tcp_write_xmit(sk, tp->nonagle))
            tcp_check_probe_timer(sk, tp);
    }
    tcp_check_space(sk);
}
```

# Slow Path

- Checks the checksum.
- Checks the timestamp option via *tcp_fast_parse_options();* performs PAWS check via *tcp_paws_discard();*
- Invokes *tcp_sequence()* to check if the packet arrived out of order, and if so, activate the *QuickAck* mode to send acks asap.
- If RST is set, invoke *tcp_reset()* to reset the connection and free the socket buffer.
- If the TCP header contains a timestamp option, update the recent timestamp stored locally with *tcp_replace_ts_recent()*.

# *Slow Path*

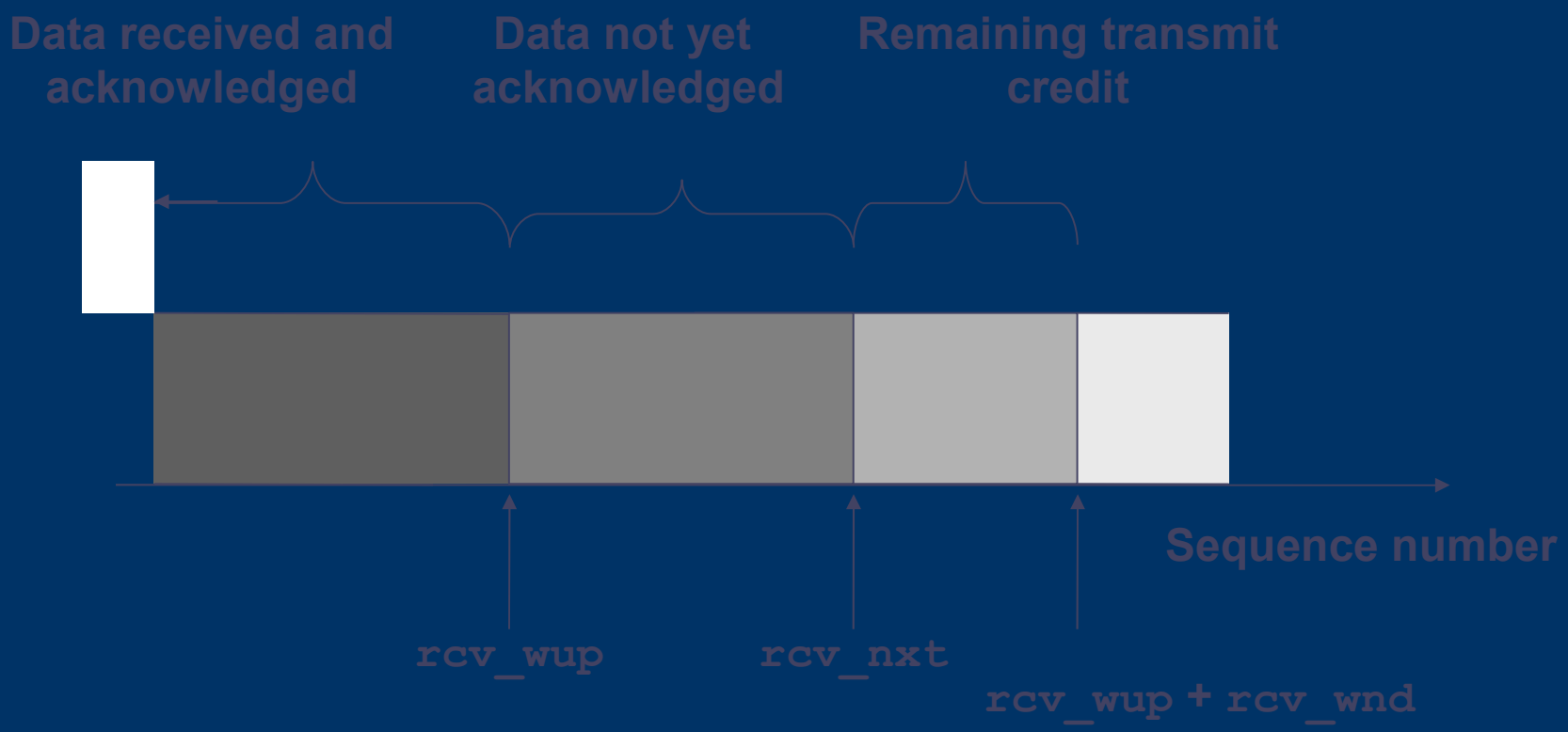
- If *SYN* is set to signal an error in an established connection, invokes *tcp_reset()* to reset the connection.
- If *ACK* is set, invoke *tcp_ack()* to process the ack.
- If *URG* Is set, invoke *tcp_urg()* to process the priority data.
- Invokes tcp_data() and tcp_data_queue() to process the payload.
  - Checks if the receive queue of the sock structure has sufficient space.
  - Inserts the segment into the receive queue or the out of order queue.
- Invokes *tcp_data_snd_check()* and *tcp_ack_snd_check()* to check whether data or acks waiting can be sent.

# Helper Function – tcp_ack_snd_check()

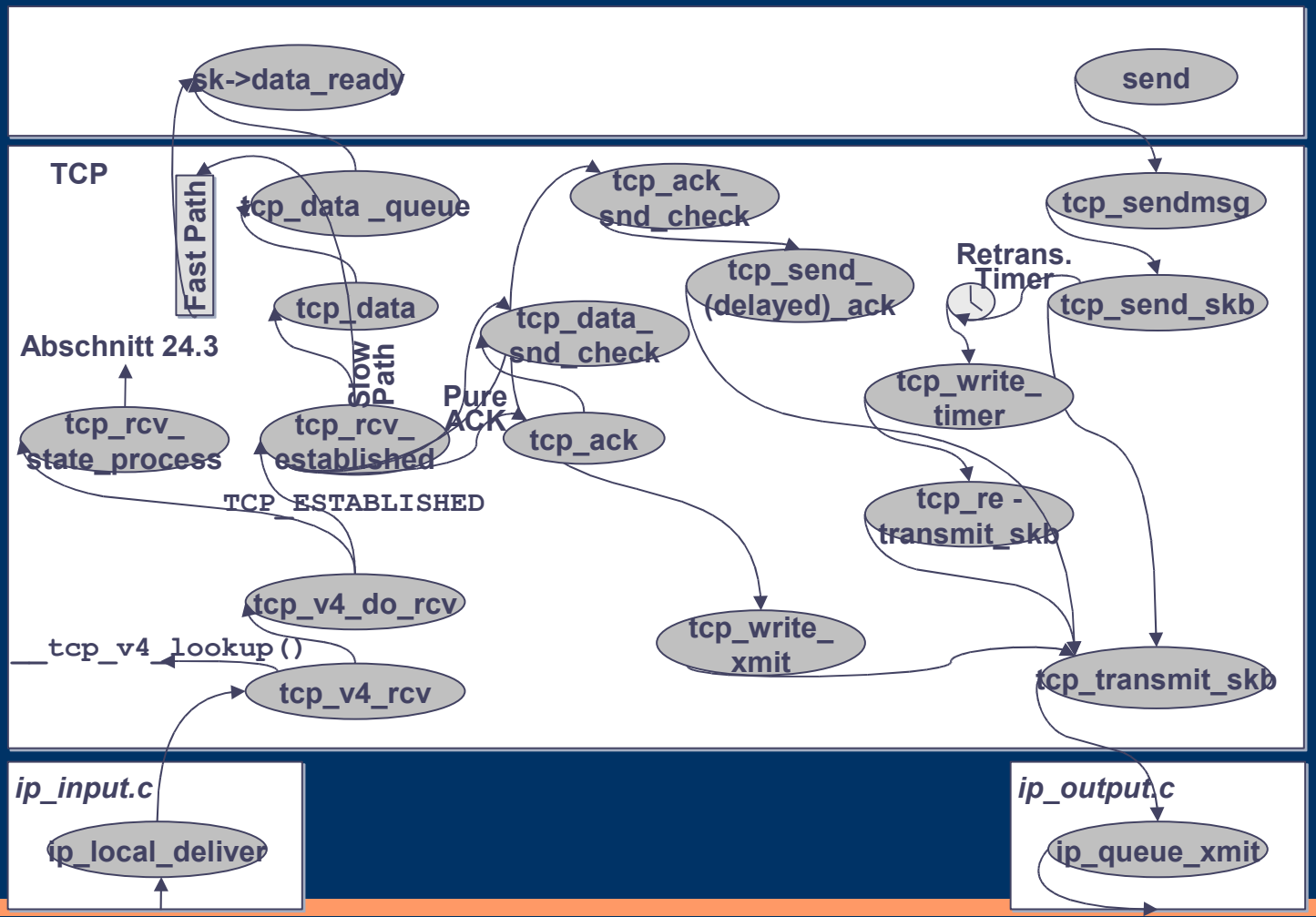
- *tcp_ack_snd_check(sk)* checks for various canses where acks can be sent.

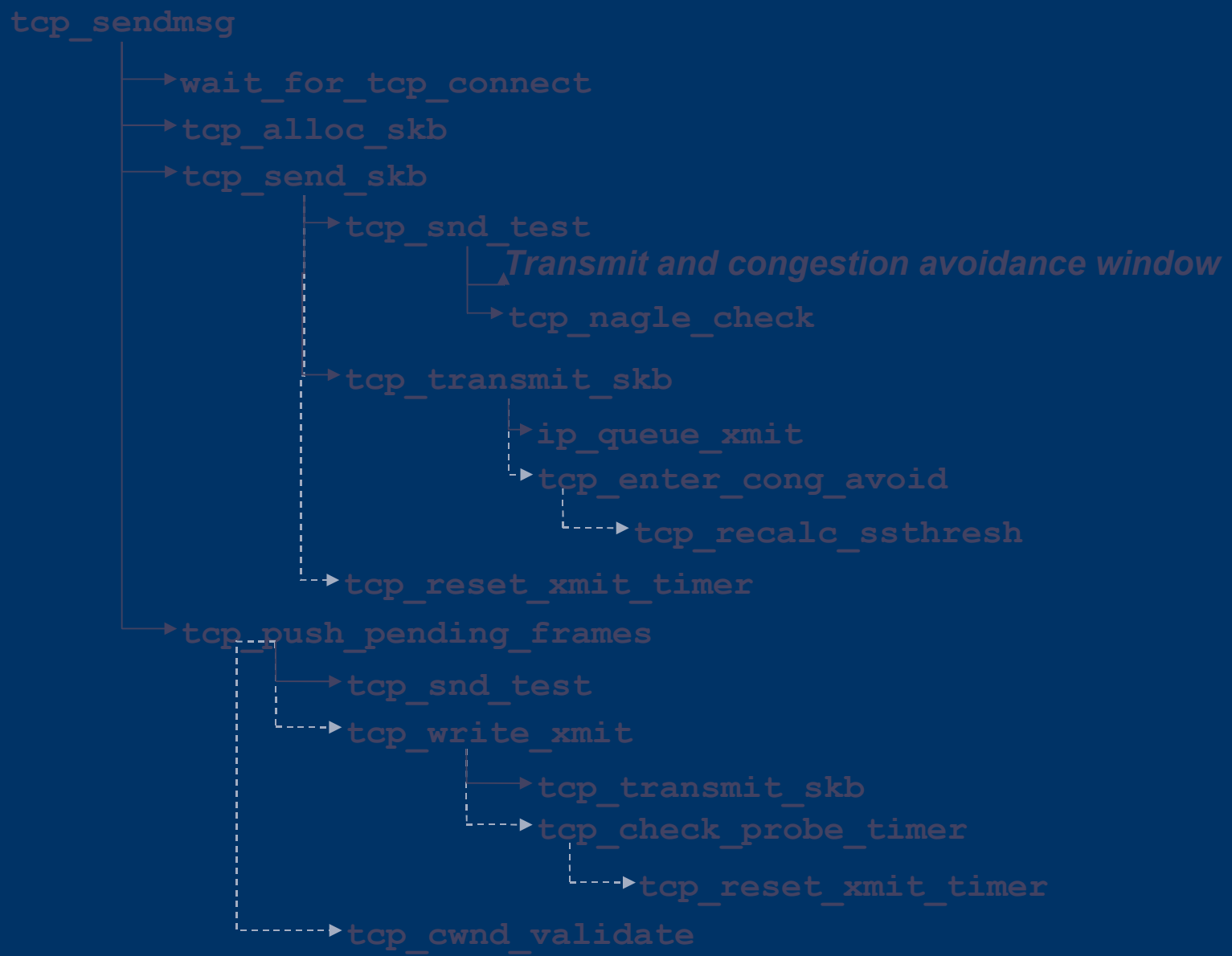
```
static __inline__ void tcp_ack_snd_check(struct sock *sk)
 {
      struct tcp_opt *tp = &(sk->tp_pinfo.af_tcp);
      if (!tcp_ack_scheduled(tp)) { * We sent a data segment already. */
              return;
      }
      /* More than one full frame received... */
      if (((tp->rcv_nxt - tp->rcv_wup) > tp->ack.rcv_mss
      /* ... and right edge of window advances far enough. */
      && __tcp_select_window(sk) >= tp->rcv_wnd) ||
      /* We ACK each frame or  we have out of order data*/
      tcp_in_quickack_mode(tp) || (skb_peek(&tp->out_of_order_queue) != NULL))
      {         /* Then ack it now */
              tcp_send_ack(sk); 3890
      } else { /* Else, send delayed ack. */
              tcp_send_delayed_ack(sk);
      }
 }
```

# *Window Kept at the Receiver*



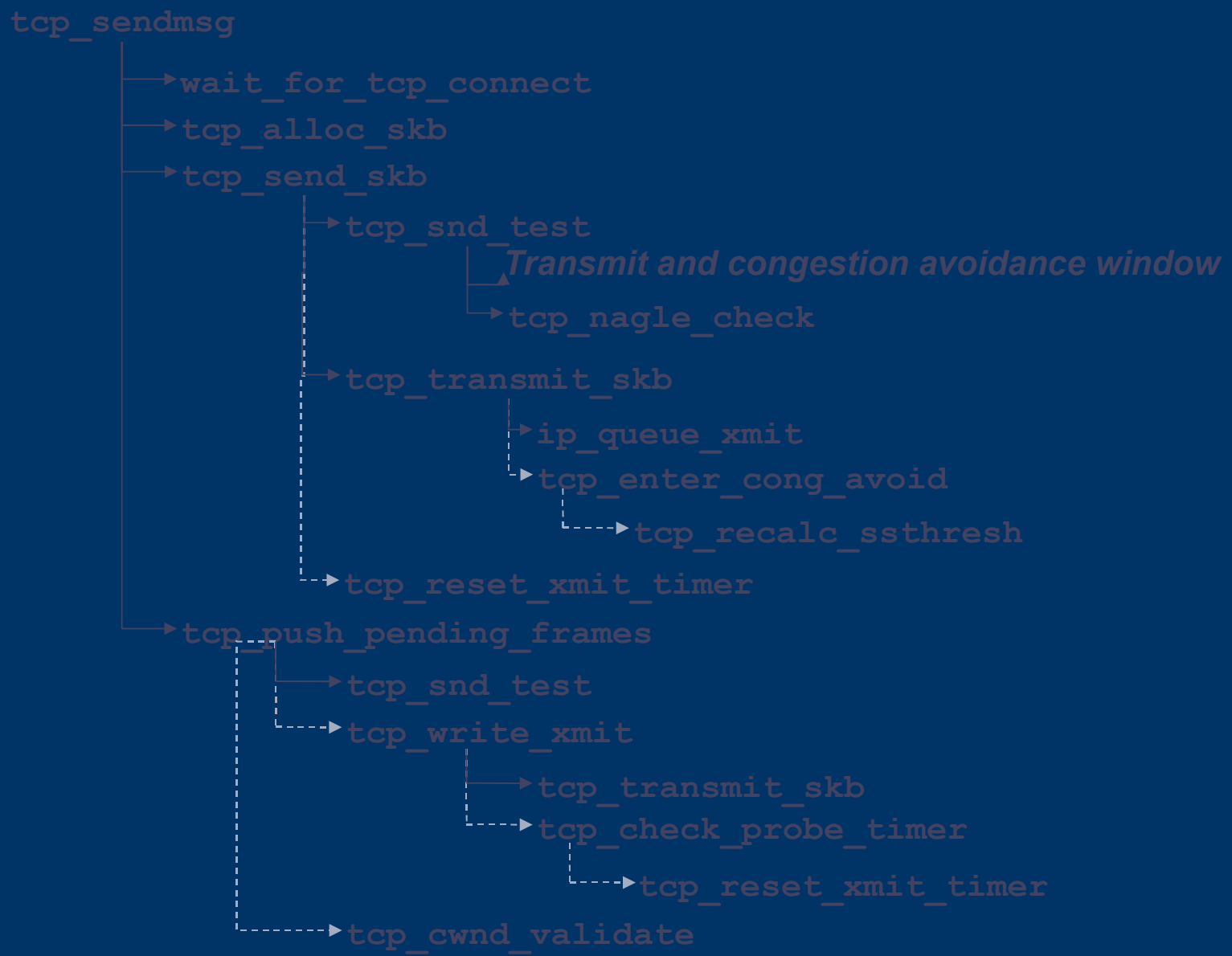
# TCP Implementation in Linux




tcp_sendmsg
wait_for_tcp_connect
tcp_alloc_skb
tcp_send_skb
tcp_snd_test
Transmit and congestion avoidance window
tcp_nagle_check
tcp_transmit_skb
ip_queue_xmit
tcp_enter_cong_avoid
tcp_recalc_ssthresh
tcp_reset_xmit_timer
tcp_push_pending_frames
tcp_snd_test
tcp_write_xmit
tcp_transmit_skb
tcp_check_probe_timer
tcp_reset_xmit_timer
tcp_cwnd_validate

# *tcp_sendmsg()*

- *tcp_sendmsg(sock,msg,size)* copies payload from the user space into the kernel space and send it in the form of TCP segments.
  1. Checks if the connection has already been established. If not, invokes *wait_for_tcp_connect().*
  2. Computes the maximum segment size (*tcp_current_mss*).
  3. Invokes *tcp_alloc_skb()* and copies the data from the user space.
  4. Invokes *tcp_send_skb()* to put the socket buffer in the transmit queue of the sock structure.
  5. Invokes –*tcp_push_pending_frames()* to take segments from *tp→write_queue* and transmit them.


tcp_sendmsg
wait_for_tcp_connect
tcp_alloc_skb
tcp_send_skb
tcp_snd_test
Transmit and congestion avoidance window
tcp_nagle_check
tcp_transmit_skb
ip_queue_xmit
tcp_enter_cong_avoid
tcp_recalc_ssthresh
tcp_reset_xmit_timer
tcp_push_pending_frames
tcp_snd_test
tcp_write_xmit
tcp_transmit_skb
tcp_check_probe_timer
tcp_reset_xmit_timer
tcp_cwnd_validate

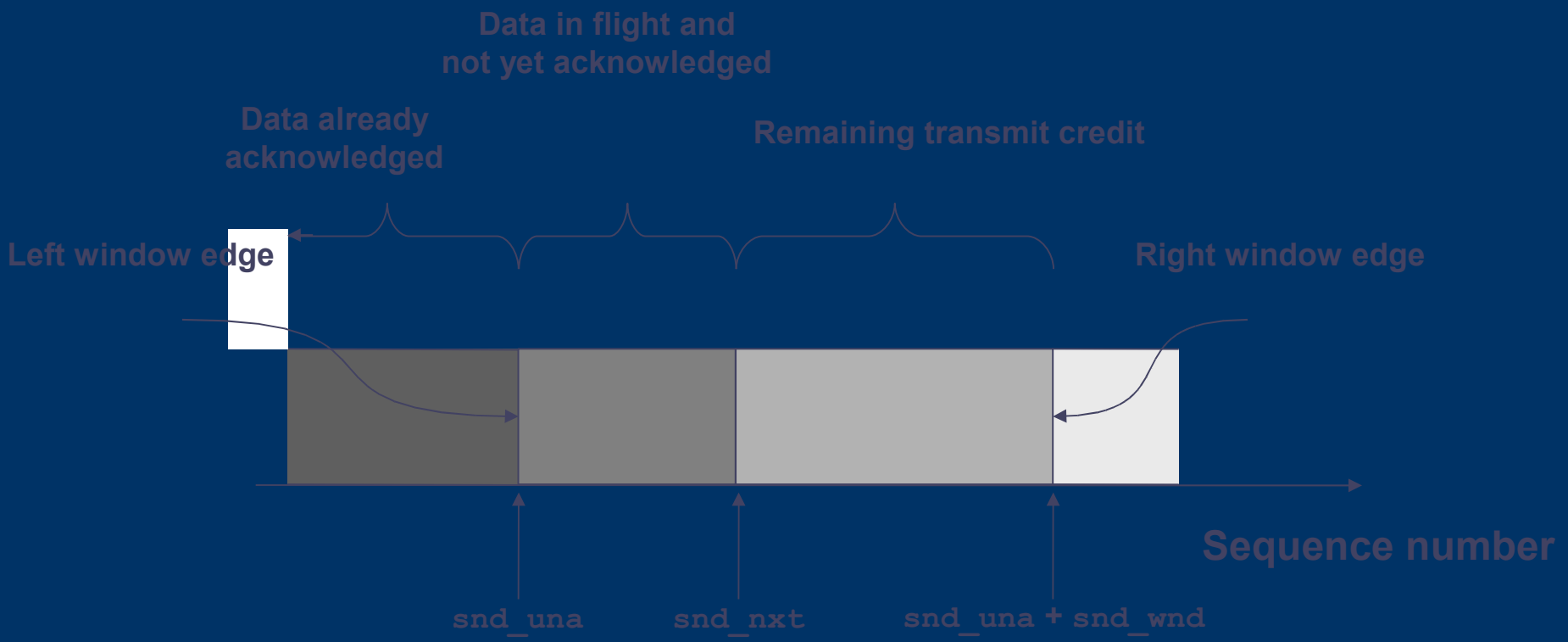
# *tcp_send_skb()*

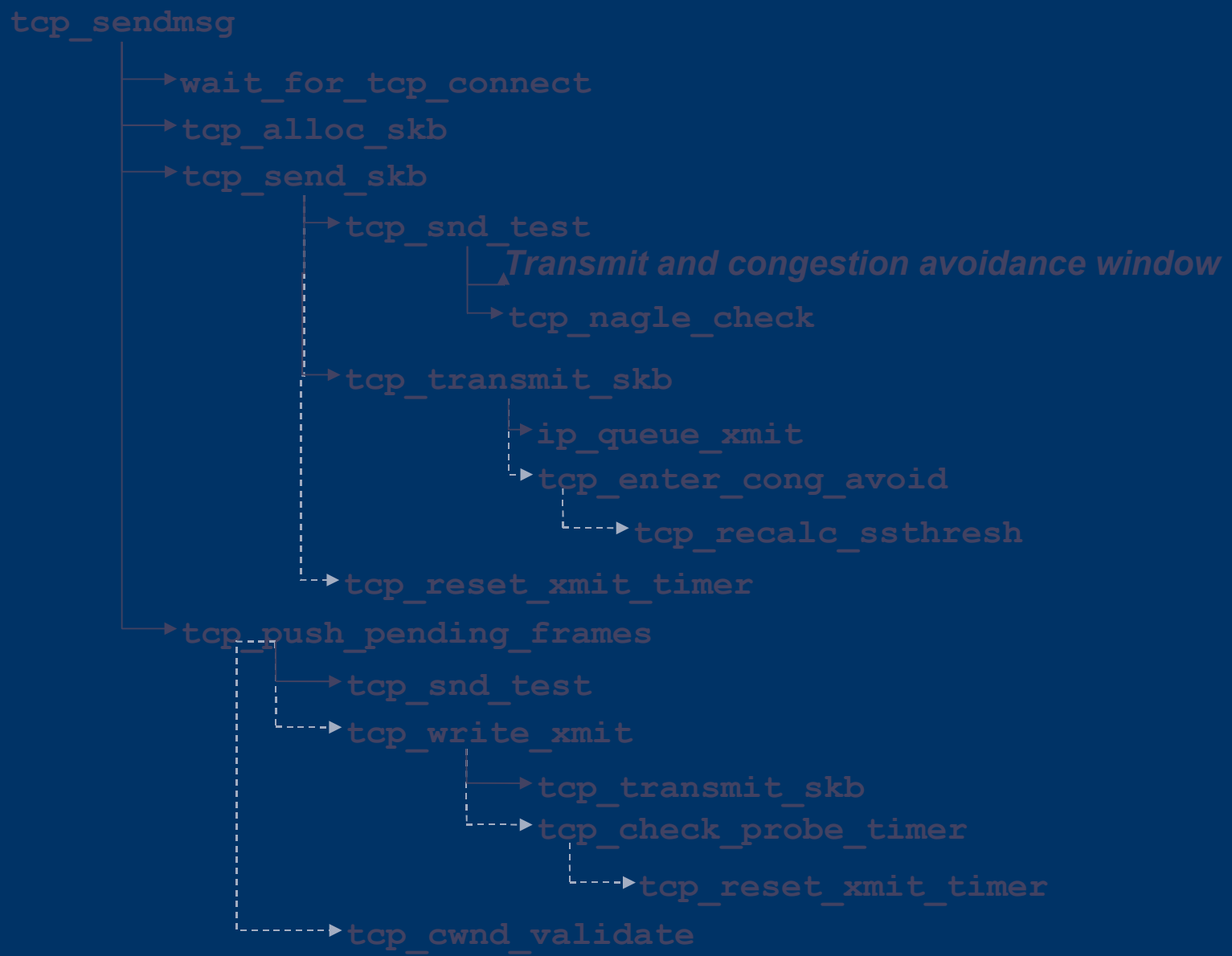
1. Adds the socket buffer, *skb*, to the transmit queue *sk→write_queue*
2. Invokes *tcp_snd_test()* to determine if the transmission can be started.
3. If so, invokes tcp_transmit_skb() to pass the segment to the IP layer.
4. Invokes *tcp_reset_xmit_timer()* for automatic retransmission.

# tcp_snd_test()

```
static __inline__ int tcp_snd_test(struct tcp_opt *tp, struct
        sk_buff *skb, unsigned cur_mss, int nonagle)
{
        return ((nonagle==1 || tp->urg_mode || !tcp_nagle
        _check(tp, skb, cur_mss, nonagle)) &&
       ((tcp_packets_in_flight(tp) < tp->snd_cwnd) ||
         (TCP_SKB_CB(skb)->flags & TCPCB_FLAG_FIN))
       && !after(TCP_SKB_CB(skb)->end_seq, tp->snd_una
        + tp->snd_wnd));
}
```

# Window Kept at the Sender




tcp_sendmsg
wait_for_tcp_connect
tcp_alloc_skb
tcp_send_skb
tcp_snd_test
Transmit and congestion avoidance window
tcp_nagle_check
tcp_transmit_skb
ip_queue_xmit
tcp_enter_cong_avoid
tcp_recalc_ssthresh
tcp_reset_xmit_timer
tcp_push_pending_frames
tcp_snd_test
tcp_write_xmit
tcp_transmit_skb
tcp_check_probe_timer
tcp_reset_xmit_timer
tcp_cwnd_validate

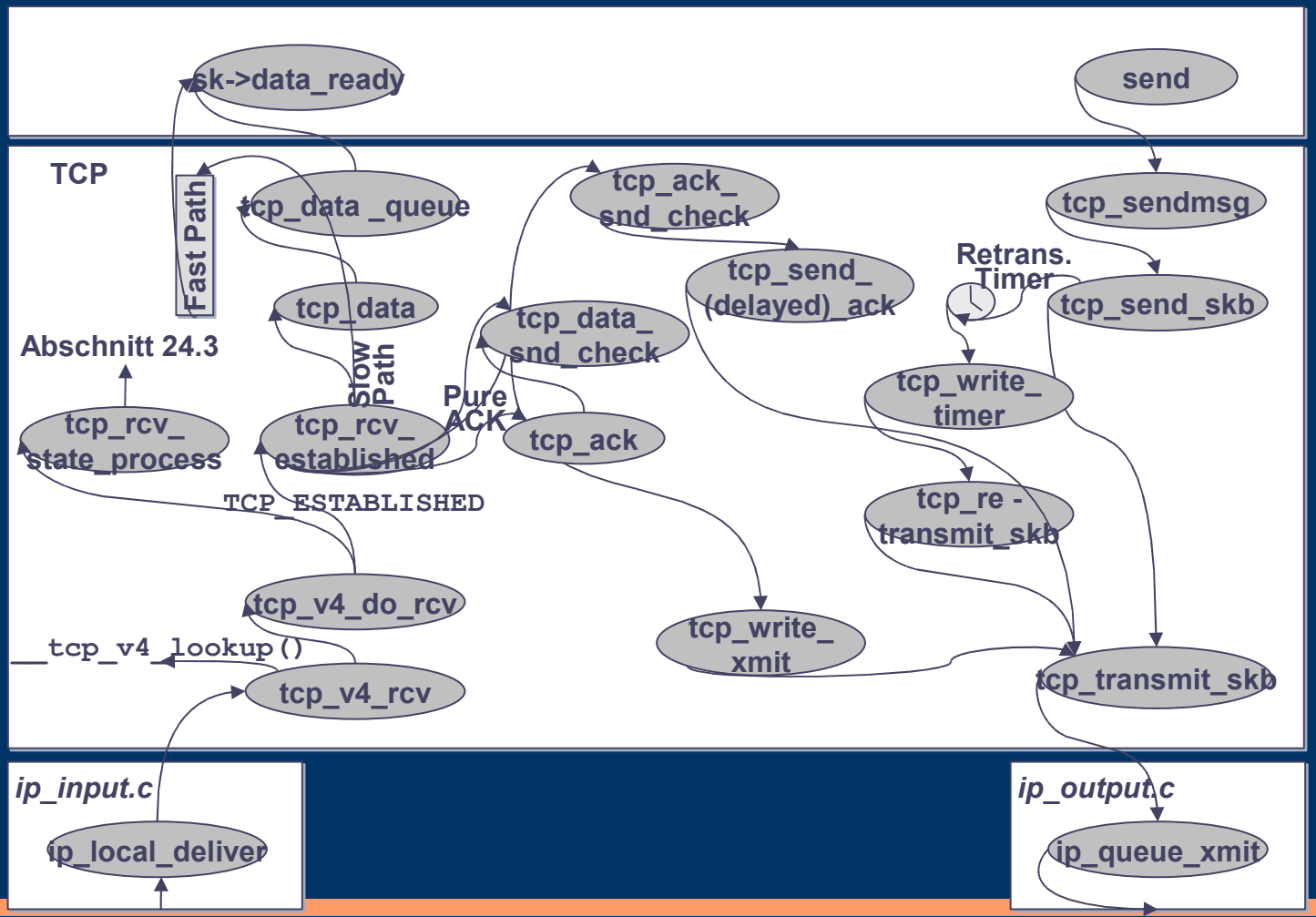
# *tcp_transmit_skb()*

1. Fills the TCP header with the appropriate values from the *tcp_opt* structure.
2. Invokes *tcp_syn_build_options()* to register the TCP options for a SYN packet and *tcp_build_and_update_options()* to register the option for all other packets.
3. If ACK is set, the number of permitted *QuickAck* packets is decremented in *tcp_event_ack_sent()* method. The timer for delayed ACKs is stopped.
4. If the segment contains payload, checks if the retransmission timer has expired. If so, the congestion window, *snd_cwnd*, is set to the minimum value (*tcp_cwnd_restart*).

# *tcp_transmit_skb()*

1. Invokes *tp→af_specific→queue_xmit()* (i.e., *ip_queue_xmit()* for IPv4) to pass the socket buffer to the IP layer.
2. Invokes *tcp_enter_cwr()* to adapt the threshold value for the slow start algorithm (if the segment is the first segment of a connection).

# TCP Implementation in Linux



# *tcp_push_pending_frames()*

```
struct sk_buff *skb = tp->send_head;

 if (skb) {
       if (!tcp_skb_is_last(sk, skb))
                  nonagle = 1;
       if (!tcp_snd_test(tp, skb, cur_mss, nonagle) ||  tcp
       _write_xmit(sk, nonagle))
                  tcp_check_probe_timer(sk, tp);
 }
tcp_cwnd_validate(sk, tp);
```

**Continues to send segments from the transmit queue of sk, as long as it is allowed by tcp_snd_test()**