Networking, USB, and Threads

CSEE W4840

Prof. Stephen A. Edwards

Columbia University

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Ethernet and the Internet

Sockets

USB: The Universal Serial Bus

libusb 1.0

POSIX Threads (pthreads)

Ethernet and the Internet

Ethernet

Started in about 1976 at Xerox PARC

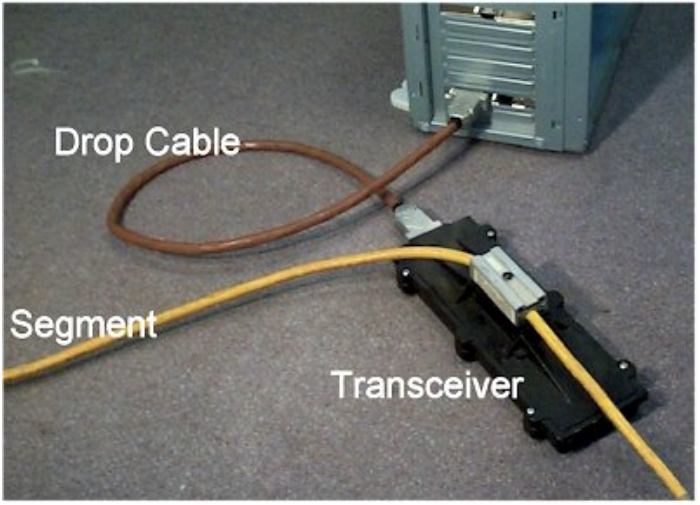
IEEE Standard 802.3

Carrier-sense multiple access/carrier detect protocol:

1. Listen to the cable
2. If nobody's there, start talking
3. If someone interrupts, stop, and retry after a random time

10Base-5 “Thicknet”

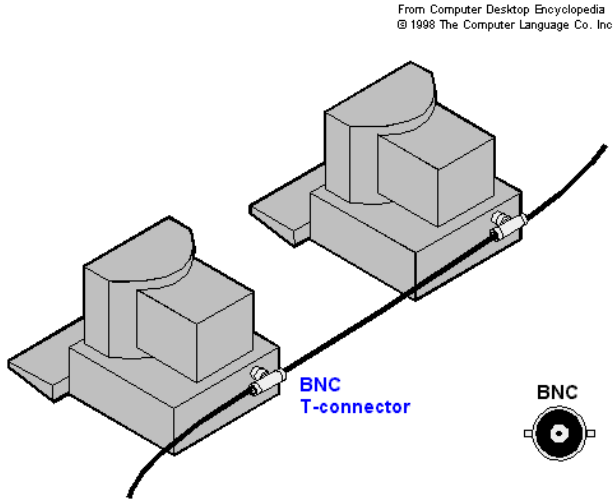
Shared coax bus with “vampire tap” tranceivers 802.3 std. suggests yellow



From http://www.turkcenet.org/yerel_htm/10base5.htm

10Base-2 “Thinnet”

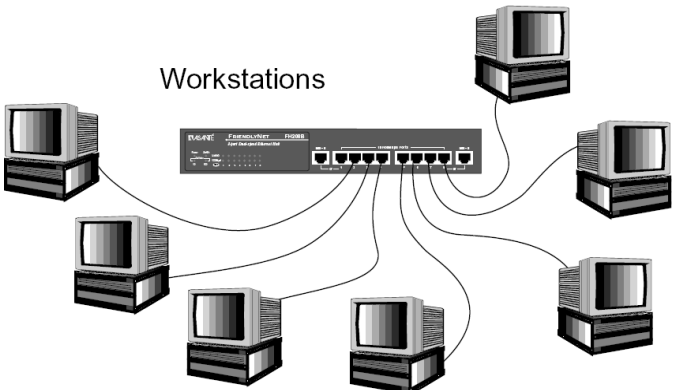
50-Ohm coax segments with BNC “T” connectors Coax invariably black



From http://www.answers.com/topic/10base2

10Base-T and 100Base-T

Put the shared medium in a hub: star topology



Star topology

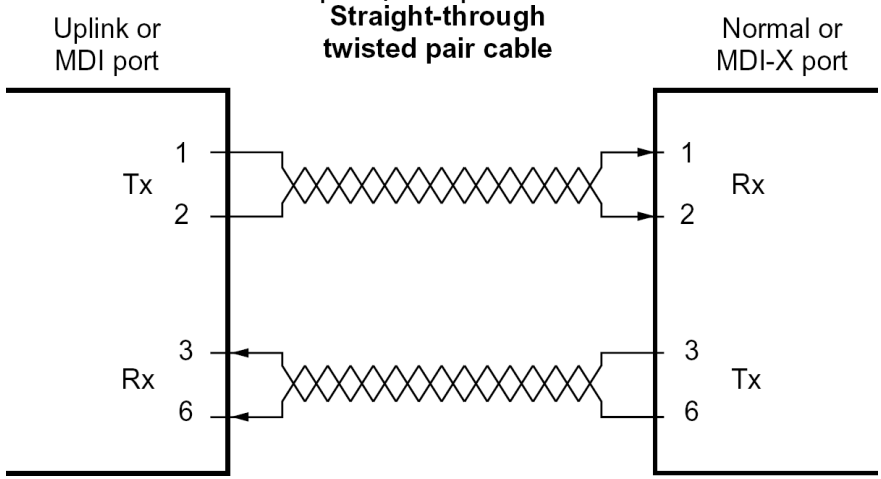
Everybody uses it now

Choice of colors

From http://www.asante.com/downloads/legacy/fh200bugra.pdf and http://www.connectworld.net/cables_u/patch-cable-manufacturer.html

100Base-TX wiring (CAT 5)

Pair of twisted pairs, one pair for each direction.

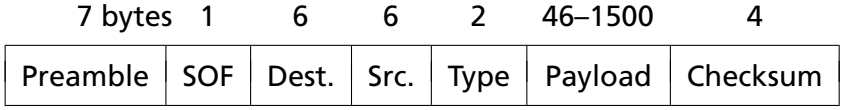


Hub-to-computer cable is straight-through.

Computer-to-computer cable is a “crossover;” most hardware can now adapt

From the Netgear FN104TP 4 port hub manual off of Amazon.com

An Ethernet Frame



SOF	Start of Frame
Dest.	Destination address
Src.	Source address
Type	Type of packet or length of data field 0x0800 for IP, 0x0806 for ARP, etc.

Bytes sent LSB first

Minimum packet length: 64 (6 + 6 + 2 + 46 + 4)

Lengths $>$ 1500 indicate packet type

Ethernet (MAC) addresses

48 bits $\approx$ 281 trillion (world population: 7.9 billion)

Bits 48–24	Vendor code (OUI)
Bit 41	0=ordinary, 1=group (broadcast) address
Bits 23–0	Serial number

On one of my machines:

```
$ ifconfig eth0
eth0 Ethernet HWaddr 00:18:f3:ef:2b:36
```

OUI (Organizationally Unique Identifier):

00:18:f3 is ASUS (the machine's motherboard manufacturer)

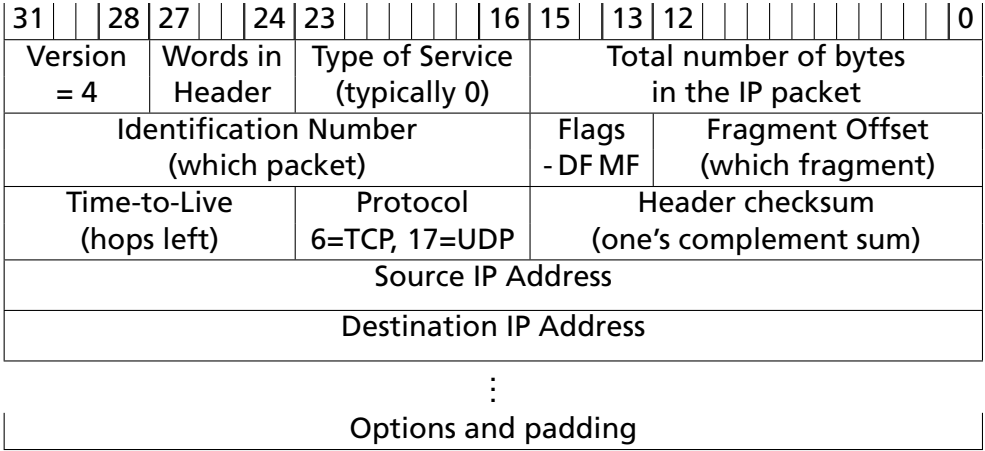
Address FF:FF:FF:FF:FF:FF is broadcast

An Ethernet Packet

00d006269c00	Destination MAC address (router)
00087423ccab	Source MAC address (desktop)
0800	Type = IP packet
45	IPv4, 5 word (20-byte) header
00	Normal service
0028	Total length = 40 bytes
c31c	Identification (unique)
4000	“Don’t Fragment”
40	64 hops to live
06	TCP protocol
3ff1	Header checksum (one’s complement)
803b1372	Source IP 128.59.19.114 (desktop)
40ec6329	Destination IP 64.236.99.41

deac 0050 bf49 9ba6 a1a4 8bed 5010 ffff 1093 0000 (payload)

IP Header


31 28 27 24 23 16 15 13 12 0
Version = 4
Words in Header
Type of Service (typically 0)
Total number of bytes in the IP packet
Identification Number (which packet)
Flags - DF MF
Fragment Offset (which fragment)
Time-to-Live (hops left)
Protocol 6=TCP, 17=UDP
Header checksum (one's complement sum)
Source IP Address
Destination IP Address
Options and padding

IP Addresses

32 bits $\approx$ 4 billion (world population: 7.9 billion)

First *n* bits indicate network (*n* = 8, 16, 24)

For example, columbia.edu
owns 128.59.0.0 – 128.59.255.255

Magical addresses:

127.0.0.1	"Me"
192.168.x.x	Never assigned worldwide
10.x.x.x	Never assigned worldwide
255.255.255.255	Broadcast

Sockets

Sockets

```
// Create an Internet socket (SOCK_STREAM = TCP)
int sockfd = socket(AF_INET, SOCK_STREAM, 0);

#define IPADDR(a,b,c,d) (htonl(((a)<<24)|((b)<<16)|((c)<<8)|(d)))

#define SERVER_HOST IPADDR(192,168,1,1)
#define SERVER_PORT htons(42000)        // host to network byte order short

struct sockaddr_in serv_addr = { AF_INET, SERVER_PORT, { SERVER_HOST } };

// Connect to the server
connect(sockfd, (struct sockaddr *) &serv_addr, sizeof(serv_addr));

// Write to the socket
write(sockfd, "Hello␣World!\n", 13);

// Read from the socket: block until data arrives
#define BUFFER_SIZE 128
char recvBuf[BUFFER_SIZE];
read(sockfd, &recvBuf, BUFFER_SIZE - 1));
```

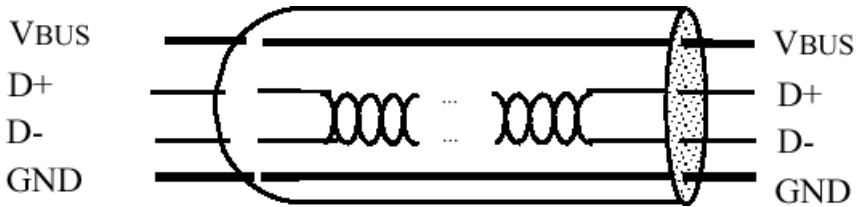
USB: The Universal Serial Bus

USB: Universal Serial Bus

1.5 Mbps, 12 Mbps, 480 Mbps (USB 2.0), 5 Gbps (USB 3.0; two additional pairs)

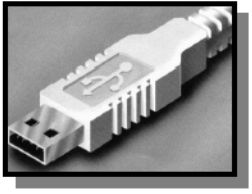
Point-to-point, differential, twisted pair

3–5m maximum cable length



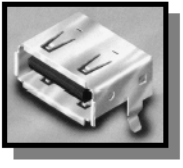
Series "A" Connectors

- Series "A" plugs are always oriented **upstream** towards the *Host System*



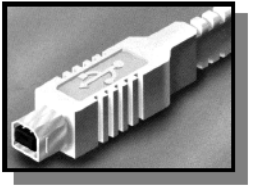
"A" Plugs
(*From the USB Device*)

"A" Receptacles
(*Downstream Output from the USB Host or Hub*)



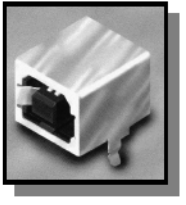
Series "B" Connectors

- Series "B" plugs are always oriented **downstream** towards the *U*SB *Device*



"B" Plugs
(*From the Host System*)

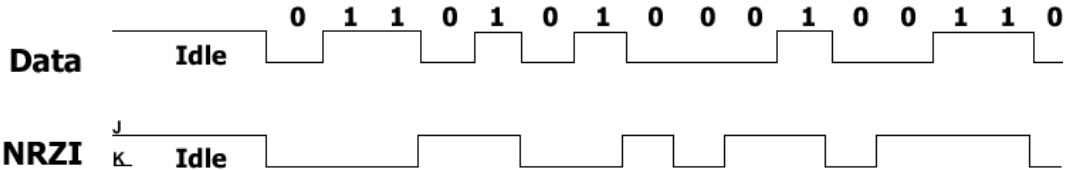
"B" Receptacles
(*Upstream Input to the USB Device or Hub*)



USB signaling

NRZI: 0 = toggle, 1 = no change

Bit stuffing: 0 automatically inserted after six consecutive 1s



Each packet prefixed by a SYNC field: 0 0 0 1 1

Low- vs. full-speed devices identified by different pull-ups on D+/D- lines

USB Packets

Always start with SYNC

4-bit type; 4-bit type complemented

2 bits distinguish Token, Data, Handshake, and Special; two more bits select sub-types

Data, depending on packet type

Data checked using a CRC

Addresses (1-128) assigned by bus master, each with 16 possible endpoints

USB Protocol

Polled bus (USB 1.0, 2.0): host initiates all transfers. USB 3.0 is full-duplex

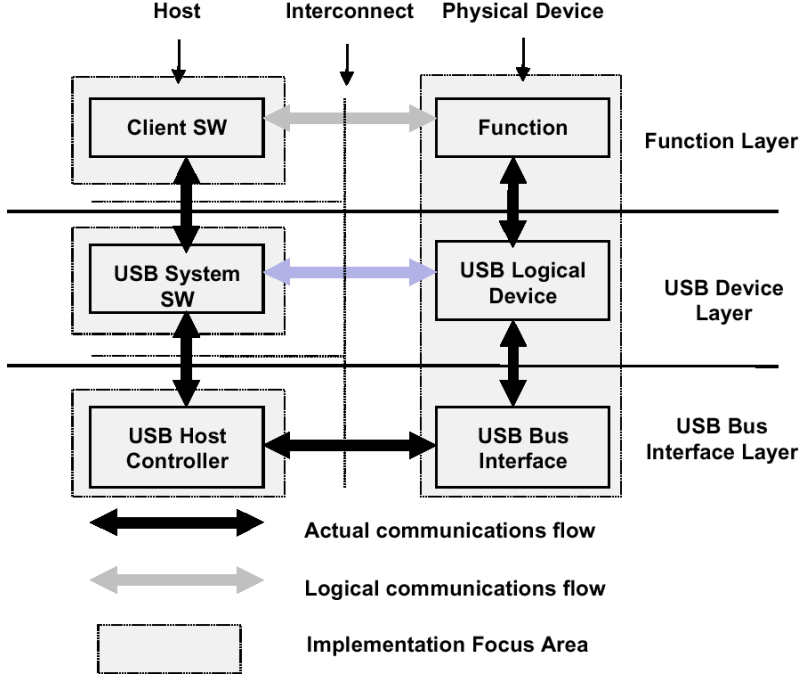
Most transactions involve three packets:

- "Token" packet from host requesting data
- Data packet from target
- Acknowledge from host

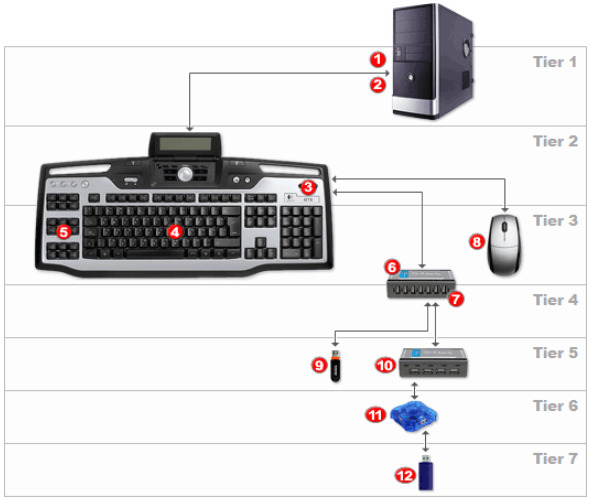
Supports both streams of bytes and structured messages (e.g., control changes).

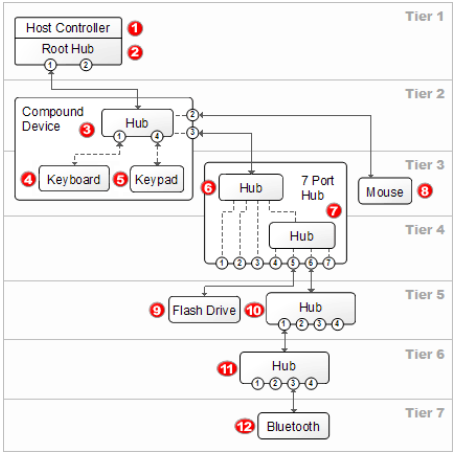
USB Data Flow Types

- Control
  For configuration, etc.
- Bulk Data
  Arbitrary data stream: bursty
- Interrupt Data
  Timely, reliable delivery of data. Usually events.
- Isochronous Data
  For streaming real-time transfer: prenegotiated bandwidth and latency


Host
Interconnect
Physical Device
Client SW
Function
Function Layer
USB System SW
USB Logical Device
USB Device Layer
USB Host Controller
USB Bus Interface
USB Bus Interface Layer
Actual communications flow
Logical communications flow
Implementation Focus Area

USB Bus Topology





Source: http://www.usblyzer.com/usb-topology.htm

lsusb output

Front: USB keyboard
Back: IR receiver
Back: Monitor hub w/
    webcam
    microphone
Back: 7-port hub w/
    SD card reader
    Bluetooth dongle
    SoCKit board (USB Blaster)
    SoCKit board (Serial)

```
Bus 002 Device 001: ID 1d6b:0001 Linux Foundation 1.1 root hub
Bus 002 Device 002: ID 0471:0815 Philips (or NXP) eHome Infrared Receiver
Bus 002 Device 006: ID 04d9:1203 Holtek Semiconductor, Inc. Keyboard
Bus 001 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
Bus 001 Device 002: ID 0409:005a NEC Corp. HighSpeed Hub
Bus 001 Device 039: ID 03f0:b116 Hewlett-Packard Webcam
Bus 001 Device 005: ID 0409:005a NEC Corp. HighSpeed Hub
Bus 001 Device 041: ID 03f0:3724 Hewlett-Packard Webcam
Bus 001 Device 004: ID 04cc:1521 ST-Ericsson USB 2.0 Hub
Bus 001 Device 006: ID 0bda:0119 Realtek Semiconductor Corp. Storage Device (SD card reader)
Bus 001 Device 007: ID 0a5c:2101 Broadcom Corp. BCM2045 Bluetooth
Bus 001 Device 042: ID 09fb:6810 Altera
Bus 001 Device 043: ID 0403:6001 Future Technology Devices International, Ltd FT232 USB-Serial (UART) IC
```

lsusb -t output

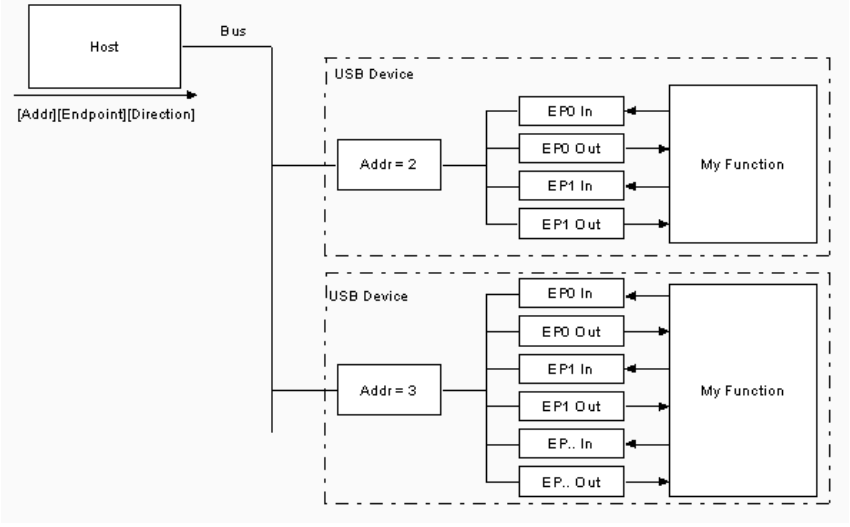
Front: USB keyboard
Back: IR receiver
Back: Monitor hub w/
    webcam
    microphone
Back: 7-port hub w/
    SD card reader
    Bluetooth dongle
    SoCKit board (USB Blaster)
    SoCKit board (Serial)

```
/:  Bus 02.Port 1: Dev 1, Class=root_hub, Driver=ohci-pci/10p, 12M
    |__ Port 3: Dev 2, If 0, Class=Vendor Specific Class, Driver=mceusb, 12M
    |__ Port 5: Dev 6, If 0, Class=Human Interface Device, Driver=usbhid, 1.5M
    |__ Port 5: Dev 6, If 1, Class=Human Interface Device, Driver=usbhid, 1.5M
/:  Bus 01.Port 1: Dev 1, Class=root_hub, Driver=ehci-pci/10p, 480M
    |__ Port 2: Dev 2, If 0, Class=Hub, Driver=hub/4p, 480M
        |__ Port 3: Dev 39, If 0, Class=Video, Driver=uvcvideo, 480M
        |__ Port 3: Dev 39, If 1, Class=Video, Driver=uvcvideo, 480M
        |__ Port 3: Dev 39, If 2, Class=Audio, Driver=snd-usb-audio, 480M
        |__ Port 3: Dev 39, If 3, Class=Audio, Driver=snd-usb-audio, 480M
        |__ Port 4: Dev 5, If 0, Class=Hub, Driver=hub/2p, 480M
            |__ Port 2: Dev 41, If 0, Class=Mass Storage, Driver=usb-storage, 480M
    |__ Port 4: Dev 4, If 0, Class=Hub, Driver=hub/7p, 480M
        |__ Port 2: Dev 6, If 0, Class=Mass Storage, Driver=usb-storage, 480M
        |__ Port 3: Dev 7, If 0, Class=Wireless, Driver=btusb, 12M
        |__ Port 3: Dev 7, If 1, Class=Wireless, Driver=btusb, 12M
        |__ Port 3: Dev 7, If 2, Class=Vendor Specific Class, Driver=, 12M
        |__ Port 3: Dev 7, If 3, Class=Application Specific Interface, Driver=, 12M
        |__ Port 5: Dev 42, If 0, Class=Vendor Specific Class, Driver=, 480M
        |__ Port 6: Dev 43, If 0, Class=Vendor Specific Class, Driver=ftdi_sio, 12M
```

Devices, Configurations, Interfaces, and Endpoints

Devices	Keyboards, Mice: physical object
Configurations	usually one
Interfaces	“logical device”: usually one; my webcam has 4
Endpoints	one per input/output stream

USB Addresses and Endpoints



Source: `http://www.beyondlogic.org/usbnutshell/usb3.shtml`

USB Keyboard: lsusb (highlights)

```
Bus 002 Device 007: ID 413c:2003 Dell Computer Corp. Keyboard
Device Descriptor:
    bDeviceClass            0 (Defined at Interface level)
    idVendor           0x413c Dell Computer Corp.
    idProduct          0x2003 Keyboard
    bNumConfigurations      1
    Configuration Descriptor:
        bNumInterfaces          1
        Interface Descriptor:
            bInterfaceNumber        0
            bNumEndpoints           1
            bInterfaceClass         3 Human Interface Device
            bInterfaceSubClass      1 Boot Interface Subclass
            bInterfaceProtocol      1 Keyboard
            iInterface              0
                HID Device Descriptor:
                    bcdHID               1.10
                    bNumDescriptors         1
                    bDescriptorType        34 Report
                    wDescriptorLength      65
            Endpoint Descriptor:
                bEndpointAddress     0x81  EP 1 IN
                bmAttributes            3
                    Transfer Type            Interrupt
                    Synch Type               None
                    Usage Type               Data
                wMaxPacketSize     0x0008  1x 8 bytes
```

```
Bus 001 Device 006: ID 0bda:0119 Realtek Semiconductor Corp. Storage Device (SD card reader)
Device Descriptor:
    bDeviceClass            0 (Defined at Interface level)
    idVendor           0x0bda Realtek Semiconductor Corp.
    idProduct          0x0119 Storage Device (SD card reader)
    bNumConfigurations      1
    Configuration Descriptor:
        bNumInterfaces          1
        bConfigurationValue     1
        iConfiguration          4 CARD READER
        bmAttributes         0x80
            (Bus Powered)
        MaxPower              500mA
        Interface Descriptor:
            bNumEndpoints           2
            bInterfaceClass         8 Mass Storage
            bInterfaceSubClass      6 SCSI
            bInterfaceProtocol     80 Bulk-Only
            Endpoint Descriptor:
                bEndpointAddress     0x01  EP 1 OUT
                bmAttributes            2
                    Transfer Type            Bulk
                    Synch Type               None
                    Usage Type               Data
                wMaxPacketSize     0x0200  1x 512 bytes
            Endpoint Descriptor:
                bLength                 7
                bDescriptorType         5
                bEndpointAddress     0x82  EP 2 IN
                bmAttributes            2
                    Transfer Type            Bulk
                    Synch Type               None
                    Usage Type               Data
                wMaxPacketSize     0x0200  1x 512 bytes
```

libusb 1.0

Libusb 1.0

User-level C library for USB device access. lsusb built on it.

www.libusb.org

1.0 API supplants earlier libusb 0.1

Nice tutorial: http://www.dreamincode.net/forums/topic/148707-introduction-to-using-libusb-10/

Using libusb

1. Initialize the library with *libusb_init()*
2. Select your device from the list returned by *libusb_get_device_list()*. Later, free the list with *libusb_free_device_list()*.
3. Initiate contact with *libusb_open()*
4. Claim the interface with *libusb_claim_interface()*
5. Communicate using the various *libusb_. . . _transfer()* functions
6. Release the interface with *libusb_release_interface()*
7. Close the device with *libusb_close()*
8. Close the library with *lubusb_exit()*

libusb: Finding a Keyboard

```
libusb_device **devs;
struct libusb_device_descriptor desc;
struct libusb_device_handle *keyboard = NULL;
ssize_t num_devs, d; uint8_t i, k;
uint8_t *endpoint_address;
num_devs = libusb_get_device_list(NULL, &devs);
for (d = 0 ; d < num_devs ; d++) {
  libusb_device *dev = devs[d];
  libusb_get_device_descriptor(dev, &desc);

  if (desc.bDeviceClass == LIBUSB_CLASS_PER_INTERFACE) {
    struct libusb_config_descriptor *config;
    libusb_get_config_descriptor(dev, 0, &config);
    for (i = 0 ; i < config->bNumInterfaces ; i++)
      for ( k = 0 ; k < config->interface[i].num_altsetting ; k++ ) {
        const struct libusb_interface_descriptor *inter =
          config->interface[i].altsetting + k;
        if ( inter->bInterfaceClass == LIBUSB_CLASS_HID &&
             inter->bInterfaceProtocol == USB_HID_KEYBOARD_PROTOCOL) {
          libusb_open(dev, &keyboard);
          *endpoint_address = inter->endpoint[0].bEndpointAddress;
          libusb_claim_interface(keyboard, i);
          ubusb_free_device_list(devs, 1);
          return keyboard;
```

libusb: Reading from a Keyboard

```
#define USB_LCTRL  (1 << 0)
#define USB_LSHIFT (1 << 1)
#define USB_LALT   (1 << 2)
#define USB_LGUI   (1 << 3)
#define USB_RCTRL  (1 << 4)
#define USB_RSHIFT (1 << 5)
#define USB_RALT   (1 << 6)
#define USB_RGUI   (1 << 7)

struct usb_keyboard_packet {
  uint8_t modifiers;
  uint8_t reserved;
  uint8_t keycode[6];
};

struct libusb_device_handle *keyboard;
uint8_t endpoint_address;

libusb_interrupt_transfer(keyboard, endpoint_address,
                          (unsigned char *) &packet,
                          sizeof(packet),
                          &transferred, 0);
    if (transferred == sizeof(packet))
      // Got a new keyboard event
```

USB HID Keyboard Protocol Packet

Page 60 of `http://www.usb.org/developers/hidpage/HID1_11.pdf`

Byte	Meaning
0	Modifier keys
1	Reserved
2	Keycode 1
	⋮
7	Keycode 6

USB HID Keycodes

Page 53: http://www.usb.org/developers/hidpage/Hut1_12v2.pdf

Code	Meaning
0	No event
⋮	
4	a or A
5	b or B
⋮	
29	z or Z
30	1 or !
⋮	
38	9 or (
39	0 or)
40	Enter
⋮	

00 00 00 00 00···00	Nothing pressed
00 00 04 00 00···00	“A” pressed
02 00 04 00 00···00	Shift+A
03 00 04 00 00···00	Shift+Ctrl+A
02 00 04 00 00···00	Shift+A
02 00 04 05 00···00	Shift+A+B

POSIX Threads (pthreads)

Creation and Termination

```c
#include <stdio.h>
#include <pthread.h>

void *mythread(void *ptr)
{
  printf("%s\n", (char *)ptr);
  return NULL;
}

int main()
{
  pthread_t thread1, thread2;
  const char *message1 = "Thread 1", *message2 = "Thread 2";

  pthread_create( &thread1, NULL, mythread, (void *)message1);
  pthread_create( &thread2, NULL, mythread, (void *)message2);

  pthread_join( thread1, NULL);
  pthread_join( thread2, NULL);

  return 0;
}
```

http://www.yolinux.com/TUTORIALS/LinuxTutorialPosixThreads.html

Mutexes: Ensuring atomic access

```c
#include <stdio.h>
#include <pthread.h>

pthread_mutex_t mutex1 = PTHREAD_MUTEX_INITIALIZER;
int counter = 0; /* Caution: shared variable */

void *incCounter() {
  int tmp;
  pthread_mutex_lock(&mutex1); /* Grab the lock */
  tmp = counter;  /* Needlessly complicated to make a point */
  tmp = tmp + 1;
  counter = tmp;
  pthread_mutex_unlock(&mutex1); /* Release the lock */
  return NULL;
}

int main() {
   pthread_t thread1, thread2;
   pthread_create( &thread1, NULL, &incCounter, NULL);
   pthread_create( &thread2, NULL, &incCounter, NULL);
   pthread_join( thread1, NULL);
   pthread_join( thread2, NULL);
   return 0;
}
```

Condition Variables: Notifying waiters

```
pthread_mutex_t mutex1 = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t  cond1  = PTHREAD_COND_INITIALIZER;
int count;  int valid = 0;
void *writeCounter() {
  int i;
  for (i = 0 ; i < 10 ; i++) {
    pthread_mutex_lock(&mutex1);
    while (valid) pthread_cond_wait(&cond1, &mutex1);
    count = i; valid = 1;
    pthread_cond_signal(&cond1);
    pthread_mutex_unlock(&mutex1);
  }
  return NULL; }
void *readCounter() {
  int done = 0;
  do {
    pthread_mutex_lock(&mutex1);
    while (!valid) pthread_cond_wait(&cond1, &mutex1);
    printf("%d\n", count);
    valid = 0;  done = count == 9;
    pthread_cond_signal(&cond1);
    pthread_mutex_unlock(&mutex1);
  } while (!done);
  return NULL; }
```