Physical Layer Cabling: Twisted-Pair

- Introduction
- Structured Cabling
- Unshielded Twisted-Pair Cable
- Terminating Cat6/5e UTP Cables
- Cable Testing and Certification
- 10G Ethernet over Copper
- Troubleshooting Cabling Systems

Introduction

- In this lecture and the next, we examine the implementation of Layer 1 (***Physical***) in the OSI model
  - This, of course, concerns hardware-level interconnections between networking devices.
  - In other words – ***cabling***
- Here, we will focus primarily on CAT5e cabling, with some attention to the newer CAT6 standard.
- This will include a hands-on lab exercise! ☺

Structured Cabling Specifications

- Today, the dominant standard for a structured cabling system is the ***EIA/TIA 568-B***
  - ***EIA*** → Electronics Industries Alliance
  - ***TIA*** → Telecommunications Industries Alliance
- In 2000, it supplanted the EIA/TIA 568-***A*** standard
- The EIA/TIA 568-B standard contains three parts…
  - EIA/TIA-568-B.**1** → Commercial Cabling (Primary)
  - EIA/TIA-568-B.**2** → Twisted Pair Cabling
  - EIA/TIA-568-B.**3** → Fiber Optic Cabling

Six Subsystems

- A structured cabling system provides for data connections on a wider network through six main subsystems.
- Those are:
  1. Building Entrance
  2. Equipment Room
  3. Backbone Cabling
  4. Telecommunications Closet
  5. Horizontal Cabling
  6. Work Area

Six Subsystems

- The ***building entrance*** is where the *external* cabling (e.g., from an ISP) connects to the system's network *internals*.
- In the ***equipment room*** (ER), you will find the most complex of the networking equipment, such as *servers*.
- ***Backbone cabling*** forms the connections between the *major centers* of the cabling system, such as the ER, both between and within buildings.

Six Subsystems

- The ***telecommunications closets*** (TC) – also called "rooms" or "enclosures" – are areas where backbone cabling and horizontal cabling terminate and cross over.
- ***Horizontal cabling*** forms the final leg of the journey from the entrance to the work area outlets – that is, the receptacles where you link your devices to the network.
- The ***work area*** includes the individual networked devices (e.g., computers and printers), cables, jacks, and other familiar components.

➢ In this class, we will deal mostly with ***the last two*** – *horizontal cabling* and *work area*.

Cross-connects in Systems

- A term you may hear repeatedly is cross-connect, which refers to locations where one set of cables terminates to be connected to network hardware or other cables.
- These will occur at different locations between the entrance and the work areas
  - These cross-connects are called **`main`**, **`intermediate`**, and **`horizontal`**
  - They help form a *hierarchical* star topology
- See Figures **2-1** and **2-2** for differing visualizations

Horizontal Cabling

- Again, horizontal cabling is the last link between your *work area* and the *telecommunications closet* (TC).
- This part should be planned very carefully, considering:
  - Current networking needs
  - Future growth and corresponding networking needs
- Between a network-connected device (in the work area) and network hardware (e.g., switches/hubs) in the TC, you may have a total of 100 meters of cabling.
  - This includes the cables on either side of the horizontal cabling
  - ***What might be the reason for this?***

UTP Cabling

- In terms of physical connections in computer networks, one of the most common media you will find is **`unshielded twisted-pair`** (UTP) cabling.
- You may also hear this type called "copper", in reference to the material of the wires inside.
- In computer networking, it generally refers to *Ethernet cables*:
  - Category 3 (**`CAT3`**)
  - Category 5 (**`CAT5`**) and 5e (**`CAT5e`**)
  - Category 6 (**`CAT6`**)
  - And more...

UTP Cabling

- In general, "twisted pair" signifies pairs of insulated copper wires, twisted around one another
- The twisting helps to improve signal transmission
  - This has to do with the *phases* of the paired wires
  - One wire in the pair has a positive phase, while the other has a negative phase.
  - This is called a balanced mode of operation
  - It reduces crosstalk by curbing electromagnetic interference
- If you are familiar with landline telephones, this features in **`CAT3`** cables – two twisted-pairs, terminated in an RJ11 jack

UTP Cabling

- In the case of Ethernet cables, this will entail:
  - Four pairs of twisted, color-coded copper wires
    - **`CAT5/5e:`** 24 gauge
    - **`CAT6:`** 23 AWG (thicker)
  - Inside a sheath, or ***jacket***
  - Terminated at each end by RJ-45 (8P8C) connectors (Figure 2-6)
- These constituted your standard ***unshielded*** cables (See Figure 2-8)
- However, you can also have ***shielded*** cables, with extra coverings for further signal improvement

Shielded **Twisted-Pair (STP) Cabling**

- The idea behind shielding is to prevent signal interference, between and within cables
- Cable crosstalk: **`https://www.youtube.com/watch?v=SguxCeOFPQk`**
- Cable shielding comes in a number of forms:
  - Shielding of individual pairs and/or cable as a whole
  - Foil shielding
  - Braided shielding
- However, shielded cable can be more expensive. Before investing in it, ask yourself: Do you really need it?

`http://www.belden.com/resourcecenter/cablebasics/upload/Shielding.pdf`

Twisted-Pair Cabling

- Twisted-pair cables of Categories 5, 5e, and 6 will consist of *four* **color-coded**, ***twisted*** pairs:
  - **Green and Green/White**
  - **Blue and Blue/White**
  - **Orange and Orange/White**
  - **Brown and Brown/White**
- They will be terminated in an ***RJ-45*** connector, or ***8P8C*** (8 position, 8 contact) – since each wire will have a specific place in the connector.

Twisted-Pair: Patch

- We will first look at color codes for a ***patch*** cable, which is usually used to connect a device to a jack/outlet.
- Color codes will specify which wires go in which positions.
- Looking at the RJ-45 connector, open end facing you and shiny part facing up, the wire order, from left to right is:

Orange/White	**Blue/White**
Orange	**Green**
Green/White	**Brown/White**
Blue	**Brown**

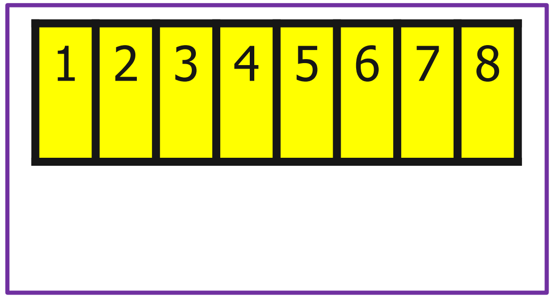
Twisted-Pair: Patch

- To terminate the cable…
  1. Cut the needed length of cable – **only** as long as you need
  2. Strip the ends of the cable – but NOT the wire insulation
  3. Separate and straighten the wires
  4. Arrange them in proper color-code order
  5. Cut them to a length that will leave enough to reach the end of the connector but enough cable covering to be crimped
  6. Place in crimper and crimp the RJ-45 connector
  7. ***Test*** the cable (with proper tester settings) to ensure it works!

Twisted-Pair: Specifics

- The wire color order you were given in the lab specified which wires need to connect with which pins on the RJ-45 (8P8C) connector.

Bottom-side up:



- Such an order is called a ***color map***.
  - The given color map corresponds to the *T568B* guidelines, given in the EIA/TIA568B standard.
  - This one is the most common, so we used it in the lab exercise.

T568B Color Codes

1. Orange/White
2. Orange
3. Green/White
4. Blue
5. Blue/White
6. Green
7. Brown/White
8. Brown

Twisted-Pair: Specifics

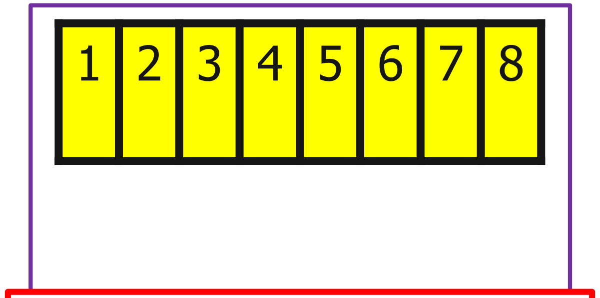
- An alternate color scheme is ***T568A***, which uses the color order specified to the right →
- Either can be used, so long as it is used consistently within the network!
- Regardless, the point is to maintain proper positioning of the pairs used for both transmitting and receiving…

T568A Color Codes

1. **Green/White**
2. **Green**
3. **Orange/White**
4. **Blue**
5. **Blue/White**
6. **Orange**
7. **Brown/White**
8. **Brown**

Twisted-Pair: Transmit and Receive

- In most Ethernet, one of the wire pairs is used for *transmitting* (**Tx**) signals, while another pair is used for *receiving* (**Rx**)
  - In each pair, one wire is *positive* (+), and the other *negative* (-)
  - The other two pairs are usually unused
  - The **Tx** and **Rx** wires correspond to different pins in the connector
  - The color scheme will tell you which wires are serving which purposes

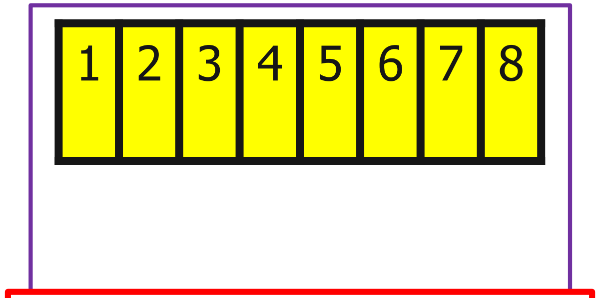


Pin Numbers and Wire Functions

1. **Tx+**
2. **Tx-**
3. **Rx+**
4. **Unused**
5. **Unused**
6. **Rx-**
7. **Unused**
8. **Unused**

Twisted-Pair: Gigabit Signals

- For Gigabit Ethernet (speeds 1 Gbps and 10 Gbps)…
  - The signals have different names
  - All four wire pairs are used
  - All pairs are bi-directional – can be used for sending or receiving data
  - Signal names →
  - Here, too, the different signals correspond to different wires, based on the color scheme

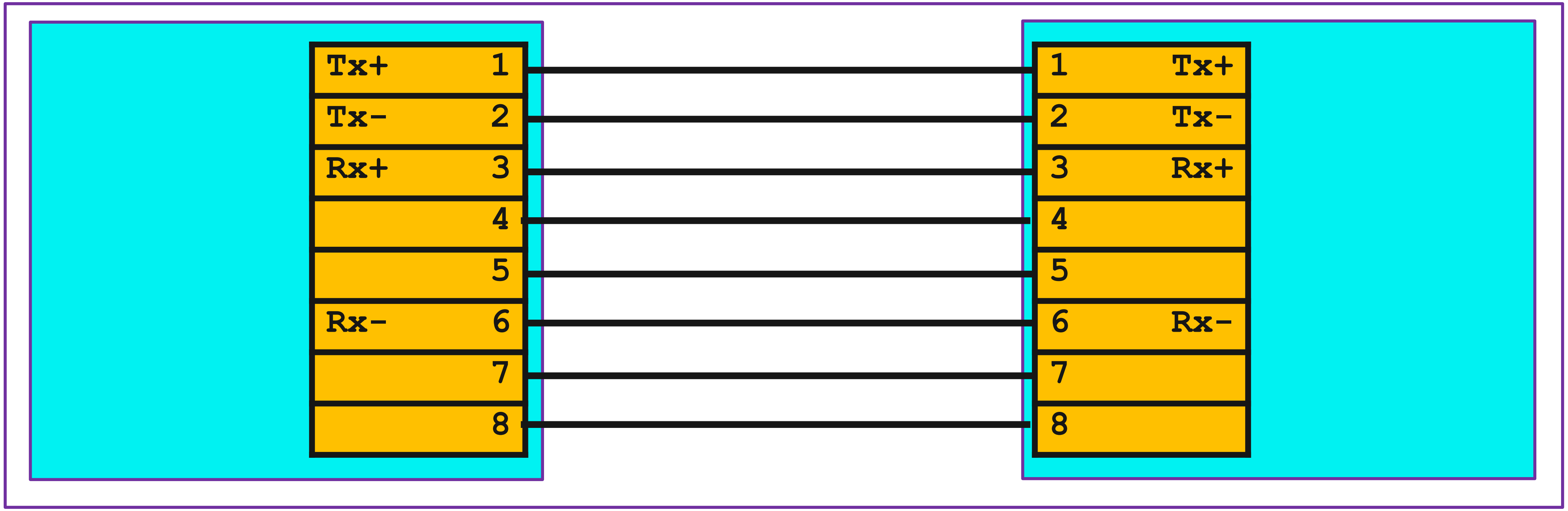


Pin Numbers and Wire Functions

1. **Bi_DA+**
2. **Bi_DA-**
3. **Bi_DB+**
4. **Bi_DC+**
5. **Bi_DC-**
6. **Bi_DB-**
7. **Bi_DD+**
8. **Bi_DD-**

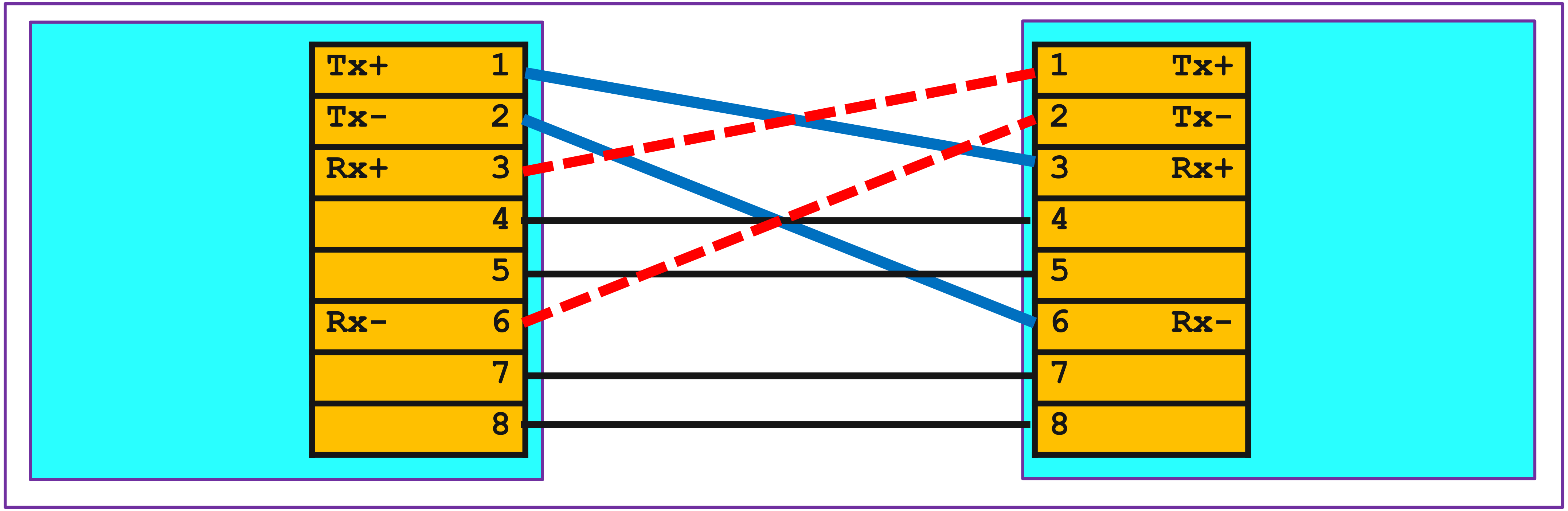
Straight-Through vs Crossover

- What you created in the lab was a ***straight-through*** patch cable, in which each wire connects to the same pin number (on the RJ-45 connectors) on each end.



Straight-Through vs Crossover

- You can also have a ***crossover*** cable, in which each wire pair connects to the transmit pins on one end and the receive pins on the other



Jack Termination for Horizontal Cabling

- In addition to patch cables, where each end is terminated in an RJ-45 connector, you may also sometimes need to terminate *horizontal cabling* for a *wall jack*.
- Here are some *general* steps for the process…
  1. Cut the needed length of cable – **plus** about a foot extra at the wall outlet end (for mistakes, etc.)
  2. Strip 1-3 inches of the cable jacket/sheath at the wall outlet end. (Be sure the wire insulation is intact.)
  3. Cut off the *pull line* – the string running down the cable length.

Jack Termination for Horizontal Cabling

4. Separate and straighten the pairs, and untwist the pairs – but only ***just enough*** for the following step!
5. Place them into the grooves on the jack according to proper color-code order. Jack should indicate grooves according both T568A and B color schemes.
6. Using a punch-down tool, push the wires down into the grooves so as to secure them and cut off excess wire.
7. Secure the jack in the wall plate.
8. Run any necessary or appropriate tests.

Jack Termination for Horizontal Cabling

- Again, these are just general steps, and specifics may vary according to hardware and networking needs
- You can see the process in this video:

  `https://www.youtube.com/watch?v=njh2sUZmMTw`
- The textbook example ("*Terminating the CAT6 Horizontal Link Cable*", Figures **2-14** through **2-21**) includes some extra details:
  - Specialized equipment, such as a lacing tool
  - A bend-limiting strain relief boot (***Figure 2-21***)

Understanding Cable: Terms

- To start, consider some measurement terminology…
  - Data units:
    - **`bit`**: Smallest unit of data, with two possible values: **`1`** or **`0`**
    - **`byte`**: A grouping of 8 bits – also called an *octet*. It is the fundamental unit for measuring data.
  - Data transmission:
    - **`hertz`** (***Hz***): A measurement of frequency, where 1 Hz = 1 cycle per second
    - **`bits-per-second`** (***bps***): A measurement of data transmission speed across a connection (Ethernet cable, wireless, etc.)

Understanding Cable: Terms

- Measurement prefixes:
  - **Kilo-** : One thousand (10^3) – 1,000
  - **Mega-** : One million (10^6) – 1,000,000
  - **Giga-** : One billion (10^9) – 1,000,000,000
  - **Tera-** : One trillion (10^{12}) – 1,000,000,000,000
- Also, we have terms relating to data transmission *speed*:
  - ***Bandwidth***: Generally refers to a communication channel's (e.g., UTP cable) *capacity* for transmission – usually expressed in ***Mhz***
  - ***Network congestion***: When transmission quality degrades due to data traffic exceeding a channel's capacity.

Understanding Cable: Terms

- ***Bottlenecking***: Another term for network congestion
- Directionality
  - ***Full-duplex***: Channel can send/receive concurrently
  - ***Half-duplex***: Channel can only send or receive, at any specific time
- Other
  - ***Latency***: Time for sending (and/or receiving) a packet
  - ***Signal-to-noise ratio***: Ratio of a *signal strength* (or statistical pattern) to *interference*, or "noise". Measured in decibels (dB)
  - ***Throughput***: A measure of *successful* data transmission, often expressed in ***bps***, with appropriate prefixes

Understanding Cable: Ethernet Variants

- Varieties of Ethernet (in terms of physical link and media access control) are defined by the IEEE 802.3 standards
  - IEEE stands for Institute of Electrical and Electronics Engineers
  - For more information, view this site: http://www.ieee802.org/3/
- Here, we are primarily concerned with the Ethernet *variants* specified in these standards – 10BASE5, 100BASE-T, 1GBASE-T, and so forth.
- Generally, the variant name consists of *three parts*: **speed**, **band** (e.g., baseband vs broadband), and **physical characteristics**.
  - Read more: **http://blog.fosketts.net/2010/04/17/1000basewhat/**

Understanding Cable: Ethernet Variants

- For example…
  - **10BASE5** would refer to **10** Mbps, using **base**band signaling, with a maximum segment length of **5**00 meters.
  - **10GBASE-T** would refer to **10 G**bps, using **base**band signaling, over **T**wisted-Pair cabling.
- *Early* Ethernet variants, such as **10BASE5** and **10BASE2**, made use of coaxial cable for data transmission
  - Which topology uses coax? (Ref. Lecture 1)
  - Developers soon saw potential for UTP cable (i.e., CAT3 – telephone cable)
  - This was called **10BASE-T** – which, as the name implies, offers data transmission speeds of ***10 Mbps*** (over ***two*** twisted-pairs)

Understanding Cable: Ethernet Variants

- Fast Ethernet supplanted previous variants by increasing transmission speed to ***100** Mbps*.
  - The **100BASE-T** standards provide this speed over twisted-pair.
  - The **100BASE-TX** variant is the most common.
- Finally, we have ***newer*** Ethernet variants, which allow for even greater speed, such as…
  - Gigabit Ethernet (**1000BASE-T** or **1GBASE-T**): *1000 Mbps*, or 1 Gbps.
  - Gigabit Ethernet (**10GBASE-T**): *10 Gbps*
- Newer varieties may require all four pairs and/or more advanced physical link hardware

Understanding Cable Types and Speed

- Twisted-pair cables are grouped into different ***categories***, which specify their upper limits with regard to bandwidth and data transmission speed.
- We will look at some now....
  - **CAT3:** Two twisted pairs of copper wire, terminated with an RJ-11; mostly used in landline telephones now, but used for Ethernet in the past. **Bandwidth: 16 Mhz**
  - **CAT5:** Four twisted pairs, color-coded. RJ-45 termination. Commonly used for Ethernet. **Bandwidth: 100 Mhz**
  - **CAT5e:** Same construction as CAT5, but with more stringent testing. Many CAT5 cables may actually meet these requirements....

Understanding Cable Types and Speed

- **CAT6:** Wires generally thicker than CAT5/5e, along with an internal separator. **`Bandwidth: 250 Mhz`**
- **CAT6a:** More tightly wound pairs. **`Bandwidth: 500 Mhz`**
- **CAT7/7a:** Not recognized by TIA/EIA. **`Bandwidths: 600 Mhz/1 Ghz`**

- Different cables will be able/tested to support different…
  - Data rates
  - Duplex modes
  - Directionality
- Some of these cables may also support *higher* data rates than normal, but at *shorter lengths*.

	CAT 3	CAT 5	CAT 5e	CAT 6	CAT 6a	CAT 7/7a
10BASE-T	√	√	√	√	√	√
100BASE-T		√	√	√	√	√
1000BASE-T		√	√	√	√	√
10GBASE-T				to 55 meters	√	√

- Higher categories have features like shielding and must meet stricter requirements
- 7a (at short distances) can handle 40 Gigabit -- and even 100 Gigabit! -- Ethernet

Testing and Certifying Cables

- For cables in these categories – 5e, 6, 6a, etc. -- to be certified, they must pass certain tests to verify that they meet certain requirements.
- These tests are conducted over a series of connections from a wall plate to a switch or hub (Figure 2-28)
  - A link is the length of cable between terminated ends.
  - The total sequence of links constitutes a full channel.
- Table 2-4 shows different specifications, in terms of performance, for different categories of cables.

Testing and Certifying Cables

- You will notice, perhaps, that the large majority of variables are measured in decibels (dB), the previously mentioned measurement of signal-to-noise ratio. The signal is how data gets from one end to the other.
- We will go over each of the variables:
- ***Attenuation*** is the loss in a signal's strength as it traverses a channel, such as a cable.
  - It is also called ***insertion loss***.
  - We would like for this value to be as low as possible.

Testing and Certifying Cables

- You have heard the term "crosstalk" before. ***Near-end crosstalk (NEXT)*** is the crosstalk occurring within a cable.
    - What we measure for this component is the ratio of signal transmitted to crosstalk received – between pairs
    - We would like for this value to be as *high* as possible.
    - Crosstalk can become more problematic at higher data rates, which is one reason CAT6 cables have internal separators between pairs.
- ***Power-sum NEXT (PSNEXT)*** deals with the combined crosstalk created by all pairs. Again, we want a *higher* value, so as to be confident that signal is outweighing crosstalk.

Testing and Certifying Cables

- ***Attenuation-crosstalk ratio (ACR)*** is measured by taking the ratio of a signal from the far end to crosstalk at the near end. Again, *higher* is better, as it indicates the cable can handle higher data loads and bandwidth.
- Many of the following measures, in fact, are advanced combinations of concepts like NEXT/FEXT, PS, and ACR:
  - Equal-level FEXT (ELFEXT)
  - PSELFEXT
  - PSACR
- More testing-related information: **http://www.informit.com/articles/article.aspx?p=1403240&seqNum=3**

Testing and Certifying Cables

- ***`Return Loss`*** is measured by taking the ratio of a signal from the far end to crosstalk at the near end. Again, *higher* is better.
- These next two are measured in *nanoseconds*, rather than decibels, as they both concern *time* rather than signal:
  - ***`Propagation delay`*** is a signal's transmission time from one end of the cable to the opposite end. Its value in a specification will be relative to a particular length of cable.
  - ***`Delay skew`*** relates to the fastest vs slowest signals along a cable – the difference in arrival times. A large delay skew can negatively impact data quality via distortion.

10 Gigabit Ethernet

- As networking needs increase, so do the demands for higher data transmission speeds, leading to 10 Gigabit Ethernet
- Allowing speeds of 10 Gbps, the standard is known as IEEE 802.3an-2006 10GBASE-T.
  - Web page: **`http://www.ieee802.org/3/an/index.html`**
  - This standard allows for 10Gbps, over twisted-pair, up to 100 m.
  - The higher speeds…
    - Require improvements in both the cabling (ex., shielding) and the **Tx**/**Rx** electronics
    - Create new issues that require extra tests

10 Gigabit Ethernet: Tests

- One fact about 10 Gigabit Ethernet is the use of ***all four wire pairs*** for transmission.
  - The 10 Gbps is split into *2.5 Gbps per twisted pair*
  - Similarly, Gigabit Ethernet is split into *250 Mbps per pair*
- A major issue in 10G Ethernet over twisted-pair is ***alien crosstalk (AXT)*** – which occurs between two different 4-pair cables
- Cable shielding can help to curb this problem – as well as other sources of noise, such as ***EMI*** (electromagnetic interference) and ***RFI*** (radio frequency interference).

10 Gigabit Ethernet: Tests

- To this end, there are special measures – variations (of more generic measures) that take *AXT* into account:
  - ***PSANEXT*** (Power-Sum **Alien** Near-End Cross-Talk)
  - ***PSAACRF*** (Power-Sum **Alien** Attenuation to Crosstalk Ratio **Far-end**)
- If these acronyms are daunting, break them down into their components.
- Another concern is the balance, or symmetry, of signals over the wire pairs, which helps prevent signal leakage

10 Gigabit Ethernet: Tests

- Testing (for categories 6a and higher) has two measures that address balance:
  - ***TCL (Transverse Conversion Loss)***
  - ***ELTCTL (Equal Level Transverse Conversion Transfer Loss)***
  - If you are interested in these, you should…
    - Read the textbook definitions
    - Look up some of the subordinate concepts: differential vs. common-mode signaling, Transverse Conversion Transfer Loss, etc.

Testing and Troubleshooting Cable

- The most sophisticated cable testers are called *certifiers*:
  - They can be set to different specifications, such as CAT5e vs 6
  - A certifier will provide a verdict of ***PASS*** or ***FAIL*** for a cable, relative to a particular class or category
  - Includes a certification report with results for various measures
- When cable tests fail, different causes may be likely:
  - Installation, such as too much untwisted length at ends
  - Cable stretching
  - Manufacturer failure to ensure conformity to specs.

Testing and Troubleshooting Cable

- The textbook features passing and failing results for a cable.
  - ***Passing*** **:** Figure 2.36
  - ***Failing*** **:** Figures 2.37-39
- At this stage, the test reports will probably appear confusing. Try to focus on some generalities
- Tests 1 and 2 address the same cable segment. At one point, it qualified by CAT5e standards, but as of Test **2**, *it no longer did*
  - The cable failed the *Wiremap* test, which concerns pin to pin links
  - It turned out that the cable had been damaged

Testing and Troubleshooting Cable

- Test 3 features a cable that fails 5e requirements on multiple points – most notably, attenuation and return loss
- The cable in Test 4 ends up failing the delay skew test on account of being longer than the maximum length
- Thus, the tests are helpful on multiple levels:
  - Determining whether a cable meets requirements for a particular category
  - If a cable fails to qualify, knowing where to look in order to figure out the reason for the failure
  - Documenting the history of a network installation
  - Identifying recurring issues in a system