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- Four sources of packet delay: *processing delay*, *queueing delay*, *transmission delay*, *propagation delay*.
  - **Transmission delay**: packet length (bits) / link bandwidth (bps).
  - **Propagation delay**: length of physical link / propagation speed.
- Queueing delay grows *exponentially* with traffic intensity $= La/R$, where L is packet length (bits), a is average packet arrival rate, R is link bandwidth (bps).
- **Packet loss** is due to packet arriving to full queue and dropped.
- **Bottleneck link**: link on end-end path that constrains end-end throughput.
- Internet protocol layers: *application*, *transport*, *network*, *link* layers.
- Cyberattacks: (1) Malware: virus, worm, Trojan horse, spyware, botnet, etc, (2) denial-of-service (DoS), (3) packet sniffing, (4) IP spoofing, (5) record-and-playback.
- Application architectures: client-server, peer-to-peer (P2P), hybrid.
- In the context of a communication session between a pair of processes:
  - Client: the process that initiates the communication.
  - Server: the process that waits to be contacted to begin the session.
- Application layer protocol defines types of messages exchanged, message syntax, message semantics, and rules for when and how processes send & respond to messages. **Public-domain protocols** are defined in RFCs, e.g. HTTP, SMTP, etc.
- **Socket**: the **application programming interface (API)** between the application layer and the network layer.
- Transport services available to applications: *reliable data transfer*, *throughput* (**bandwidth-sensitive** v.s. **elastic** applications), *timing*, *security*.
- Requirements of selected network applications:

Application	Data Loss	Throughput	Time-Sensitive
File transfer/download	No loss	Elastic	No
E-mail	No loss	Elastic	No
Web documents	No loss	Elastic (few kbps)	No
Internet telephony/ Video conferencing	Loss-tolerant	Audio: few kbps–1 Mbps Video: 10 kbps–5 Mbps	Yes: 100s of msec
Streaming stored audio/video	Loss-tolerant	Same as above	Yes: few seconds
Interactive games	Loss-tolerant	Few kbps–10 kbps	Yes: 100s of msec
Instant messaging	No loss	Elastic	Yes and no

- **Transmission Control Protocol (TCP)**:
  - Provide connection-oriented service, reliable data transfer, flow control, congestion control.
  - Does *not* provide minimum throughput guarantees, timing, and security.
- **Secure Sockets Layer (SSL)**: TCP-enhanced-with-SSL not only does everything that traditional TCP does but also provides critical process-to-process security services, including encryption, data integrity, and end-point authentication.
- Popular Internet applications, their application-layer protocols, and their underlying transport protocols:

Application	Application-Layer Protocol	Underlying Transport Protocol
Electronic mail	SMTP [RFC 5321]	TCP
Remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
File transfer	FTP [RFC 959]	TCP
Streaming multimedia	HTTP (e.g., YouTube)	TCP
Internet telephony	SIP [RFC 3261], RTP [RFC 3550], or proprietary (e.g., Skype)	UDP or TCP