IoT systems

- IoT system applications
- IoT system architectures

IoT system applications

- Soft real-time networked embedded system.
  - Input devices: tags, sensors, etc.
  - Output devices: motor controllers, displays, etc.
- Examples:
  - Computer-readable identification code for objects.
  - Appliances controlled by cell phone interface.
  - Sensor network with analytics.

Devices

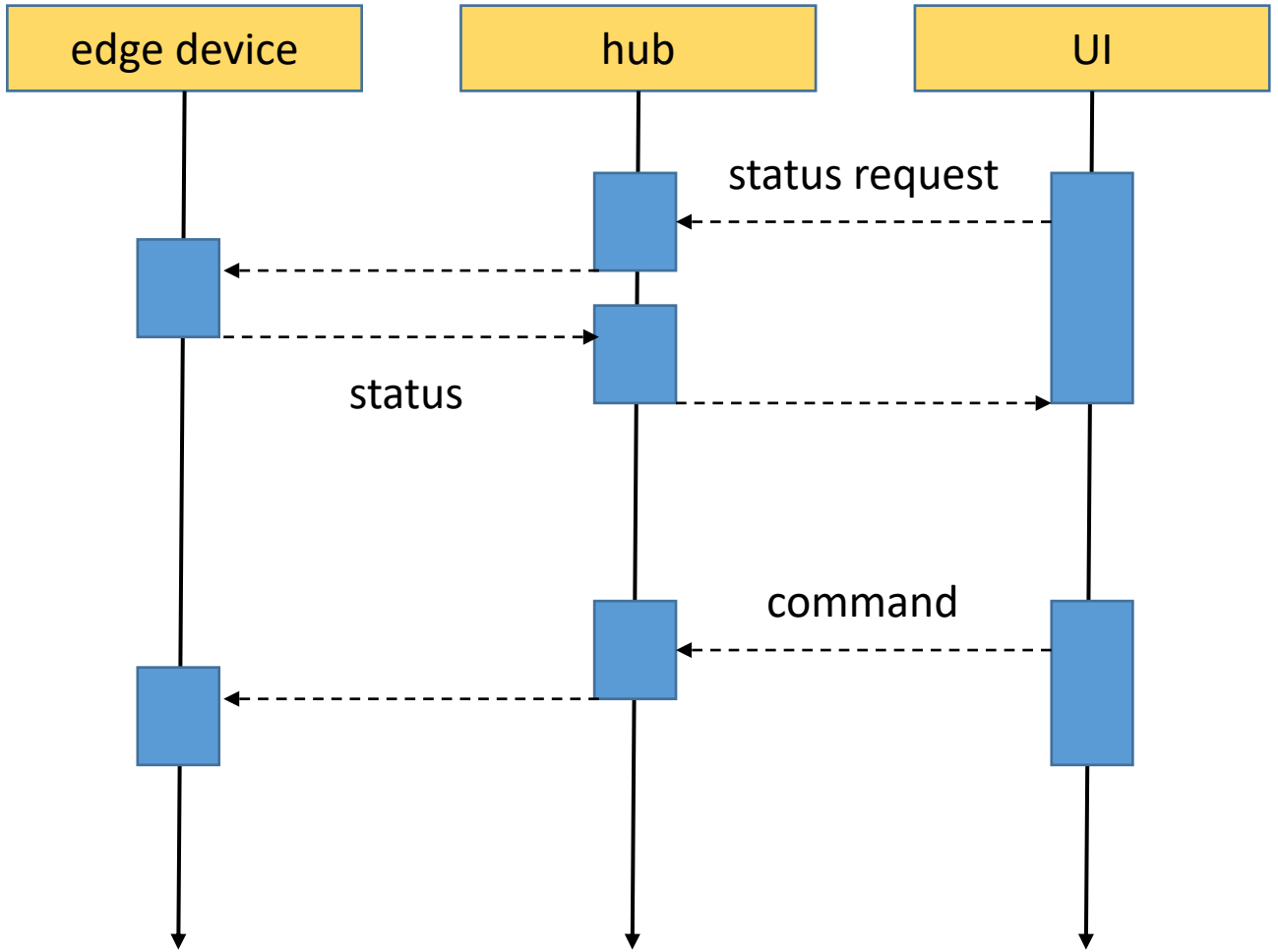
- People:
  - Implanted devices in the body.
  - Wearable devices on the body.
  - Environmental devices outside the body.
- Objects:
  - Interior: temperature sensor, etc.
  - Exterior: RFID, etc.
  - Environmental: camera, motion sensor, etc.

RFID

- RFID tag can provide object ID (Electronic Product Code, etc.), other information.
- Many tags are read-only, some are writable.
- Two types of tags:
  - Passive transmits only when it receives a request.
  - Active tag both transmits independently and responds to requests.
- Passive may also be used to refer to tags with no internal power source.
- RFID tags may operate in several different bands and at different ranges.

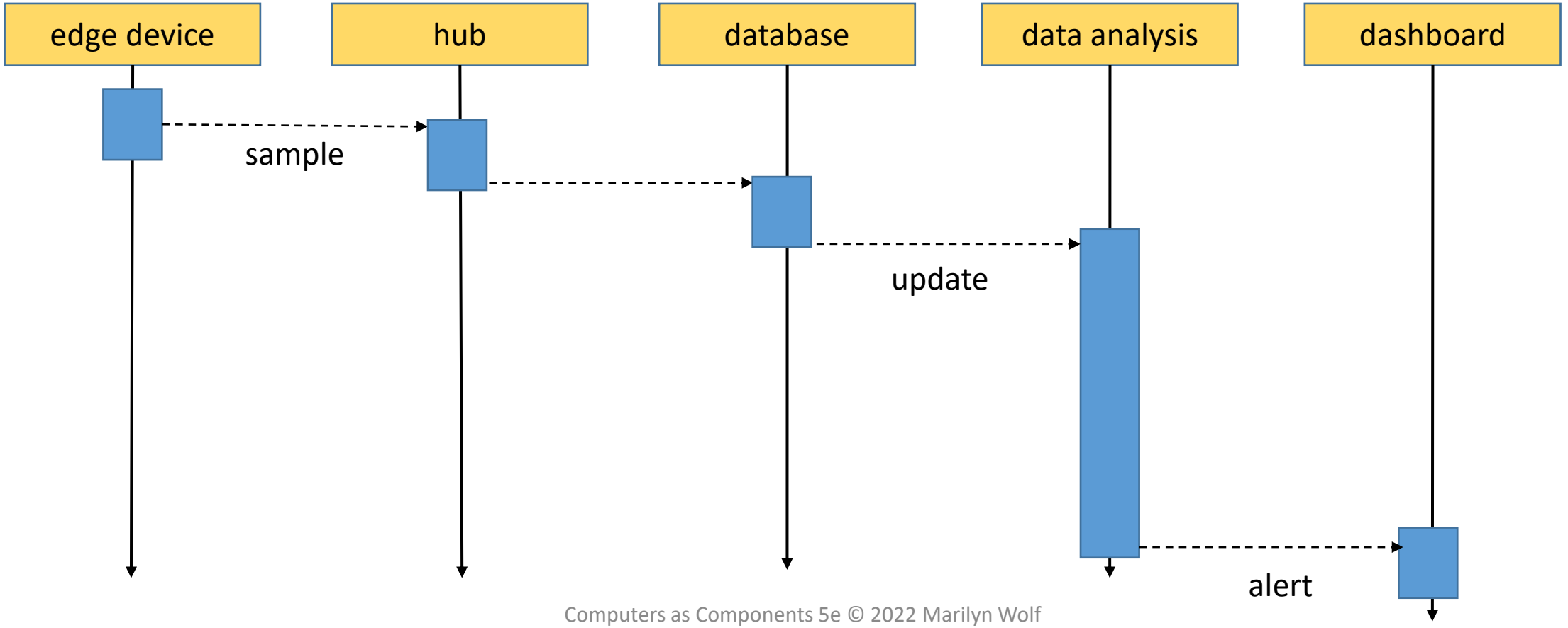
IoT system architectures

- Edge: I/O devices.
- Cloud: centralized processing.
- Smart appliance = connected appliance + network + UI.



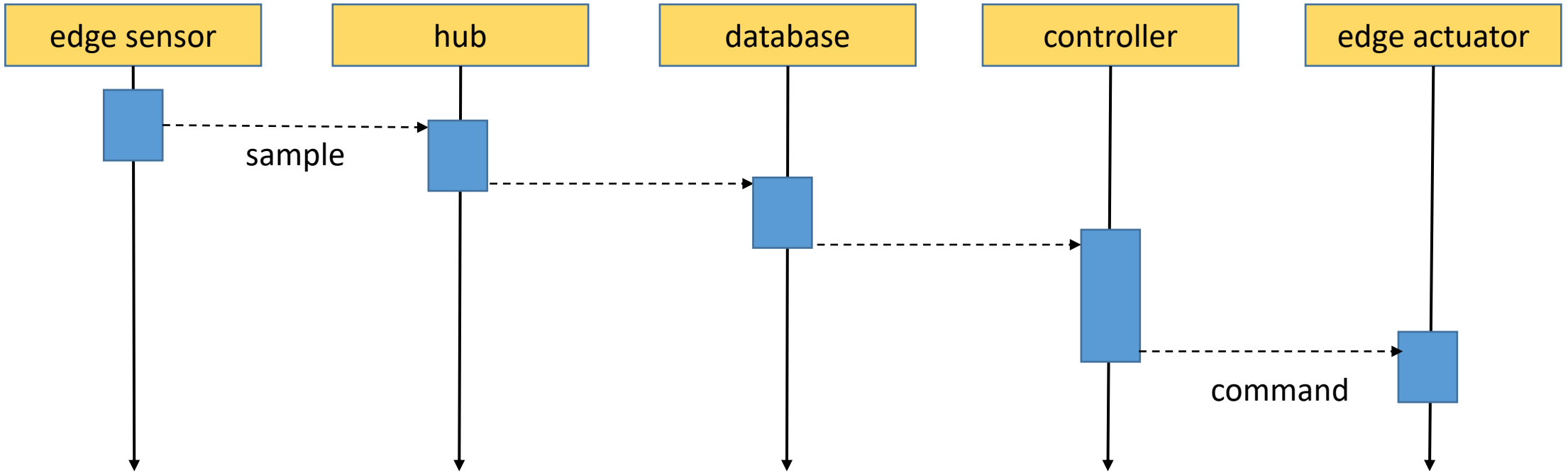
IoT system architectures, cont'd.

- Monitoring system = sensors + network + database + dashboard.



IoT system architectures, etc.

- Control system = sensors + database + controller + actuator.



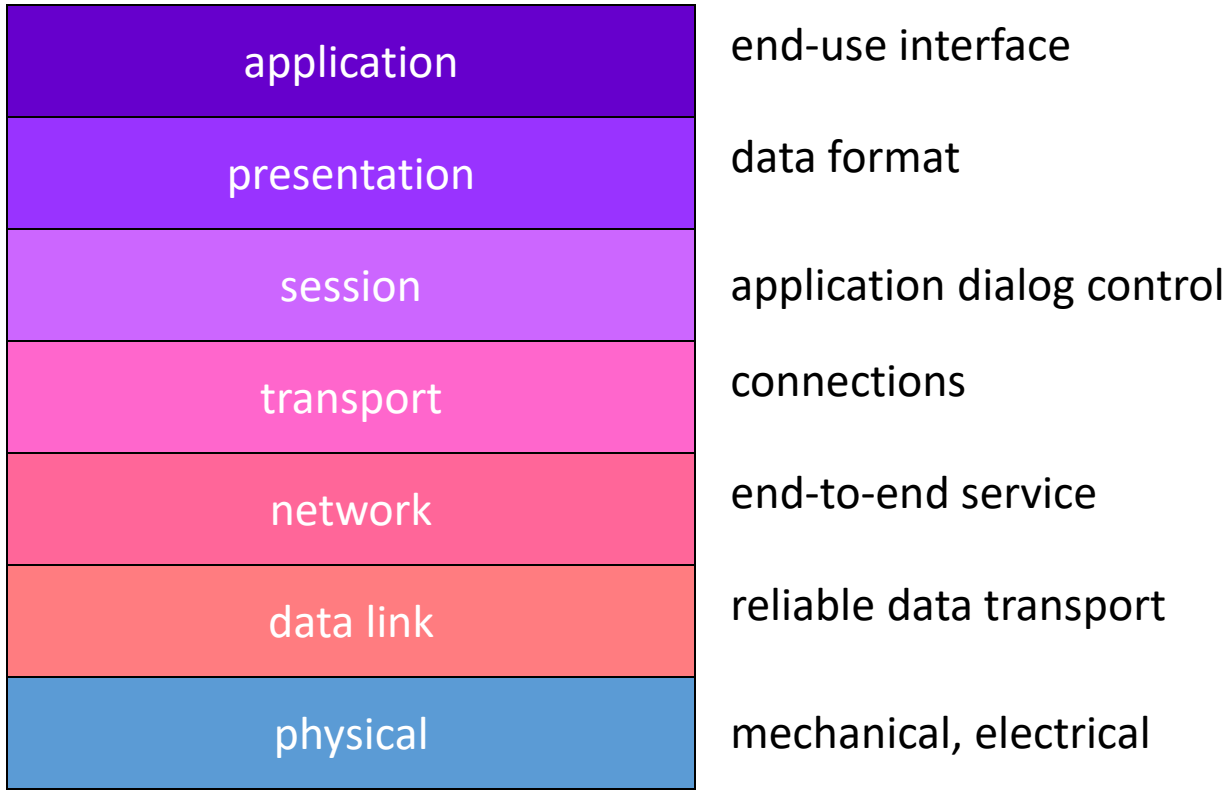
IoT systems

- OSI model for networks.
- Internet protocol.
- IoT networking concepts.
- Example networks:
  - Classic Bluetooth, Bluetooth Low Energy.
  - 802.15.4 and Zigbee.
  - Wi-Fi.

Network abstractions

- International Standards Organization (ISO) developed the Open Systems Interconnection (OSI) model to describe networks:
  - 7-layer model.
- Provides a standard way to classify network components and operations.

OSI model

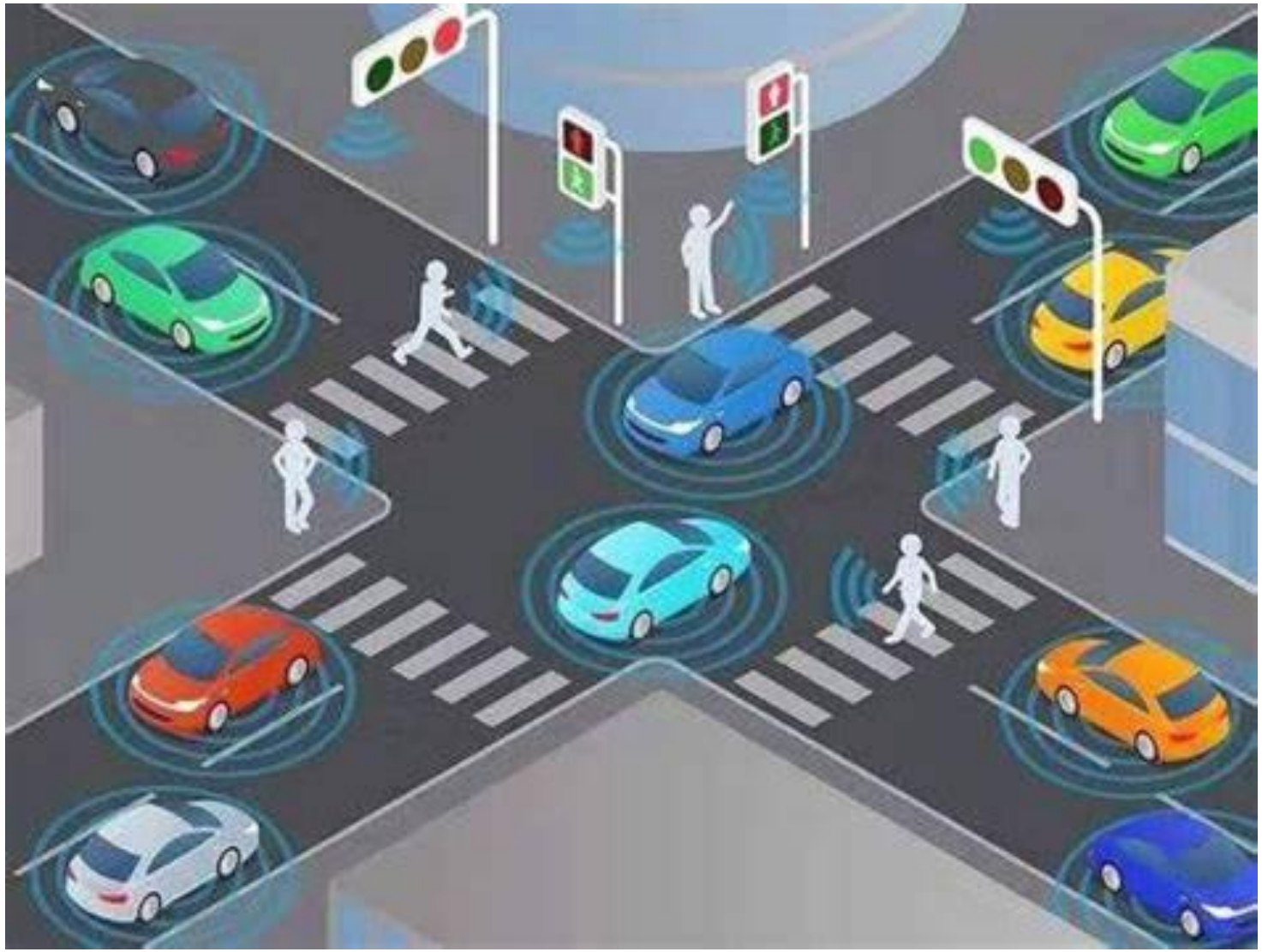


OSI layers

- Physical: connectors, bit formats, etc.
- Data link: error detection and control across a single link (single hop).
- Network: end-to-end multi-hop data communication.
- Transport: provides connections; may optimize network resources.
- Session: services for end-user applications: data grouping, checkpointing, etc.
- Presentation: data formats, transformation services.
- Application: interface between network and end-user programs

PHY

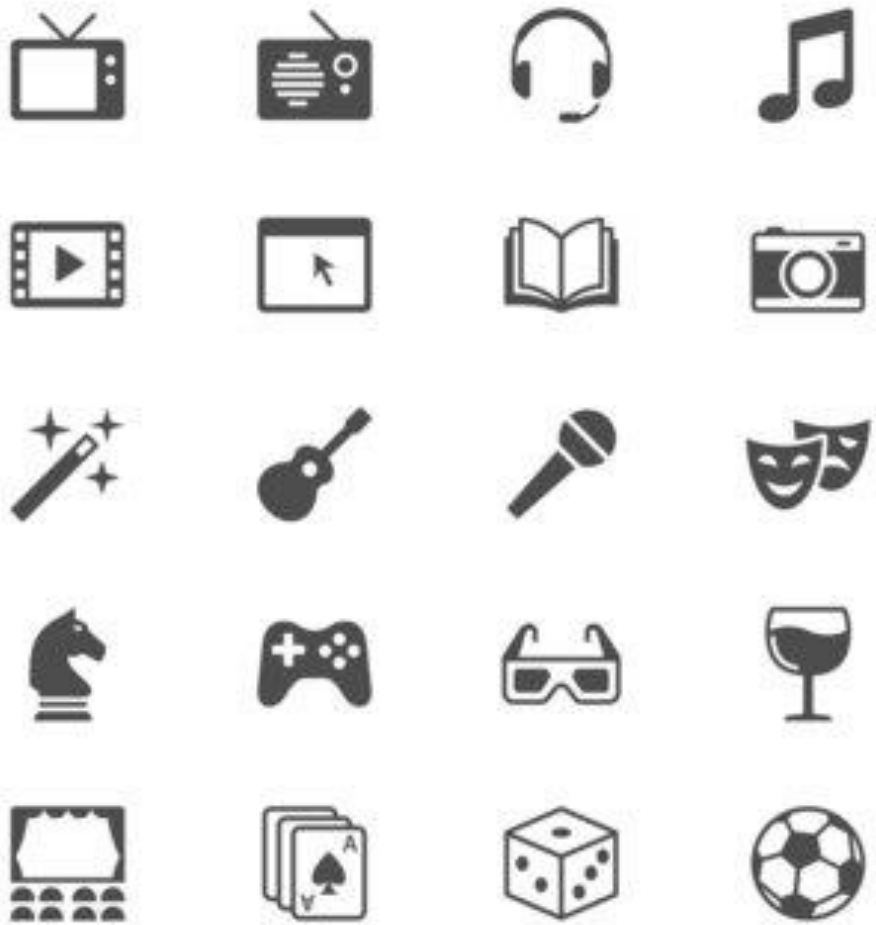
MAC



IP

Transport

APP

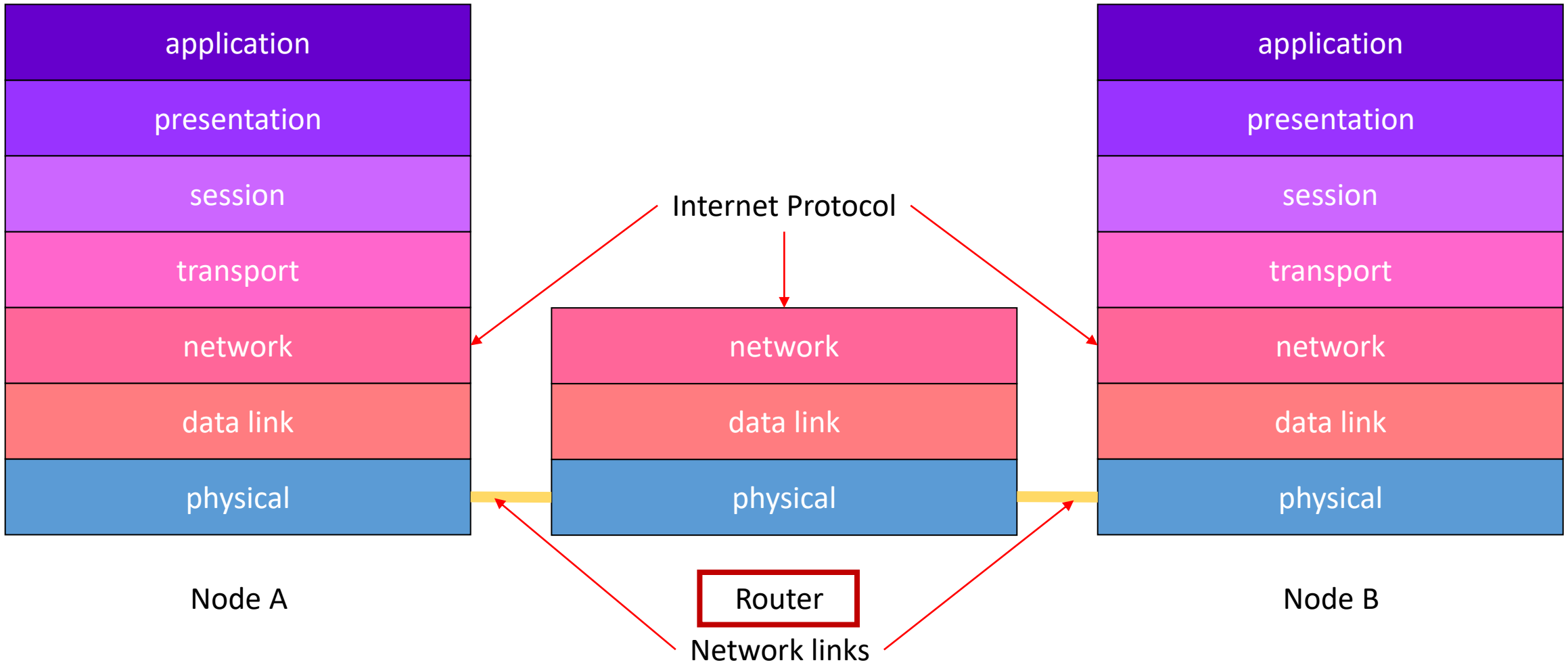


PHY and MAC

- PHY = physical layer.
  - Circuitry to transmit and receive bits.
- MAC = media access control.
  - Provides link-level services.

Internet Protocol

- Internet = network of networks.
  - Transports data from one network to another.
- The Internet uses Internet Protocol (IP).
  - Isolated networks can also use IP.



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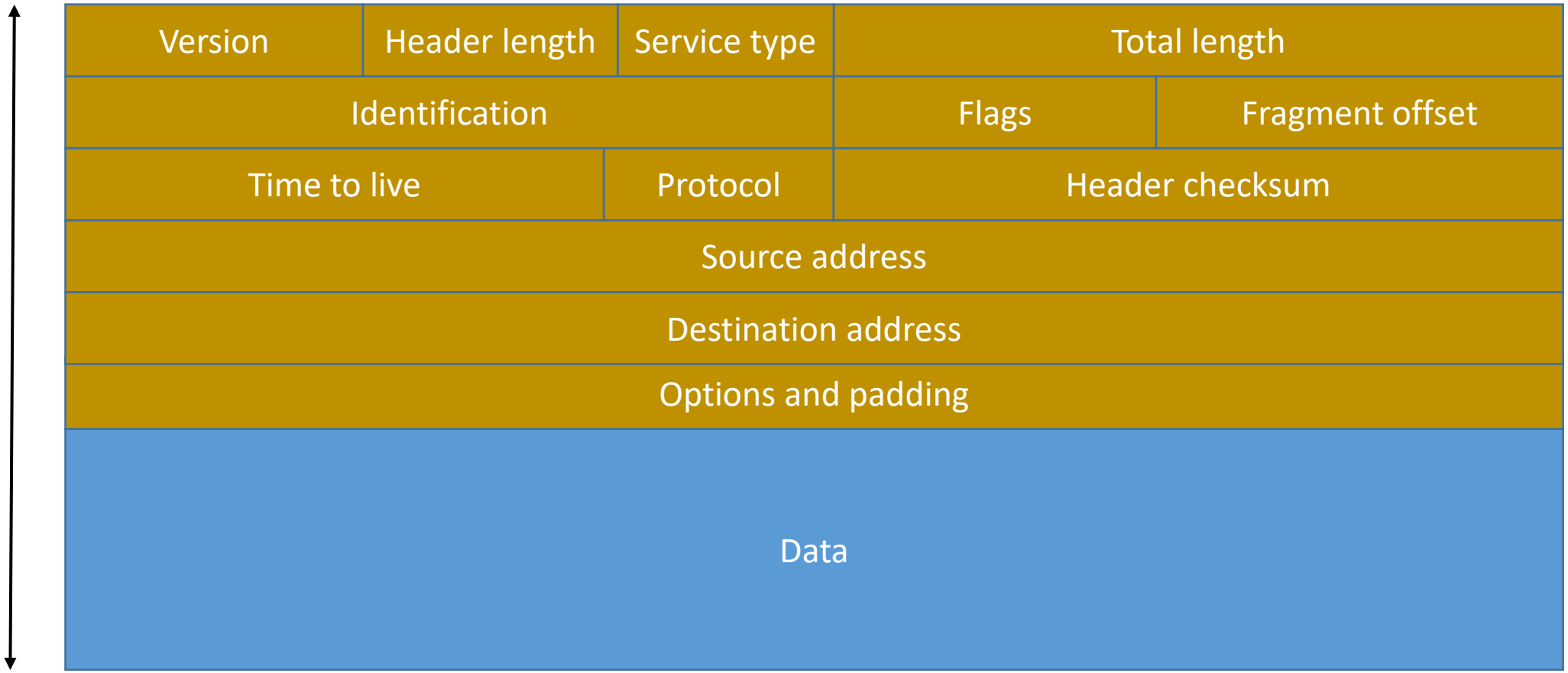


IP routing

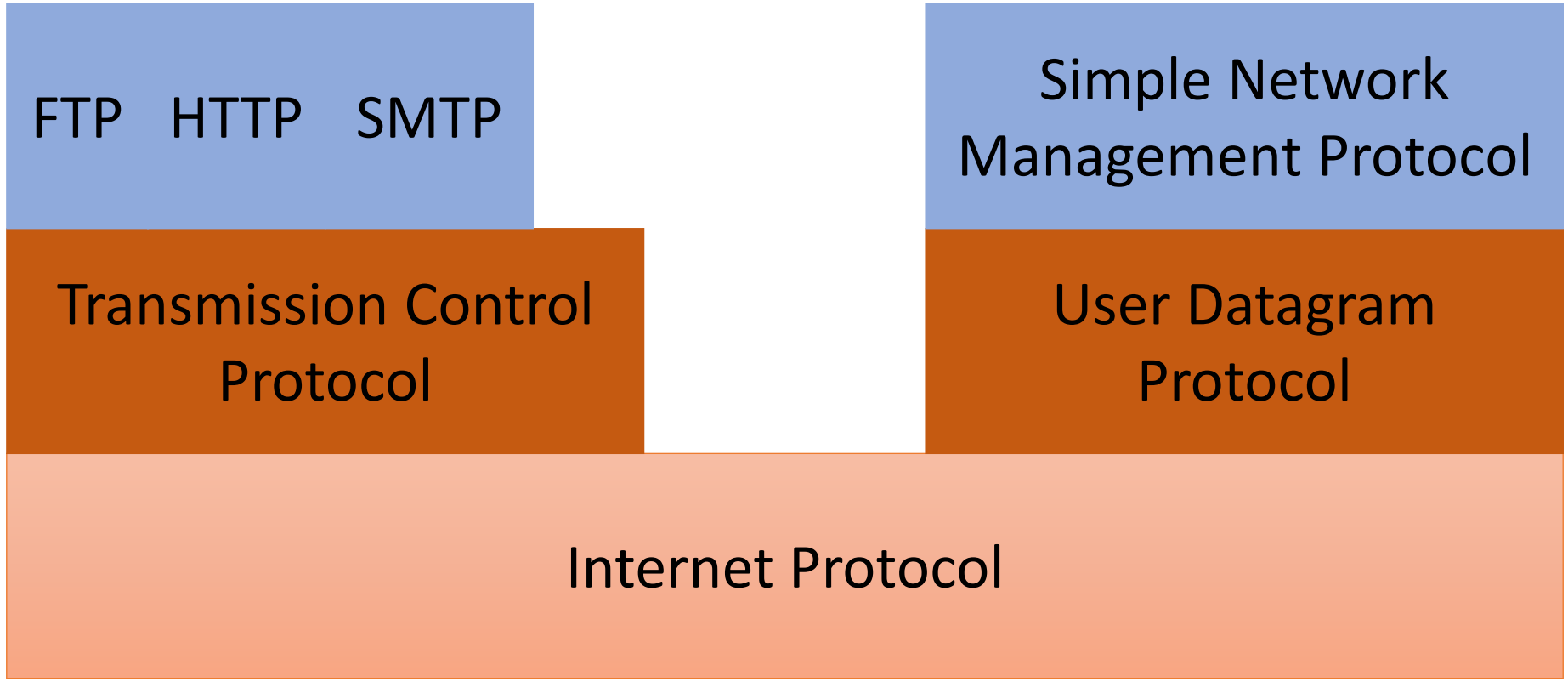
- IP routing is best effort---no guarantees of packet delivery.
- Build other services on top of IP:
  - Use handshakes to verify delivery of packet.
  - Network routers can enforce quality-of-service.

Internet services

- Domain name service (DNS):
  - Map names onto IP addresses.
- File transfer (FTP):
  - Move files from machine to machine.
- Terminal sessions:
  - Telnet provides terminal-style access.
- Web (HTTP):
  - Built on top of FTP.
- Email (SMTP):
  - Built on top of FTP.

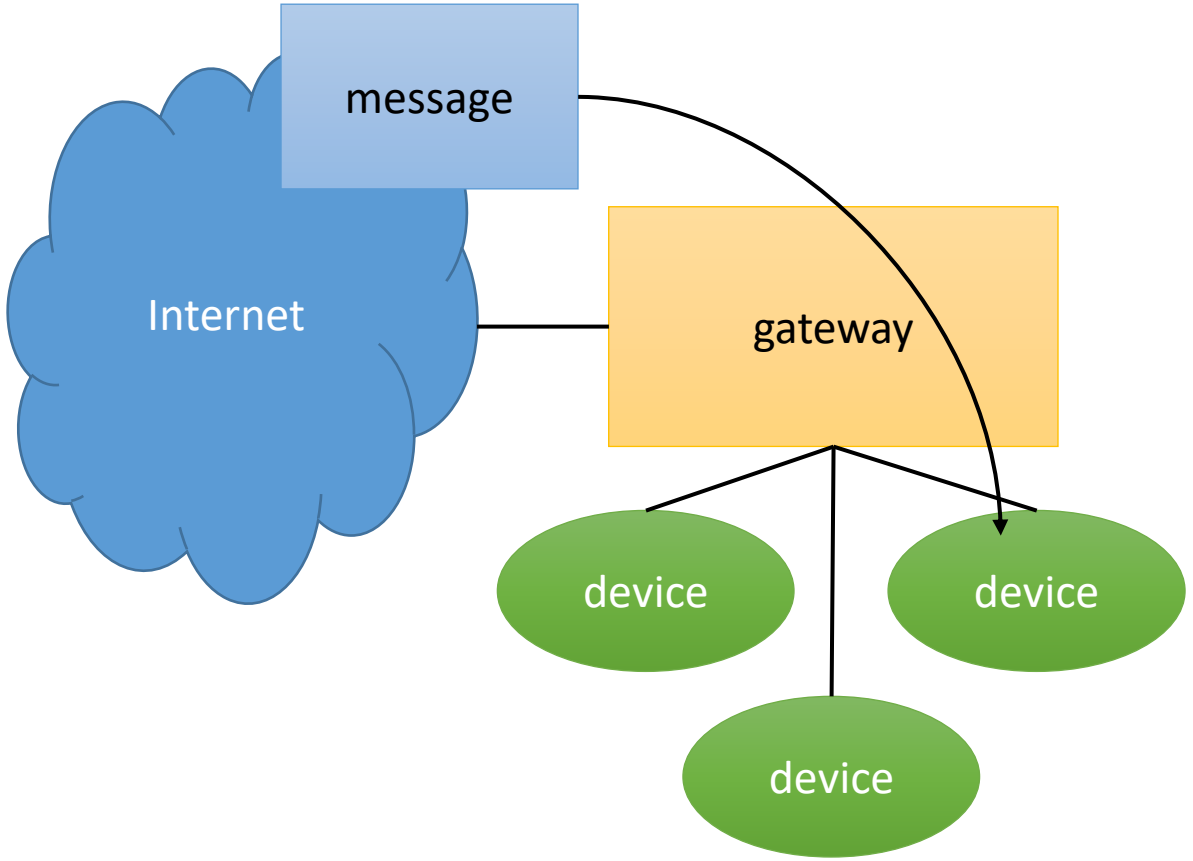
Host-to-host service

- Hides some details of IP:
  - Break host communication into IP packets at source.
  - Reassemble packets at destination.
  - Use handshake to ensure packets arrive, retransmit if necessary.
- Transmission Control Protocol (TCP):
  - Connection-oriented service.
- User Datagram Protocol (UDP):
  - Datagram service.
  - Datagram is modeled after telegram.

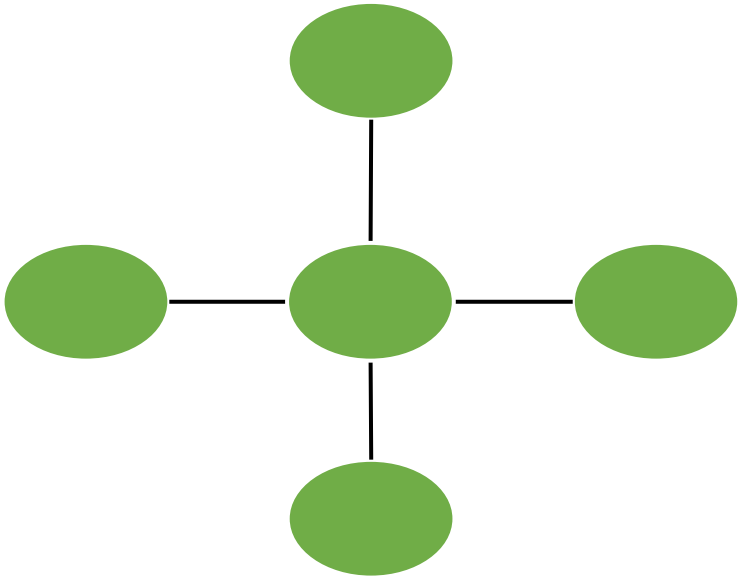


IoT networking concepts

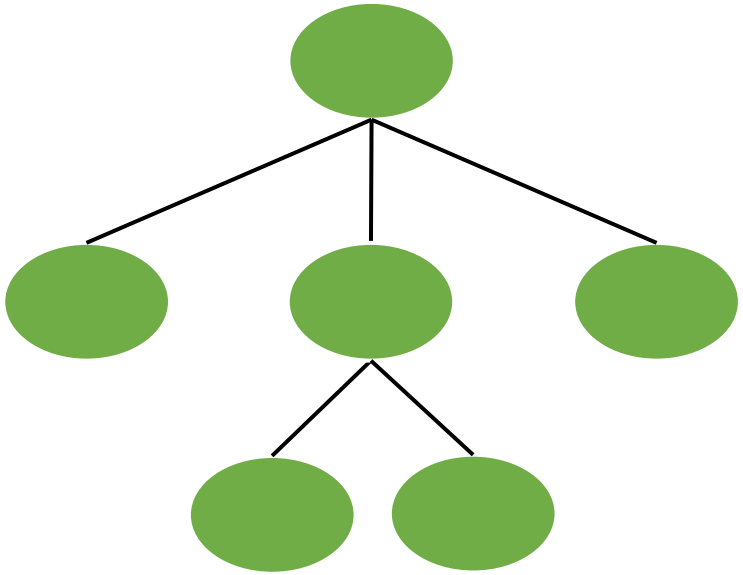
- Edge device may not run IP protocol.
  - IP connection may be provided by hub or gateway.
  - Non-IP networks are known as edge networks.
- Ad hoc network is self-organized---not set up by system administrator.
- Ad hoc network services:
  - Authentication of eligibility to join network.
  - Authorization for access to given pieces of information on the network.
  - Encryption and decryption.



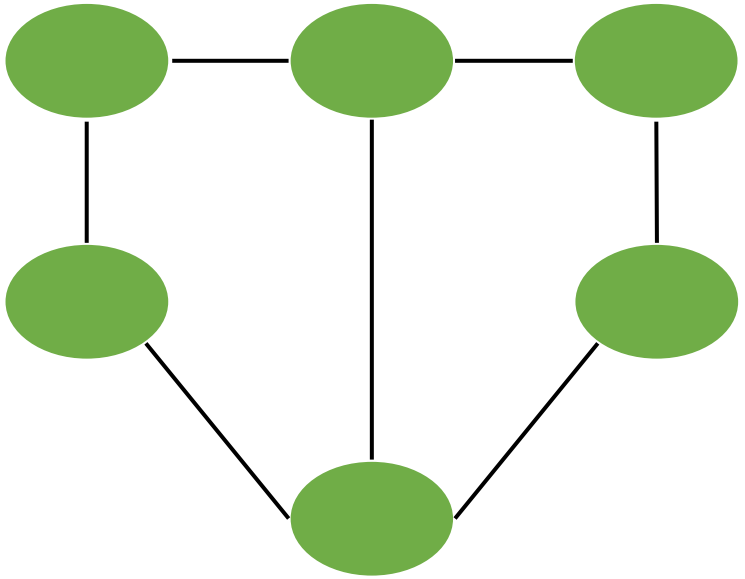
Network topologies



star



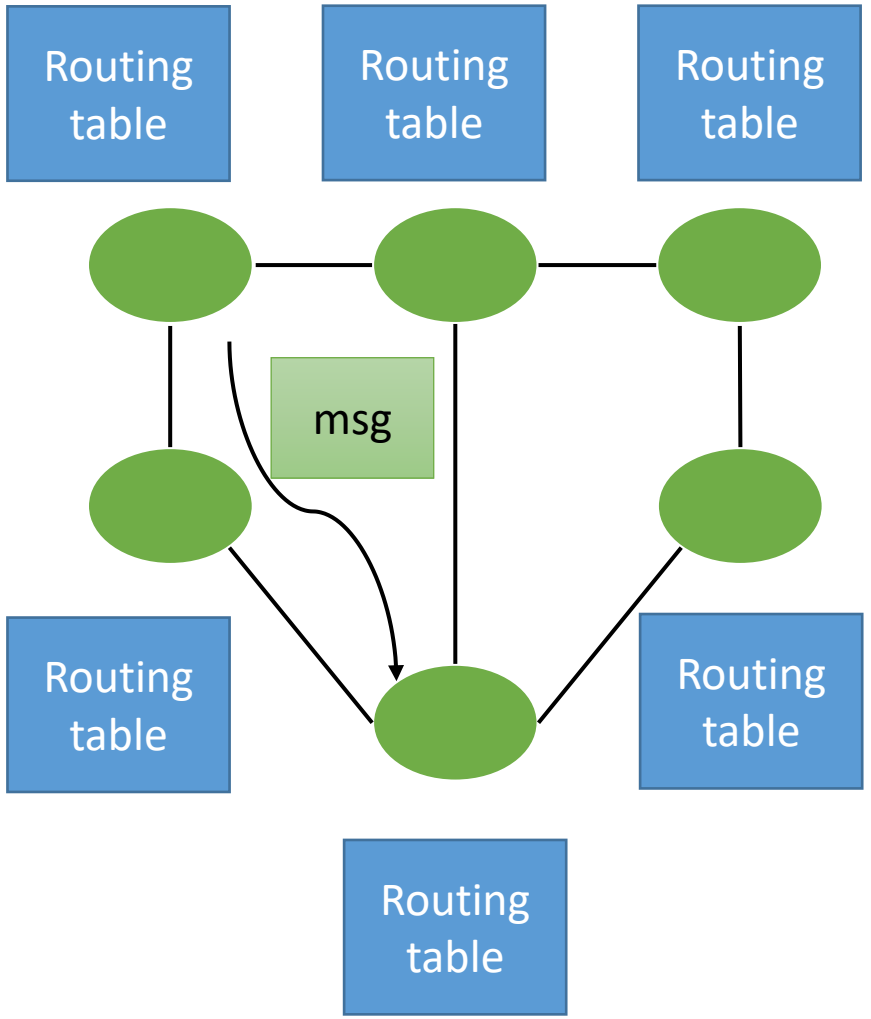
tree



mesh

Routing

- Routing discovery determines routes between source/destination pairs.
- Routing is driven by routing tables at the nodes.

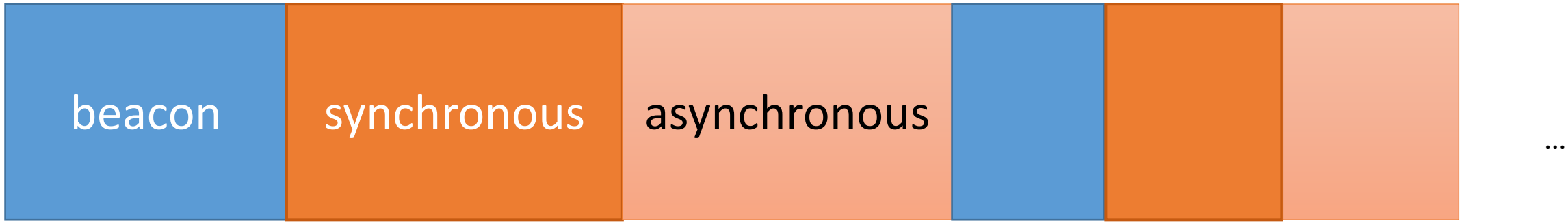


QoS

- Many networks support synchronous and asynchronous communication.
  - Asynchronous: data records, etc.
  - Synchronous: voice, etc.
- Quality-of-service (QoS): bandwidth and periodicity characteristics.
- Admission control ensures that network can handle the QoS demands of a request.

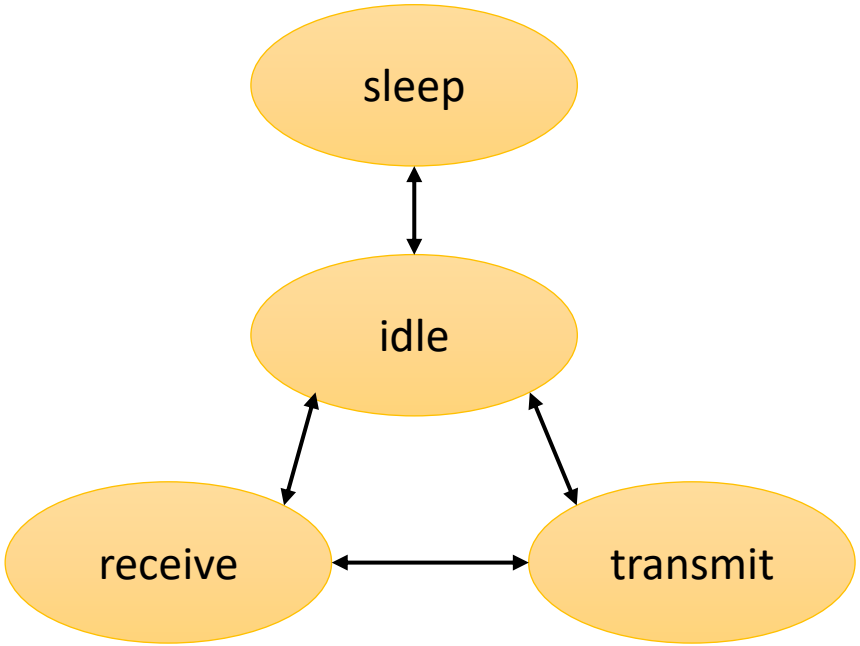
Synchronization and beacons

- Many network operations require nodes to be synchronized.
- Synchronization can be performed using beacon.
  - Beacon transmission marks the beginning of a communications interval.

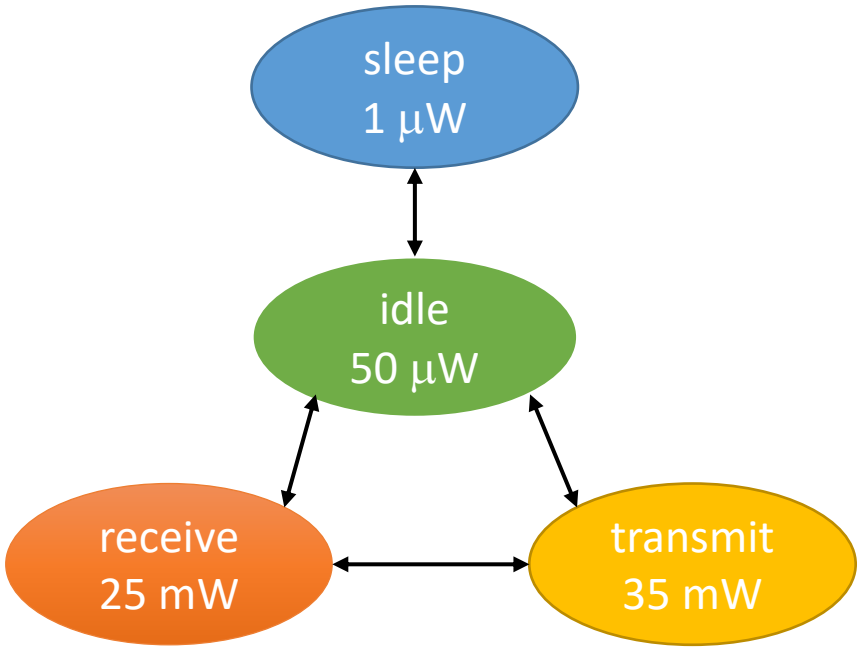


Communcations energy

- Communications energy is a large part of node energy consumption.
- Comm energy consumption depends on many factors and parameters.
  - Generally evaluated for a set of use cases.
- We can use power state machine to model communications energy cost.



Communications power state machine example



step	state	time	energy
1	sleep	1 ms	1 nJ
2	idle	10 μs	0.5 nJ
3	receive	50 μs	1.25 μJ
4	transmit	50 μs	1.75 μJ
5	receive	50 μs	1.25 μJ
6	transmit	50 μs	1.75 μJ
			total = 6 μJ

Bluetooth

- Introduced in 1999, originally for telephony applications.
- Classic Bluetooth operates in instrumentation, scientific, and medical (ISM) band in the 2.4 GHz range.
- Bluetooth networks organized as piconet.
  - One master, several slaves.
  - Slave can be active or parked.
  - A device can be a slave on several networks simultaneously.

Bluetooth stack

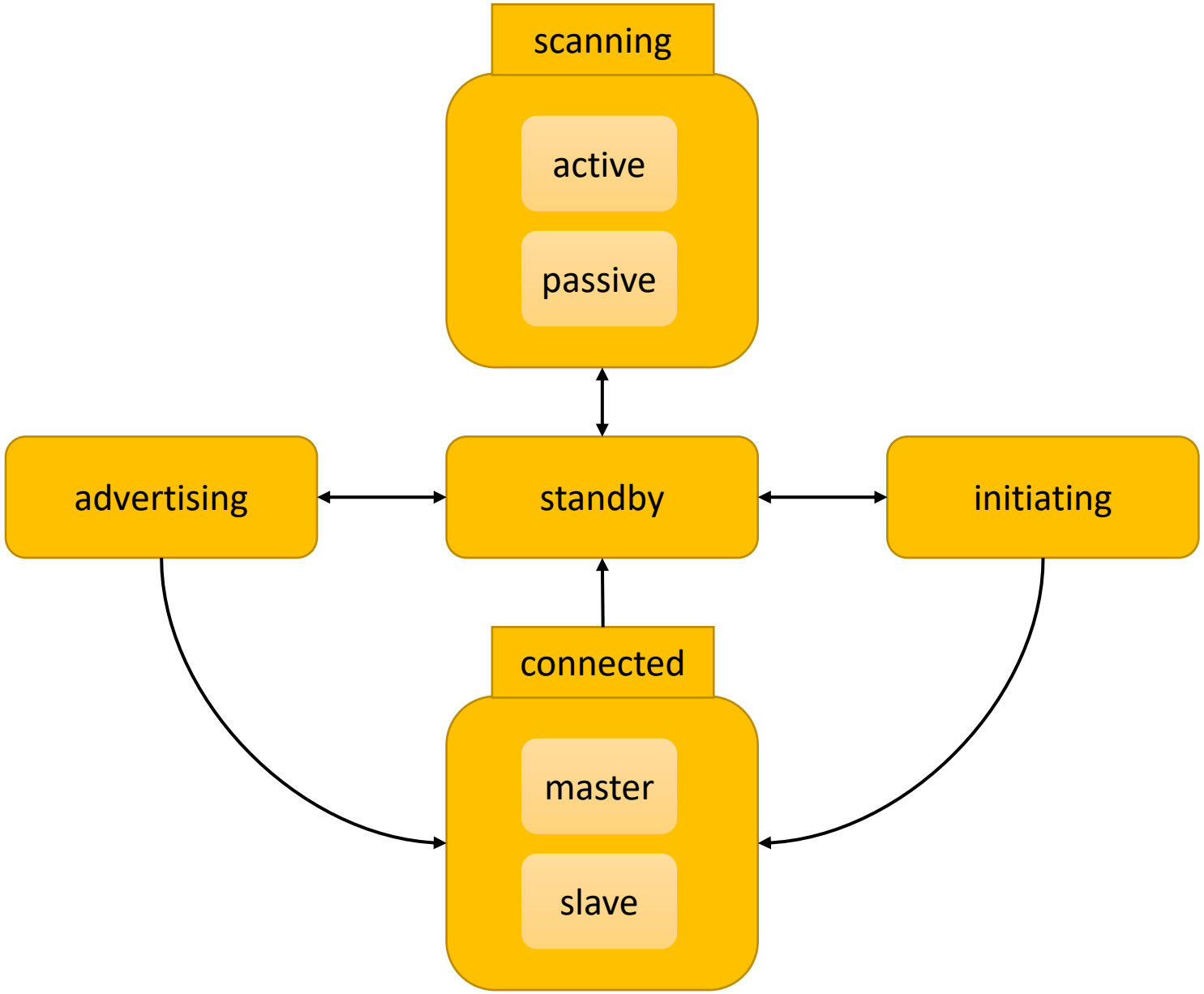
- Transport protocol:
  - Radio, baseband layer, link manager, logical link control and adaptation protocol (L2CAP).
- Middleware:
  - RFCOMM for serial port, service discovery protocol, Internet Protocol, IrDA, etc.
- Applications.

Bluetooth protocol

- Every Bluetooth device has a 48-bit Bluetooth Device Address.
- Every device has a Bluetooth clock.
- Transmissions alternate between master and slave directions.
- Two types of packets:
  - Synchronous connection-oriented (SCO) packets for QoS-oriented traffic.
  - Asynchronous connectionless (ACL) packets for non-QoS traffic.
  - SCO traffic has higher priority than ACL packets.

Bluetooth Low Energy

- Designed for very low energy operation such as button-sized battery.
  - Goal: minimize radio on-time.
- Part of Bluetooth standard but deviates from Classic Bluetooth in several ways.
- Advertising transmissions can be used to broadcast, discover devices, etc.
- Connections can be established.
- Attribute Protocol Layer allows devices to create application-specific protocols.
- Generic Attribute Profile Layer (GATT) defines basic attributes for all BLUE devices.
- Pairing devices uses a short-term key to send a long-term key.
  - Bonding: storing long-term key in device database.
  - Optional data encryption using AES.



802.15.4 and ZigBee

- 802.15.4 defines MAC and PHY layers.
  - Supports full-function and reduced-function devices.
  - Either star or peer-to-peer topology.
  - Communciation performed using frames.
  - Optional superframe provides a beacon mechanism and QoS.
- ZigBee is a set of application-oriented standards.
  - NWK layer provides network services.
  - APL layer provides application-level services.
  - Supports many different topologies.

Wi-Fi

- Originally designed for portable and mobile applications.
  - Has been adapted for lower-energy operation.
- Supports ad hoc networking.
- Network provides a set of services:
  - Distribution of messages from one node to another.
  - Integration delivers messages from another network.
  - Association relates a station to an access point.

IoT systems

- Databases.
- Timewheels.
- Example: smart home.

Databases

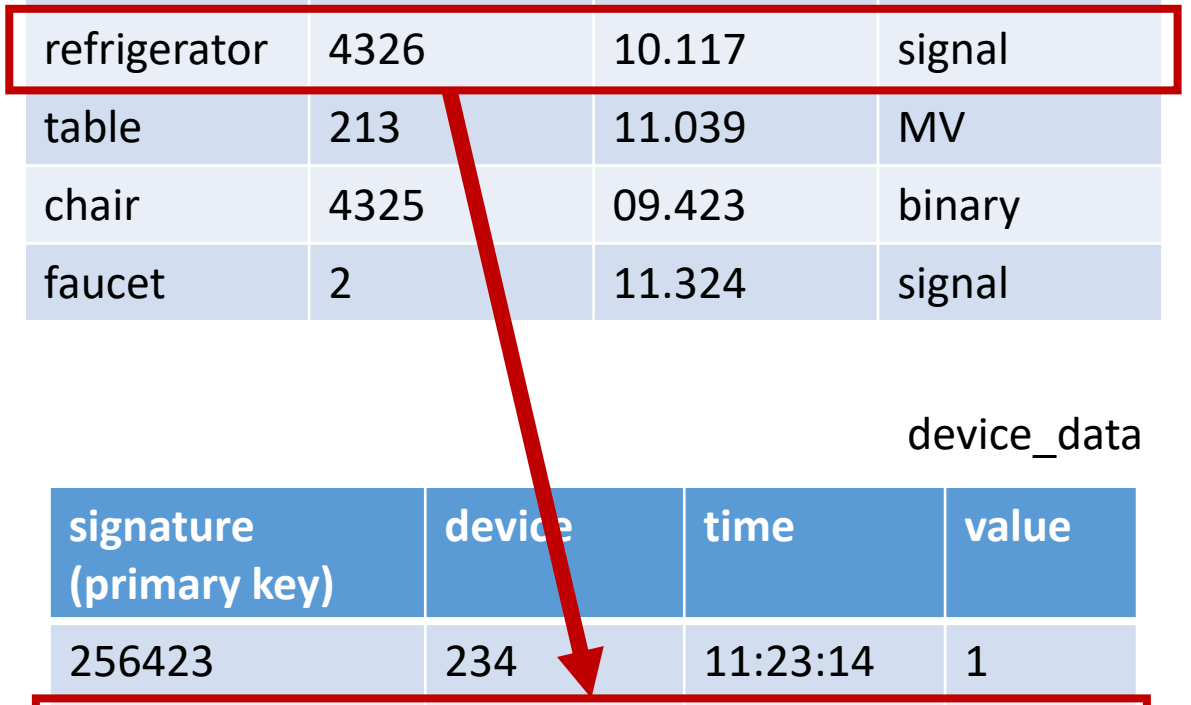
- Database holds data about devices, helps to analyze data.
- Relational database management system:
  - Domain1 X domain2 X … -> Range.
- Database organized into records or tuples:
  - Attribute: table column.
  - Record: table row.
- One column is the primary key---uniquely identifies a record.

Database example

devices

name	id (primary key)	address	type
door	234	10.113	binary
refrigerator	4326	10.117	signal
table	213	11.039	MV
chair	4325	09.423	binary
faucet	2	11.324	signal

record



device_data

signature (primary key)	device	time	value
256423	234	11:23:14	1
252456	4326	11:23:47	40
663443	234	11:27:55	0

Schemas

- Schema: definition of tables in database.
- Eliminating redundant storage of data helps to ensure database consistency.
- Normal forms help eliminate redundancies and other problems:
  - First normal form: every cell contains a single value.
  - Second: First + values of cells in a record are unique to the key.
  - Third: Second + non-key columns are independent.

Queries

- Query: request for information from database.
- Structured query language (SQL) isolates user from details of schema.
  - Select from device_data where device = 234
- Join: combine information from more than one table.
- Projection: eliminate some columns.
- Restriction: eliminate some rows.

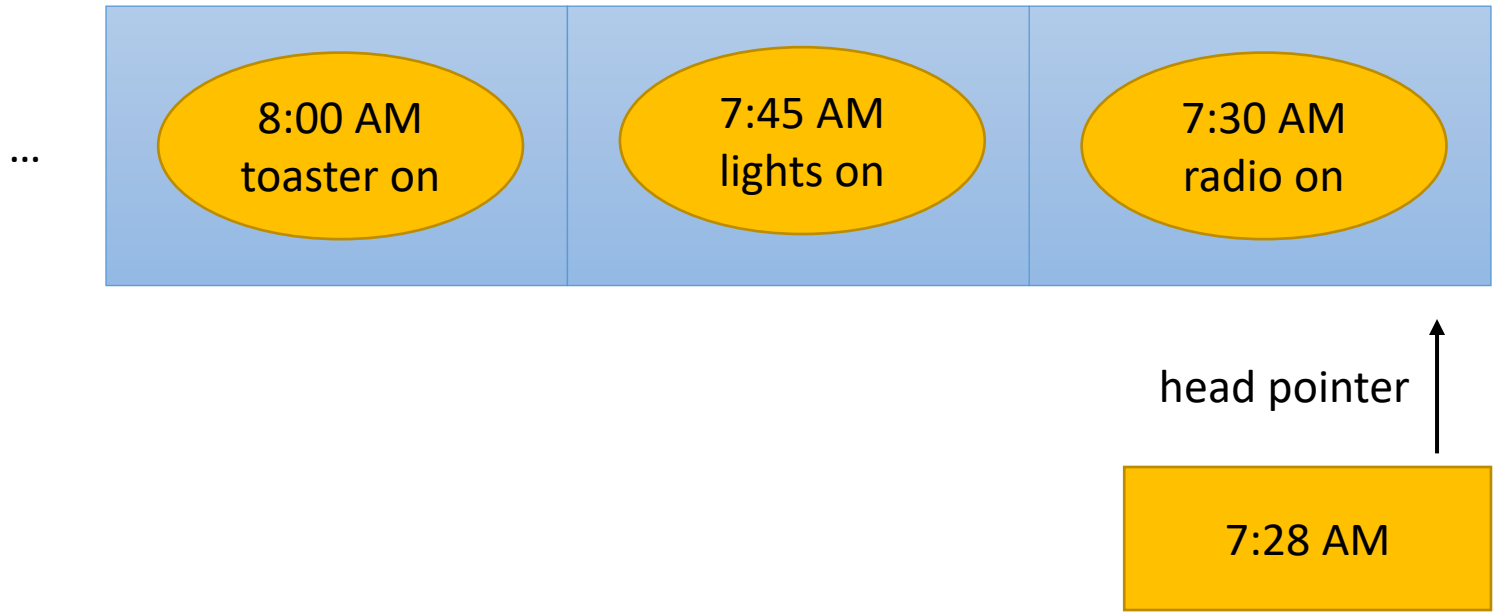
Schemaless databases

- Some simple data models do not have a schema.
  - Schemaless or noSQL.
- JSON is an example schemaless language.
  - Name/value pairs, ordered lists of values.
- Schemaless databases may be simpler to set up, harder to maintain.

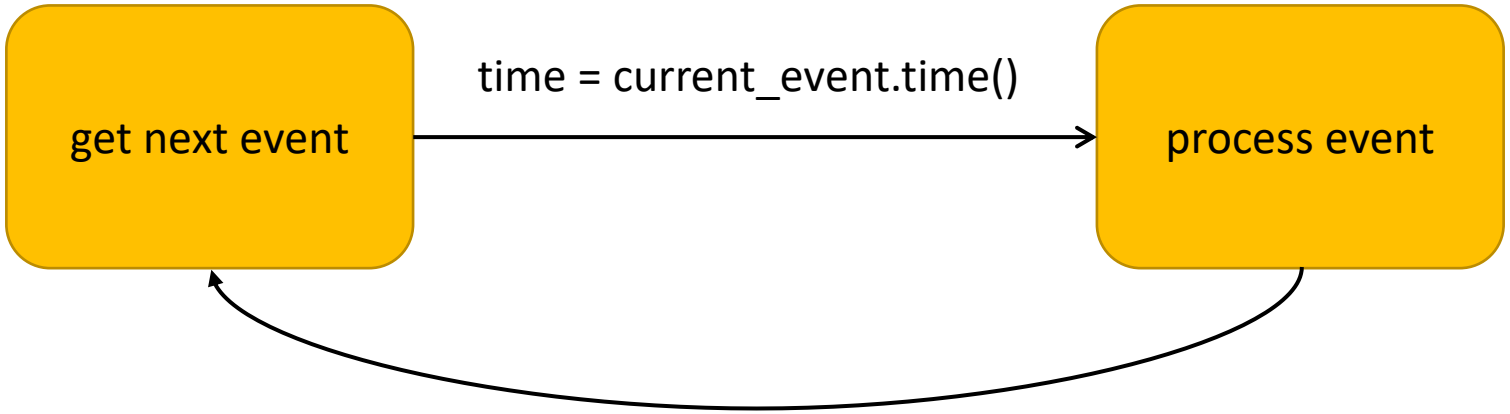
Timewheels

- Used to manage timing of events in the system.
- Timewheel is a time-sorted set of events.
  - Event placed in proper spot in timewheel queue upon arrival.
  - When current time is equal to time of event at head, event is processed.

Timewheel data structure



Timewheel state diagram

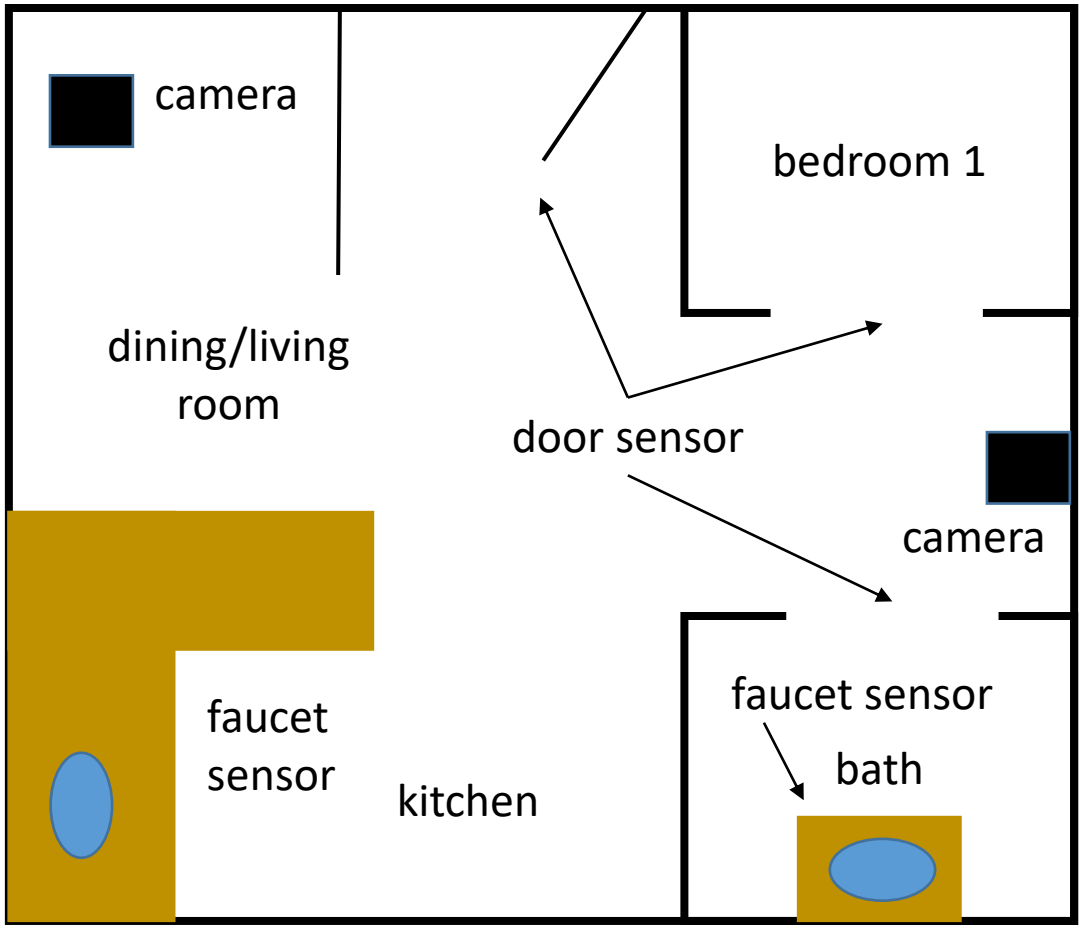


Example: smart home

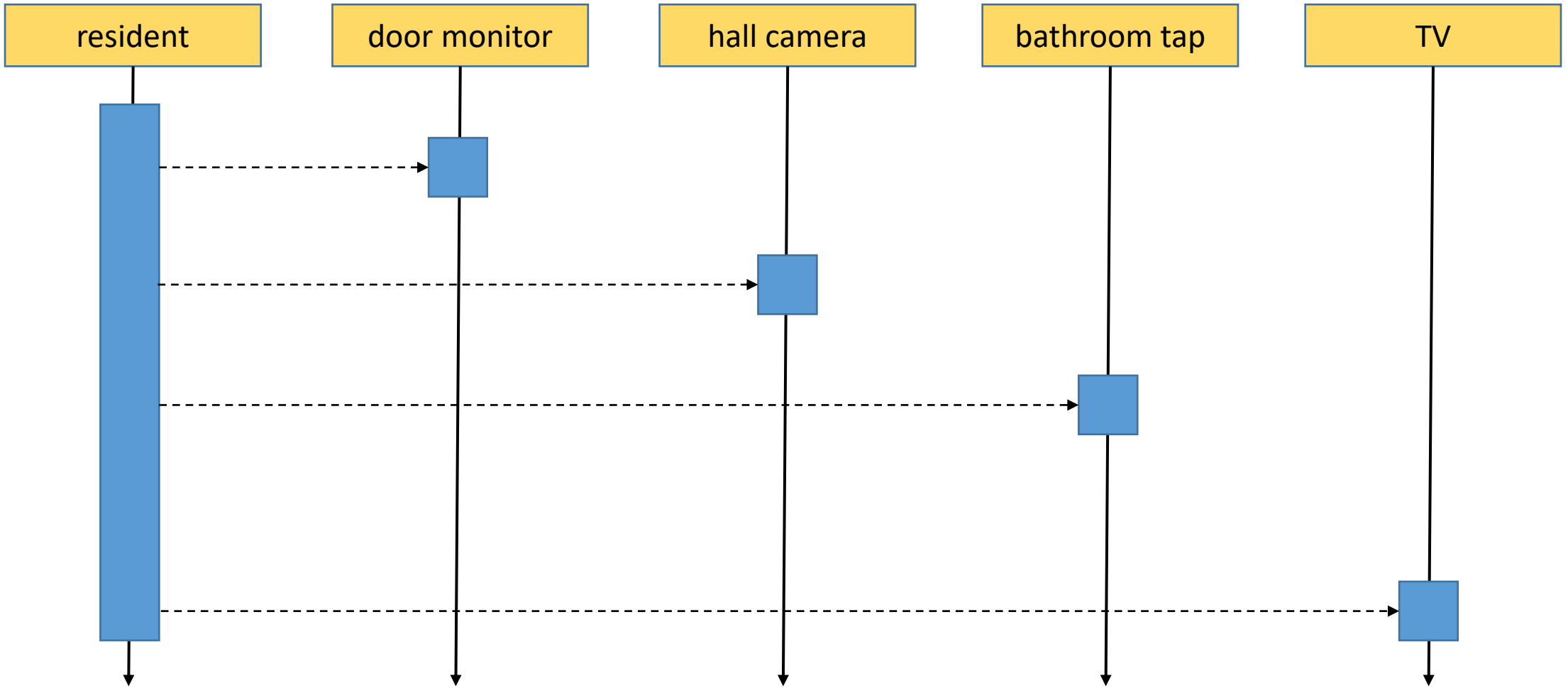
- Performs a variety of services:
  - Remote or automatic operation of lights and appliances.
  - Energy and water management.
  - Activity monitoring.
- Activity monitoring can help elderly, people with special needs:
  - Reports on daily activities.
  - Alerts for out-of-the-ordinary activity.
  - Recommendations.

Example smart home

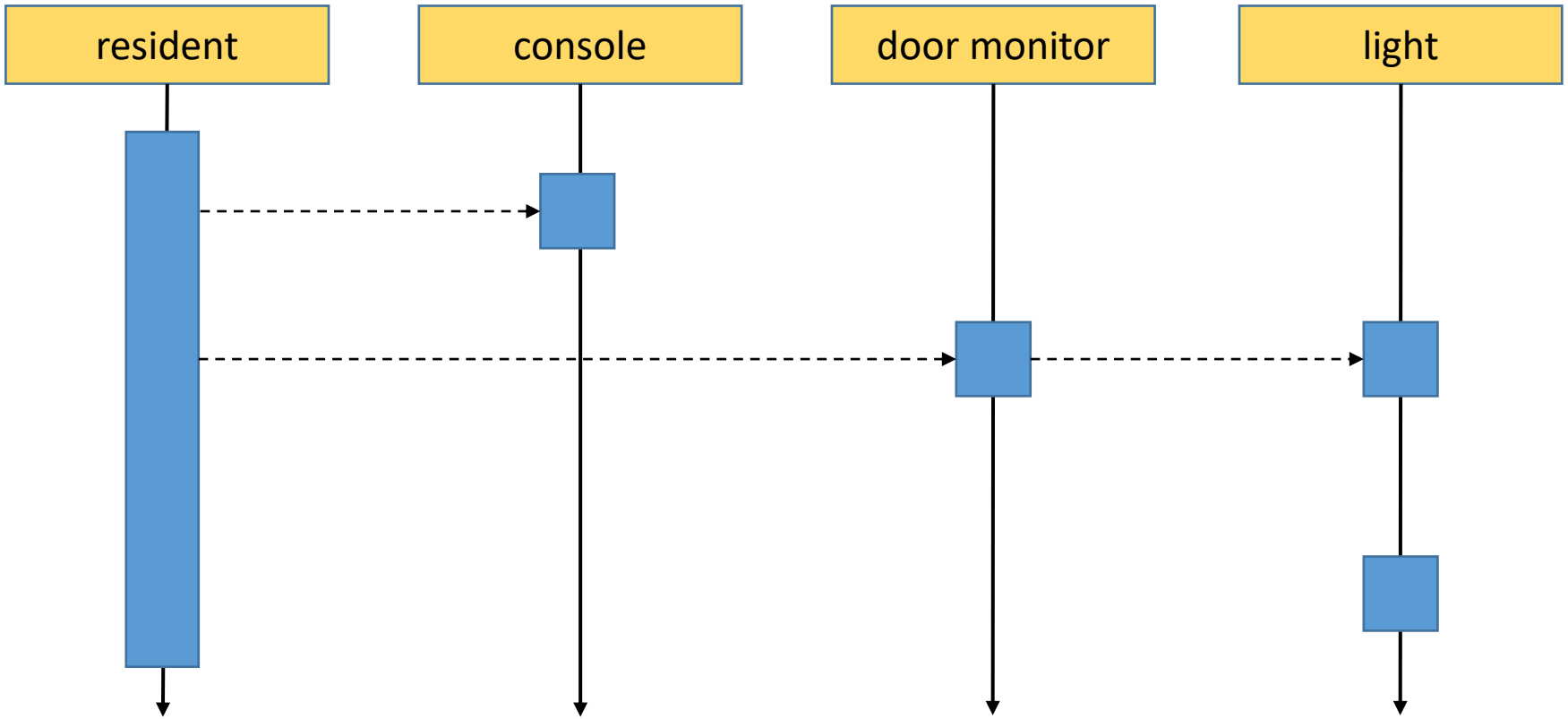
- Cameras can identify resident and their activity.
- Faucet, door sensors can identify activity but not who performs the activity.



Use case: activity monitoring



Use case: light control



Smart home object diagram