Lecture 2. Basics of networking in automotive systems: Network topologies, communication principles and standardised protocols

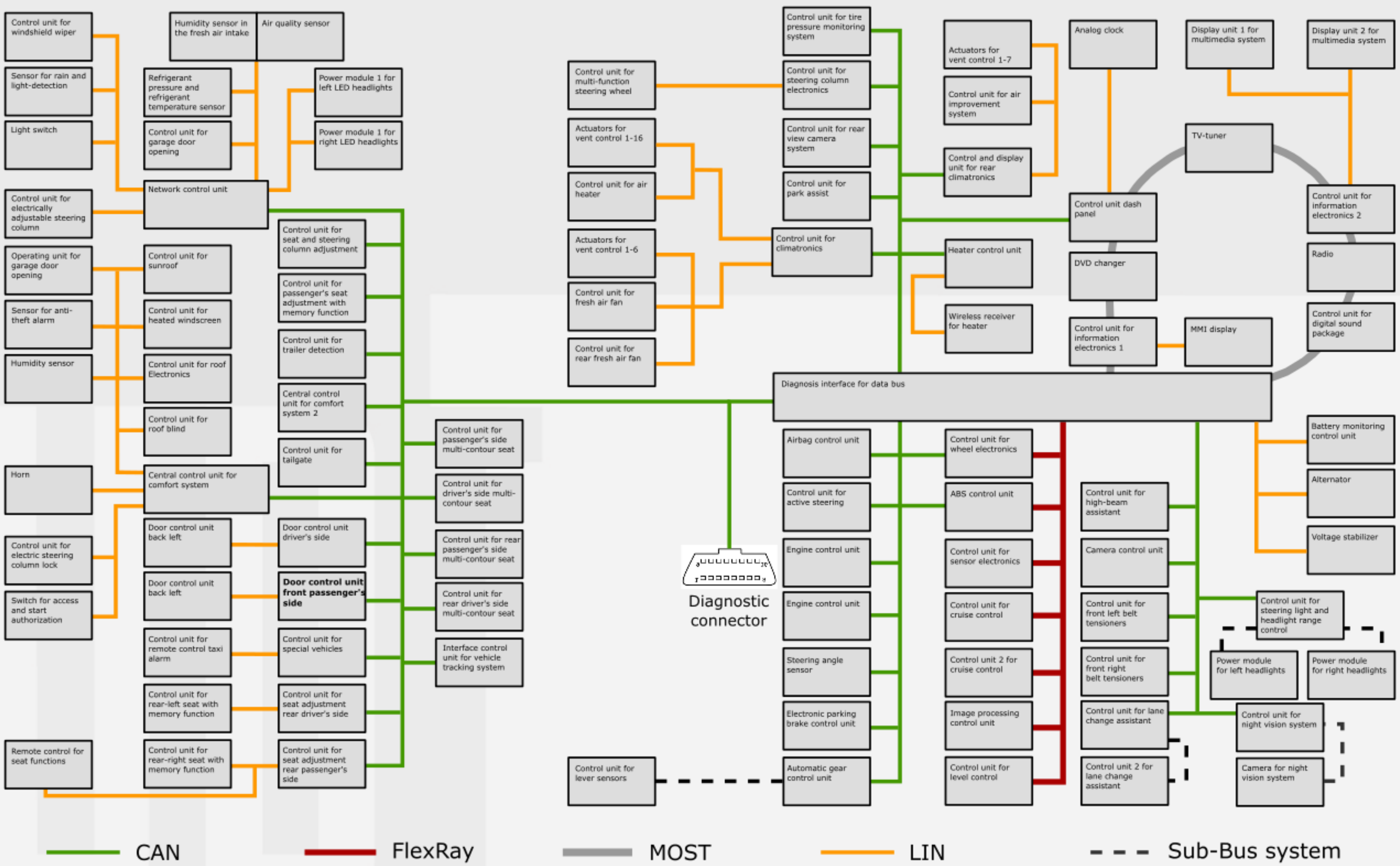
Objectives

- Introduce basic concepts used in building networks for automotive embedded systems

Main Reference

[2] Robert Bosch GmbH, *Bosch Automotive Electrics and Automotive Electronics: Systems and Components, Networking and Hybrid Drive*, 5th edition, Springer Vieweg, 2014.

Complex in-vehicle networks



In vehicle network of an Audi A8 2010 (Adapted after the AUDI A8 Service repair manual)

Networking requirements

- **Data rate** – Data volume transmitted in the time unit
- **Interference immunity** – Communication has to withstand interference from electromagnetic effects present in the automotive environment
- **Real-time capabilities**
  - **Soft real-time requirements** – The system generally conforms to the specified response time. Occasionally exceeding these timings has no considerable effects
  - **Hard real-time requirements** – Timing requirements are strict. Exceeding limitation can potentially cause to safety-critical issues
- **Number of network nodes** – Some subsystems may require a large number of nodes to achieve expected functionality

Network topology

Network topology – the structure of a network consisting of nodes and interconnections.

The communication requirements of all nodes of a designed system dictate on the network topology

All network topologies are derived from four basic topologies:

- Bus topology
- Star topology
- Ring topology
- Mesh topology

Bus topology

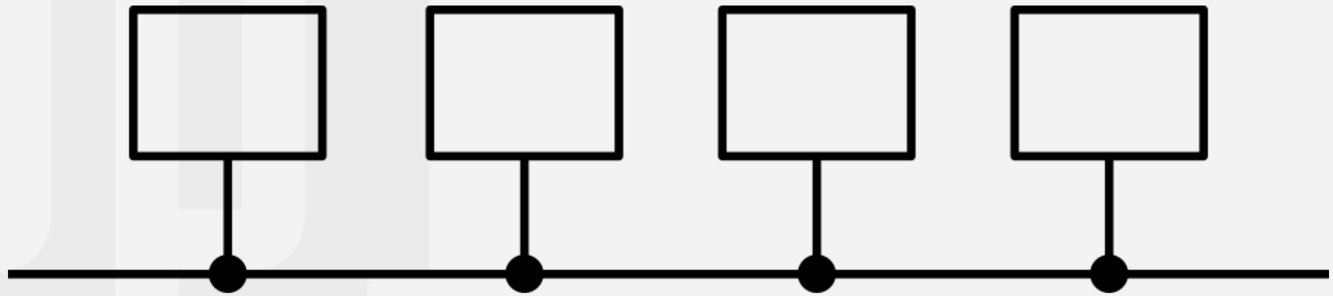
- Also known as a **linear bus**
- All nodes connected to a single cable through tap lines called **stubs**
- Messages are directly received by all nodes

Advantages:

- Adding new network nodes is easy
- Failure of one node does not impede communication between other nodes

Disadvantages:

- A defective main line leads to network failure

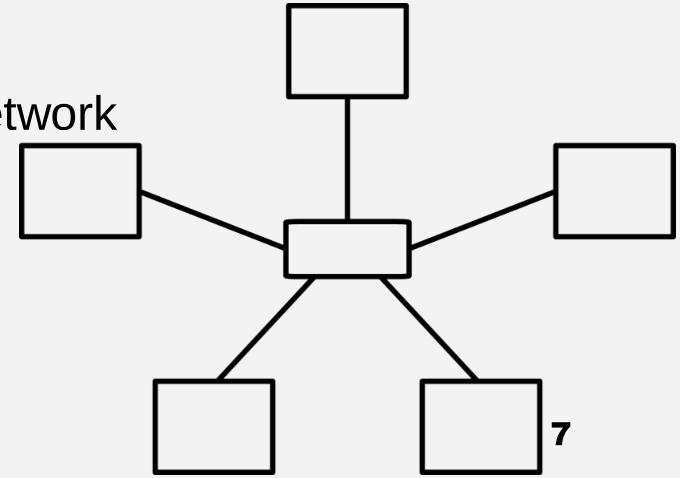


Star topology

- Consists of a main node/hub to which all other nodes are connected
- All nodes send data to the main node
- Star topologies are suitable for **safety** and **security** applications
- Star topology types:
  - **Active** – main node performs processing and message relaying
  - **Passive** – main node only connects node lines together

Advantages:
  - Adding new network nodes is easy
  - If one node (not main) fails the rest of the network continues to function

Disadvantages:
  - A defective main node disables the entire network



Ring topology

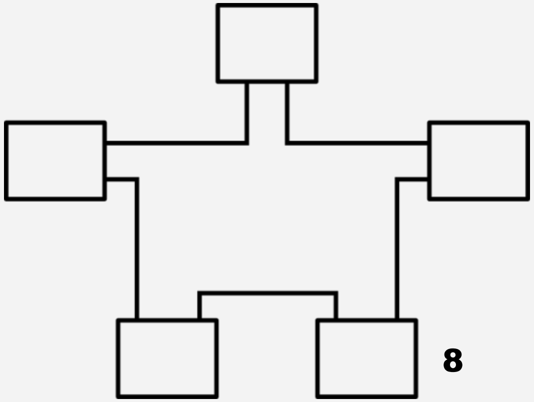
- Each node is connected to its two neighbours
- Ring topology types:
  - **Single ring** – messages sent in one direction from one station to the next one until it reaches its destination or is sent back to its origin
  - **Double ring** – transmission is bidirectional

Advantages:

- Failure of one node in a double ring does not disable communication

Disadvantages:

- A defective node in single rings prevents message transfer beyond it
- Several defective nodes will also disable a double ring



Mesh topology

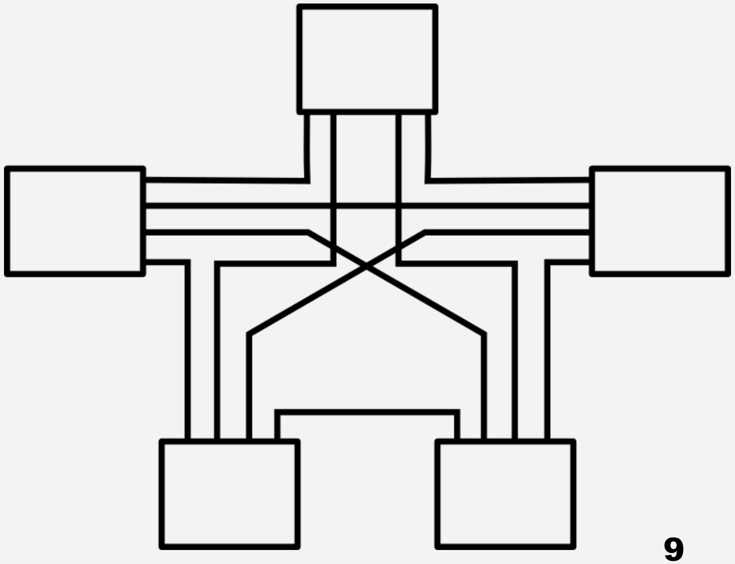
- Each node is directly connected to one or more nodes
- In a **full mesh** each node is connected to all other nodes
- Radio networks are a type of mesh topology – a message transmitted by one node is received by all nodes within range

Advantages:

- If one connection fails the message can be rerouted
- Offers a high degree of reliability

Disadvantages:

- Higher implementation costs



Hybrid topologies

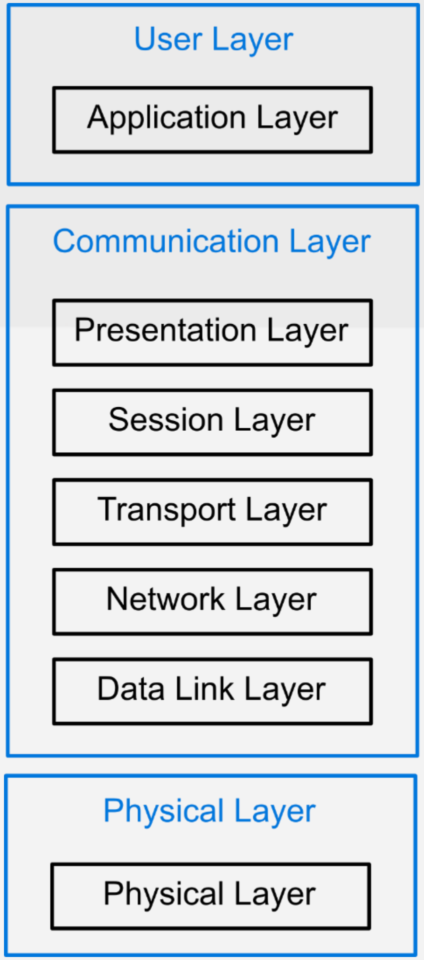
- When none of the basic technologies can accommodate the system requirements hybrid topologies are employed
- Example hybrid topologies:
  - **Star-bus topology** – the hubs of several star sub-networks are connected to a main bus
  - **Bus-star topology** – the main line of several bus sub-networks are connected to a main star hub
  - **Star-ring topology** – the main nodes of several star sub-networks are connected in a ring

Communication principles

- OSI reference model
- Addressing
- Medium access
- Event-triggered/time triggered communication

OSI reference model

- Communication protocols are described using a layered approach
- The ISO OSI model is also used as a reference in the automotive area
- Simpler communication systems do not require all OSI layers
- Automotive protocols usually only define several layers:
  - Physical layer
  - Communication layer
  - Application/User layer



(after Bosch [2], pp.76)

Physical layer

- **Symbol** - the basic logical element used to build messages
- Physical layer
  - Describes the electrical characteristics of the communication – **physical signalling**
  - Specifies the physical signalling behaviour corresponding to logical symbols (most protocols only use two symbols: logical ‘1’ and ‘0’)
- If the implementation allows one level to overwrite another line level, the overwriting level is referred to as **dominant**, while the other level is called **recessive**

Communication and user layers

- **Communication layer**
  - Transforms the data received from the application layer in a format that will be used for the actual transmission of the message by the physical layer
  - Describes the logical aspects of the protocol
  - Handles:
    - Frame format
    - Media access control
    - Collision detection and handling
    - Node synchronization
    - Error detection and handling
- **User layer**
  - The application side that processes and provides transmission data
  - User defined

Addressing

- Information that accompanies the data in order to indicate the message destination
- Addressing modes:
  - **Subscriber-oriented**
    - The message contains the data and the address of the destination node (e.g. Ethernet).
    - Only the indicated receiver node evaluates the message
  - **Message-oriented**
    - The message contains the data and a message identifier that indicates the message type
    - All receivers that use a certain message type will evaluate it on reception
  - **Transmission-oriented**
    - Transmission characteristics are used to identify message content (e..g. a message sent in a specified time slot)
    - This addressing type is often used together with subscriber or message-oriented addressing [2]

Medium access

- Medium access methods can be:
  - **Predictable**
    - medium access is done in specified point in time
    - collisions are prevented
  - **Random**
    - medium access can be achieved at any point in time as long as the medium is free
    - collision resolution methods need to be implemented
- Medium access principles:
  - **Time division multiple access (TDMA)** – Message transmission takes place in specified time slots according to a fixed schedule
  - **Master-slave** – The master node determines when messages are transmitted by interrogating slave nodes
  - **Multimaster** – Several nodes that can access the medium at any time provided no other transmission is ongoing.

Event-triggered communication

- Nodes attempt to transmit messages once an **event** set to **trigger** the transmission has occurred
- This communication model requires **collision detection** and **message prioritisation** methods

- Advantages:
  - New nodes are easily retrofitted in the network
  - Fast response time to random events
  - Network time is not pre-allocated to transmissions that may not occur
- Disadvantages:
  - Due to non deterministic network access transmission time for a certain messages cannot be known

Time-triggered communication

- Especially used in system that require a high degree of **reliability** (e.g. X-by-wire)
- Assures that messages are received within specified time limits
- Incorporate **redundant** design
- Required precise **time synchronization** between nodes

- Advantages:
  - The system is deterministic
  - Timely message transmission is assured
  - Defective nodes are efficiently detected and isolated
- Disadvantages:
  - Requires a priory system planning including future expansions
  - Response to asynchronous events is deferred to an allocated time slot

Protocols for in-vehicle communication

	CAN-C high-speed CAN	CAN-B low-speed CAN	LIN	TTP	MOST Bus	Bluetooth	Flexray
Definition	Controller area network	Controller area network	Local interconnect network	Time-triggered protocol	Media oriented systems transport	Proprietary name (Danish king)	Proprietary name
Bus type	Conventional bus	Conventional bus	Conventional bus	Conventional and optical bus	Optical bus	Wireless	Conventional and optical bus
Domains	Drivetrain	Comfort/ convenience	Comfort/ convenience	Safety-related networking	Multimedia and Infotainment	Multimedia and Infotainment	Deployment across all domains
Applications	Engine management, transmission control and ABS/ESP net-working	Body and comfort and convenience electronics net-working	Low-cost expan-sion of CAN bus for simple applications in the comfort and convenience electron-ics area	Networking in safety-related environments such as brakes, steering, railway signal boxes or aircraft landing gear	Transmission of control, audio and video information	Data transfers over short distances, e.g. mobile phone integration in the infotain-ment system	A network system for use in safety-related and simple applications
Most frequently used topology	Linear bus	Linear bus	Linear bus	Star topology	Ring topology	Network topology (radio)	Star topology
Data transfer rate	10 kbit/s to 1Mbit/s	Max. 125 kbit/s	Max. 20 kbit/s	Unspecified, typ. 10 Mbit/s	Max. 22.5 Mbit/s	Max. 3 Mbit/s (v2.0) Max. 723 kbit/s (v1.2)	Typ. 10 Mbit/s Max. 20 Mbit/s
Max. number of nodes	10	24	16	Unspecified	64	8 active (up to 256 passive)	Theoretically up to 2,048 Max. 22 per passive bus/star
Control mechanism	Event-driven	Event-driven	Time-driven	Time-driven	Time and event-driven	Event-driven	Time and event-driven
Bus lines	Copper conductors (twisted pair)	Copper conductors (twisted pair)	Copper conductor (single wire)	Copper conductors (twisted pair)	Plastic or glass optical waveguides	Electromagnetic radio waves	Copper conductors (twisted pair)
Deployment	in all vehicles	in all vehicles	in all vehicles	Premium class vehicles, aircraft, rail control systems	Premium class vehicles made by European manufacturers	All vehicles, connection be-tween multimedia equipment and infotainment system	Pilot application
Standard	ISO 1198	ISO 11519-2	LIN consortium	TTA group	MOST cooperation	Bluetooth SIG	Flexray consortium
SAE classification	Class C	Class B	Class A	Drive-by-wire	Mobile Media	Wireless	Drive-by-wire

(from Bosch [2], pp. 82)

Automotive protocols classification

Class	Transfer rates	Applications	Representatives
Class A	Low data rates (< 10kBit/s)	Sensors and actuators	LIN
Class B	Average data rates (< 125kBit/s)	Complex mechanisms for error handling, control unit networking in the comfort functions	Low speed CAN, PSI5
Class C	High data rates (< 1MBit/s)	Real-time requirements, control unit networking in the drive and running gear functions	High speed CAN
Class C+	Extremely high data rates (< 10MBit/s)	Real-time requirements, control unit networking in the drive and running gear functions	FlexRay
Class D	Extremely high data rates (> 10MBit/s)	Control unit networking in the telematics and multimedia functions	MOST, Ethernet

(after Bosch [2], pp.85)