Bluetooth: IEEE 802.15.1

→ PAN (personal area network)

Features:

- overlapping 2.4 GHz ISM frequency band

  → 2.402–2.480 GHz

- divide into 79 carrier frequencies (i.e., channels)

  → 1 MHz bandwidth each

- target range ∼10 m

- bandwidth range 125 Kbps–2 Mbps

  → between WLAN and IoT (Internet of Things)

  → has become key IoT enabling technology

Centralized master/slave architecture:

→ 1 master (M), up to 7 slave (S) devices

→ polling based MAC protocol

→ contention-free

Bluetooth MAC:

- M selects S to communicate with

  → round-robin

- frequency hopping

  → 1600 hops per second

- TDMA with 625 μsec time slots
- TDD: M even slots, S odd slots
- adaptive

  → avoid crowded frequencies

  → channel map

Operation:

- two modes

  → SCO (synchronous connection oriented): isochronous streaming, no retransmission

  → ACL (asynchronous connectionless): interactive, retransmission

- nominal bandwidth: 1 Mbps (version 1.2), up to 2 Mbps (versions 3–5)

  → enhanced data rate: 24 Mbps (3.x–4.x), 50 Mbps (5.x)

- pairing: shared private key

  → PIN based

  → incorporation of cryptographic primitives

BLE (Bluetooth Low Energy):

→ Bluetooth versions 1.x–3.x: speed

→ 4.x: focus on reducing energy consumption

→ v5.x (v5.4): power efficiency, reliability, security

→ applications: smart phones + IoT and variants

→ e.g., automobiles (e.g., smart phone instead of fob as key, TPMS), home automation (e.g., light bulbs, door-locks, security cams)

Operate at lower data rate

→ e.g., 125 Kbps–2 Mbps

→ event-driven by slave device: interrupt vs. polling

→ initiation through advertisement packets

→ focus: minimize energy consumption at slave devices

Device initiated advertisement:

- 40 channels vs. 79 for classic Bluetooth
- 3 used for advertisement
- advertisement interval: configurable 20 ms–10.24 s
- central device monitors channel activity: discovery
- responds to establish connection for data transfer
- initiated by central device, peripheral device passive

Increasing advertisement interval decreases energy consumption

→ application dependent

→ asymmetry assumption: peripheral vs. central device

→ central device: large battery capacity or connected power source

ZigBee: IEEE 802.15.4

→ low bit rate: 250 Kbps

Features

- 2.4 GHz ISM

  → 16 channels

  → plus 868 MHz and 915 MHz bands

- uses CSMA MAC protocol

  → data, ack, beacon, control frames

- both short- and long-range

  → 10 m (PAN) and 100+ m (e.g., sensor networks)

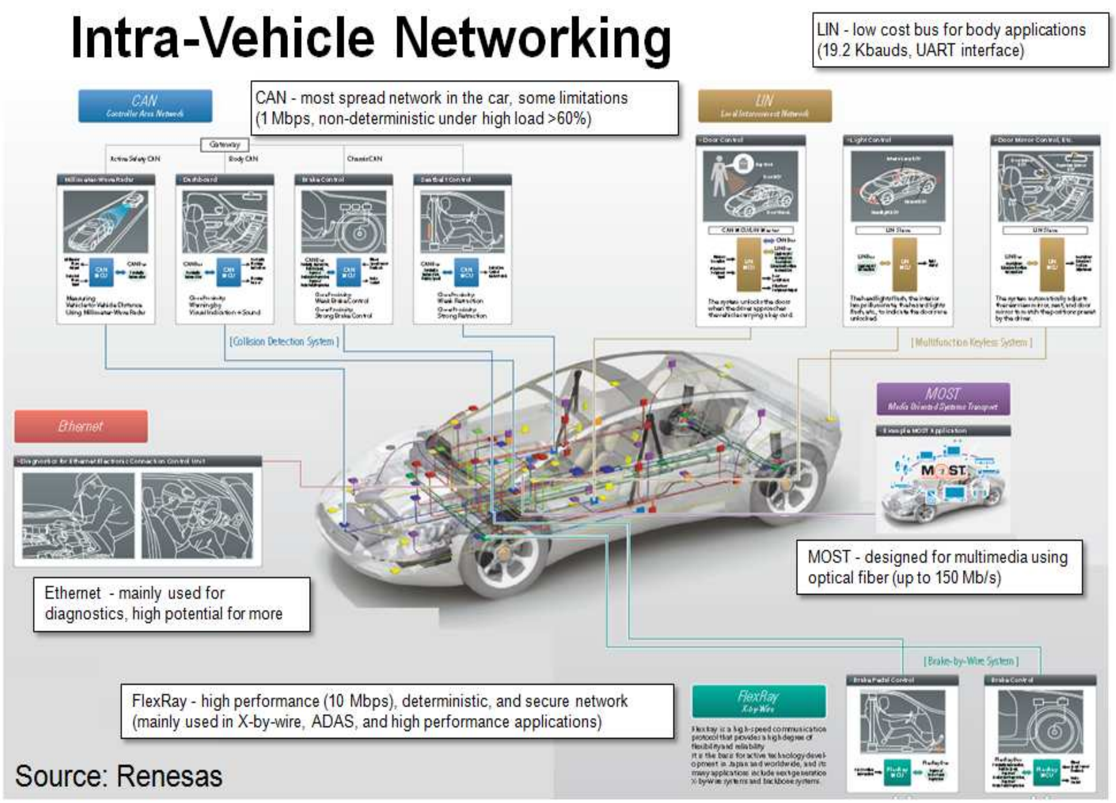
In practice, functional overlap with Bluetooth and WLAN

→ future uncertain

Control Area Network (CAN): ISO 11898

→ dominant standard for vehicular networks

CAN is dominant but on-going developments driven by changing needs.



→ CAN, LIN, Ethernet, MOST, etc.

→ intra- vs. inter-vehicle

CAN architecture:

- twisted pair copper with differential coding

  → similar to FastEthernet and telephone wires

- maximum bandwidth 1 Mbps

  → 5 Mbps on CAN-FD (flexible data-rate)

- connect tens of ECUs (electronic control units) in vehicles

  → engine, transmission, brake, suspension, sensors, lights, battery, navigation, infotainment, etc.

  → some more critical than others

  → real-time constraints

- MAC protocol: CSMA/CD

  → what's going on?

  → non-destructive arbitration (NDA)

CAN data frame format

→ 1-bit SOF (start-of-frame)

→ 11-bit identifier (CAN 2.0A)

→ 29-bit identifier (CAN 2.0B)

→ control, payload, CRC, EOF (end-of-frame) bits

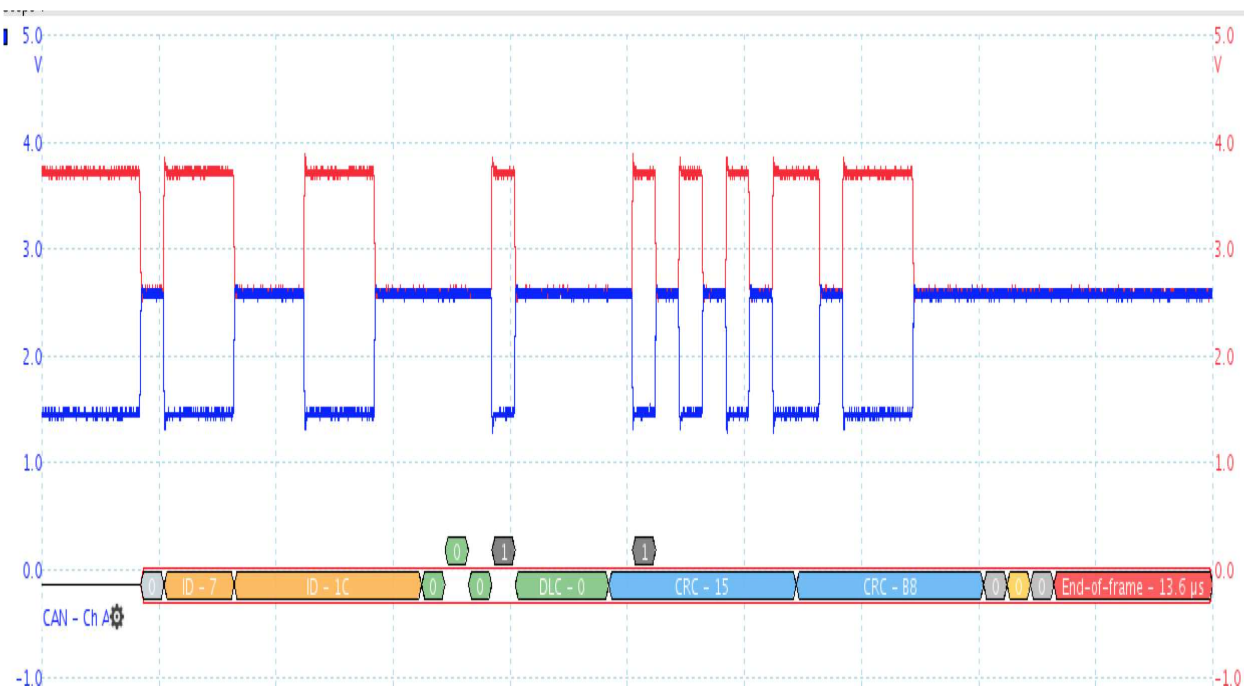
Role of 11-bit identifier field

→ packet priority

→ 00000000000: highest priority

→ 11111111111: lowest priority

Example: captured CAN frame

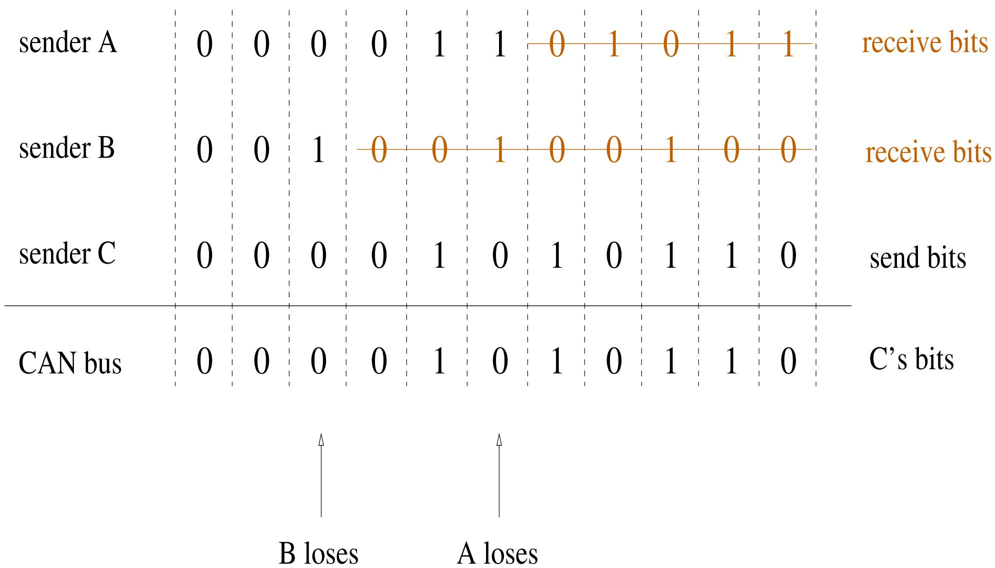


CAN HI (red) signal:

→ high voltage bit value 1

→ low voltage bit value 0

CSMA/CD with NDA example:



- bus arbitration method: wired-AND
- collision does not lead to frame destruction

  $\rightarrow$ TDMA time slots are not wasted

CSMA/CD with NDA: works as long as there is one clear winner

→ one highest priority (i.e., identifier) frame

→ careful design and operation

Suffers under weakness of priority scheduling

→ delay of lower priority frames

→ potential starvation

→ lower priority does not imply unimportant

Scalability.

Works underway for implementing generalized real-time packet scheduling.

RFID (Radio Frequency Identification) and NFC (Near Field Communication):

→ low-bit rate, short-distance wireless communication

→ NFC: close proximity (inches)

→ inductive/magnetic coupling

Device: two types

- reader/writer
- tag

Frequency band

- 125 KHz (unregulated): RFID
- 13.56 MHz (ISM): RFID, NFC
- others (e.g., 433.92 MHz, 915 MHz ISM)

Bandwidth

→ from 4 Kbps up to 848 Kbps

→ ISO 14443, 18000-x

→ NFC Forum

Tag has battery power:

- yes: active
- no: passive

  → requires specialized techniques

  → focus

Passive: inductive coupling enabled communication

- reader energizes tag

  → primary function

- clock synchronization

- backscatter

  → tag modulates reader's signal: e.g., AM

  → full duplex

- capacitor

  → transient energy store

  → half duplex

MAC protocol: polling

→ multiple tags: collision

→ e.g., inventory systems

Reader detects collision

- instruct tags to randomize

  → tags inject pseudo-random delay: i.e., CA

- tree walking

  → binary search

Three operating modes in NFC

- reader/writer
- card emulation

  → e.g., smartphone acts as tag

- peer-to-peer

  → symmetric