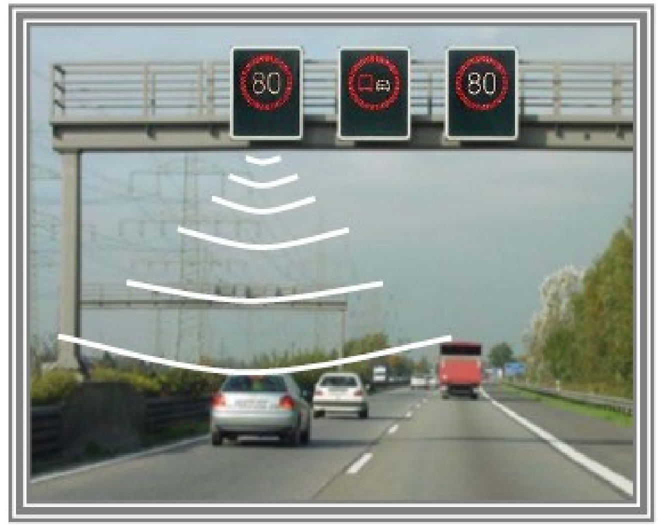
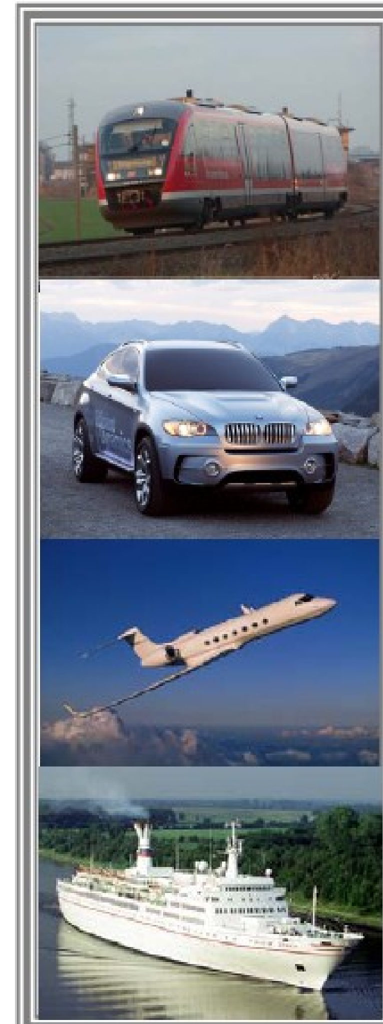
Vehicle Networks and Control Area Networks (CAN)

Intelligent Transportation Systems

Platooning



Adaptive Gantry Signs & In-vehicle signage



Intermodal transportation

Assisted Driving

Intelligent Portable Infrastructure

Autonomous Driving

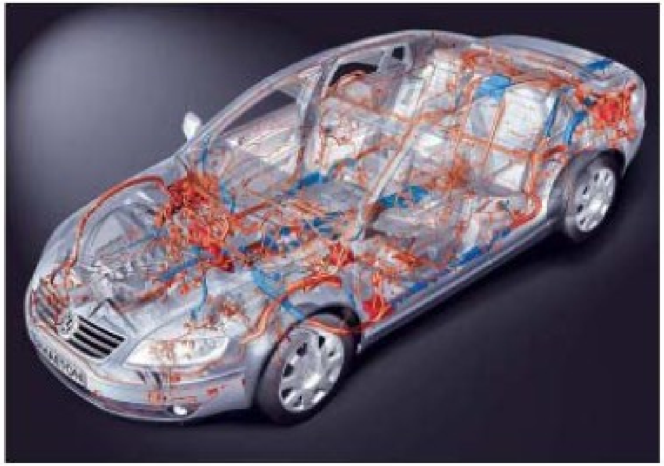
ITS Objectives

- Safety:
  - Mitigation of accident severity (passive safety)
  - Prevention of accidents (active safety)
  - Avoidance of hazardous situations (preventive safety)
- Efficiency: Reduction of travel times, fuel consumption, CO_2 emission, noise emission
- Infotainment/Comfort: Increasing comfort of driving, Additional information services
- Monetary: Cost reduction (e.g. less sensors, less road infrastructure maintenance); competitive edge

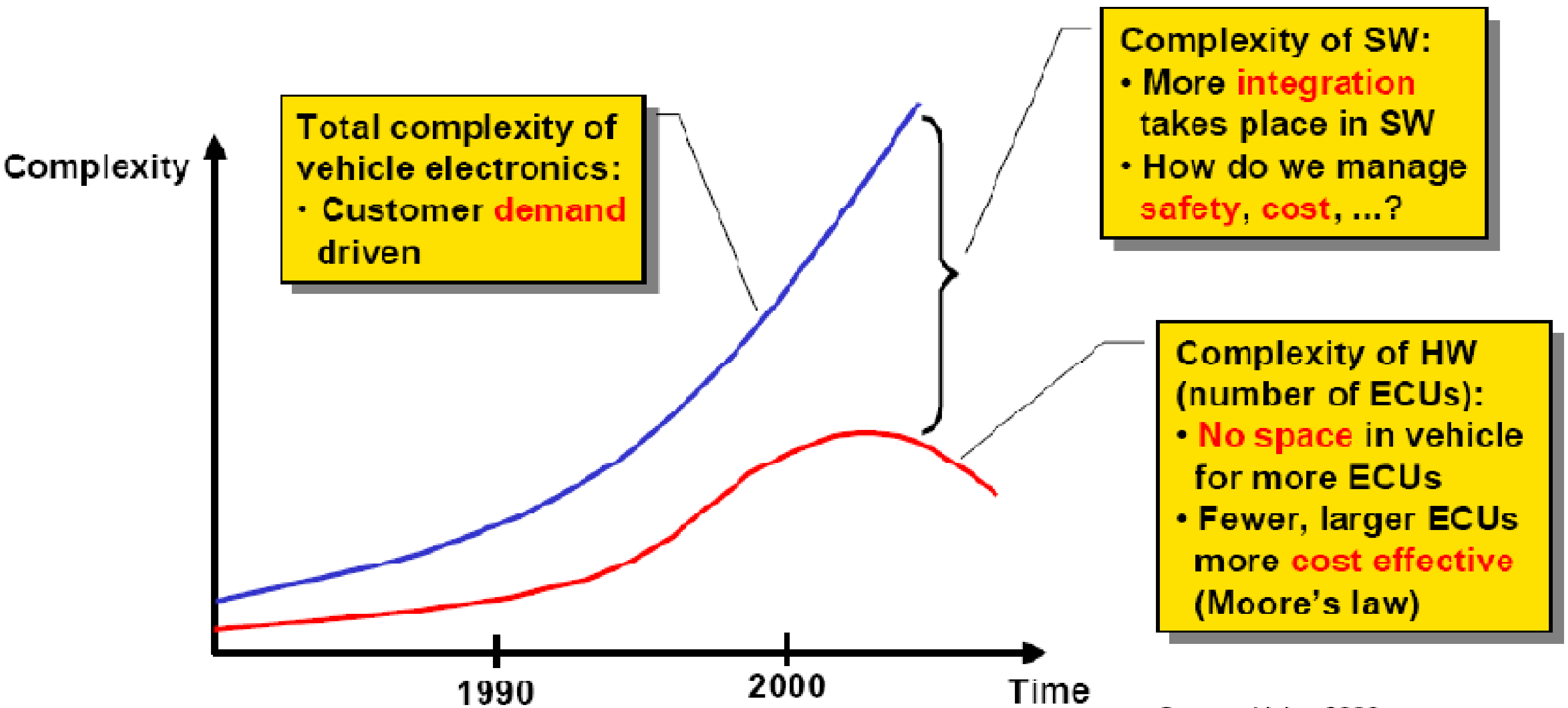
Intra-vehicle communications

- In the past: VW Käfer (1950)
  - 50 m copper wires
  - 0 Electronic Control Units (ECUs)

- Today: VW Phaeton (2004)
  - 3860 m copper wires
  - 45 networked Electronic Control Units (ECUs) / 61 ECUs total
  - 11.136 electrical parts in total
  - 3 different bus networks



Vehicle Electronics

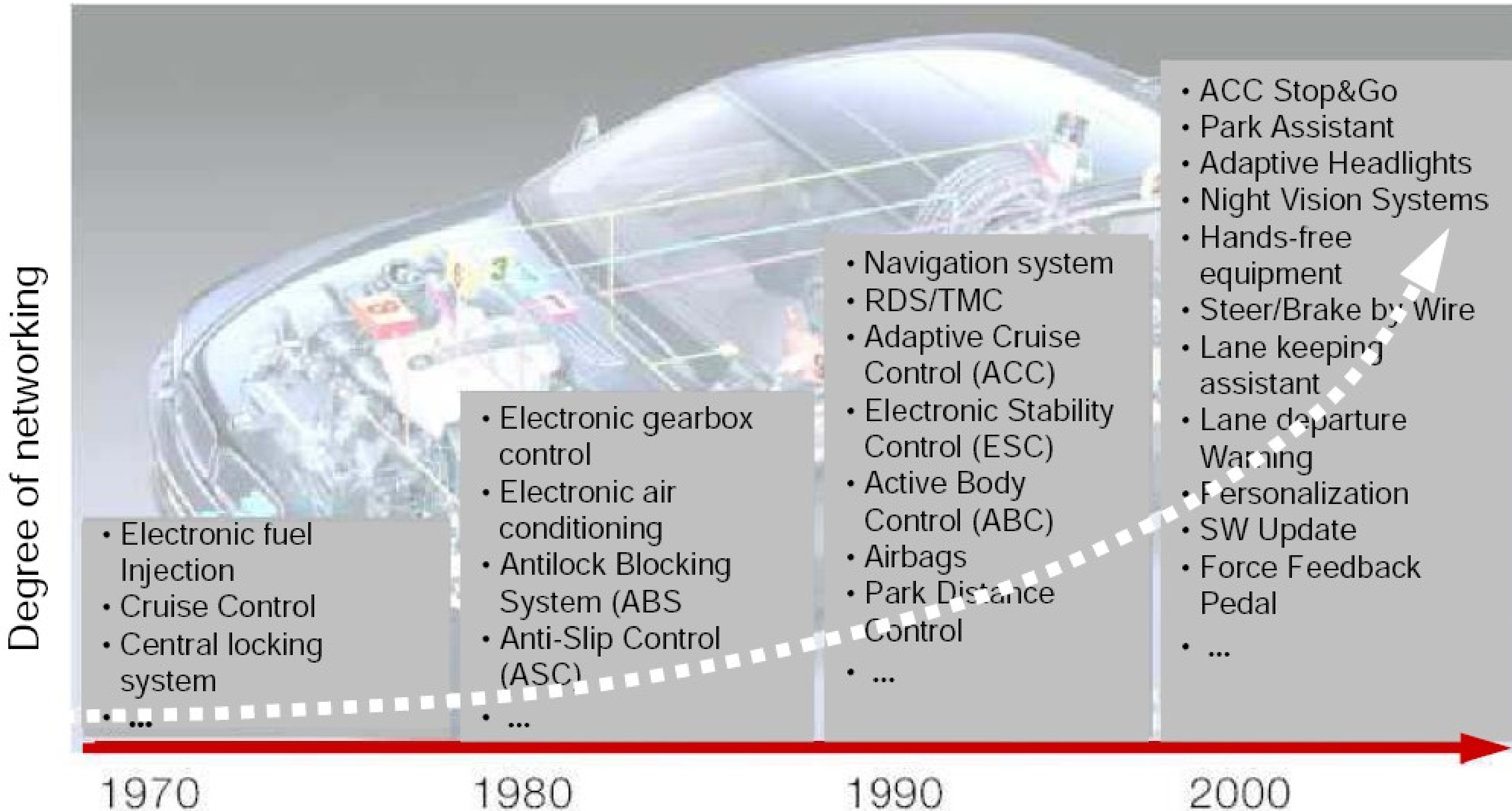


Source: Volvo 2002

$$\frac{\text{Cost of Electronic Embedded systems}}{\text{Cost of a car}} = \begin{cases} 1\% & (1980) \\ 20\% & (2005) \\ 40\% & (2015) \end{cases}$$

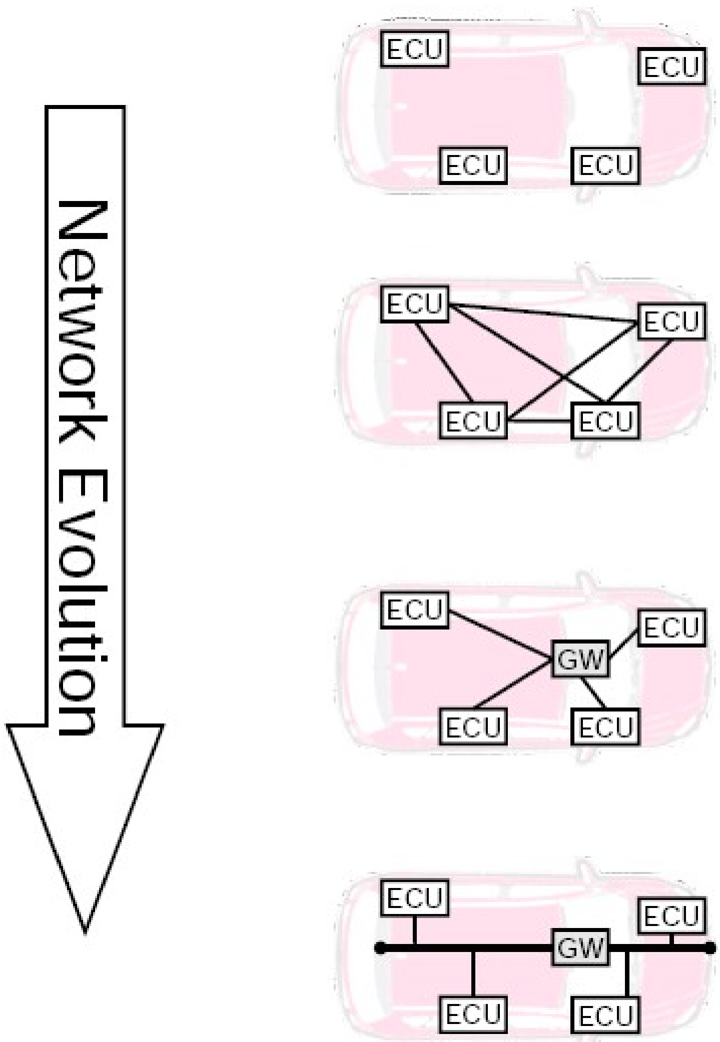
ECU: Electron
Control Unit

Intra-vehicle: Degree of Networking



Based on BMW CarIT

Network Evolution



- Stand alone ECUs
  - No networking
- Directly connected ECU (partially mesh)
- Star topology with central gateway
- Partitioned bus topology with interconnecting gateway

In-vehicle bus systems

- Volkswagen Golf V

•Engine-CAN (500 kps)

•2 private CAN (500 kps)

•Instrument-CAN (500 kps)

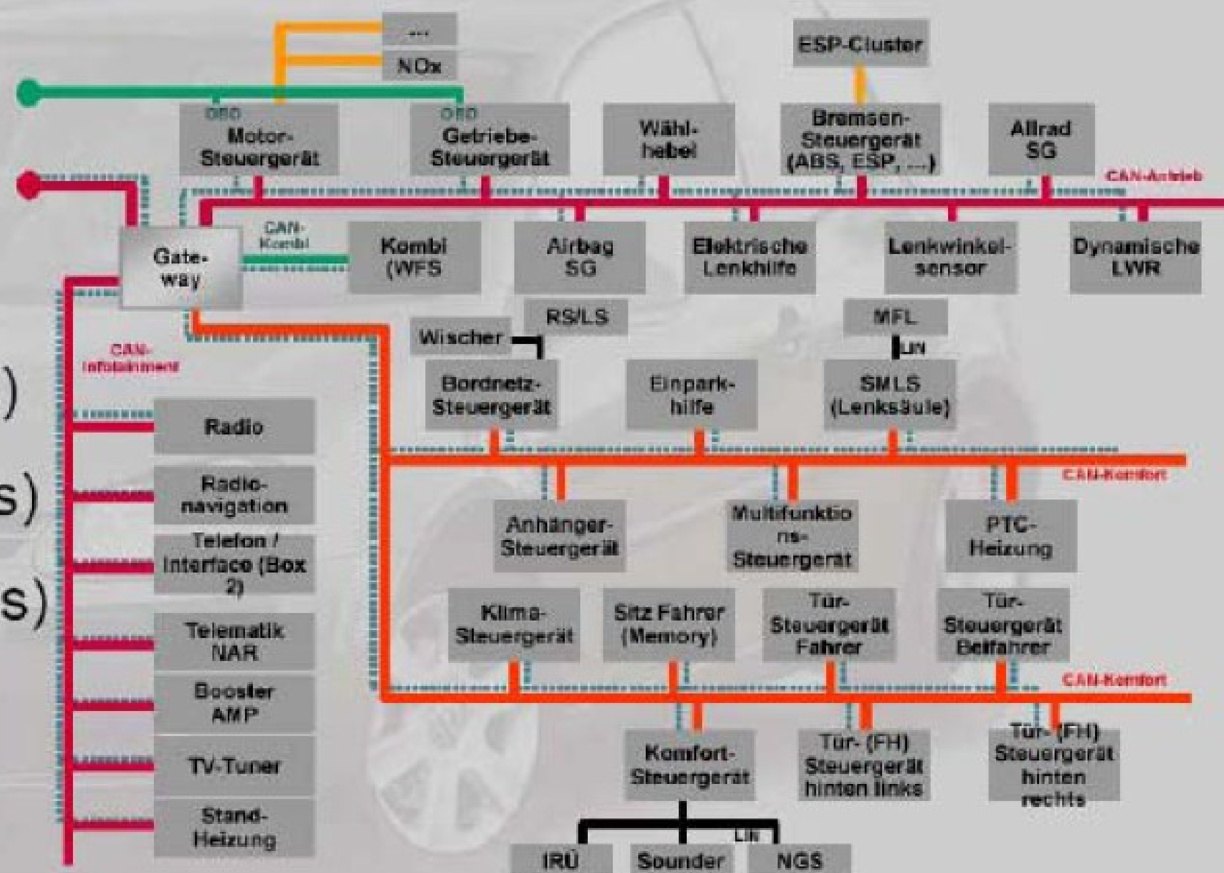
•Infotainment-CAN (100 kps)

•Convenience-CAN (100 kps)

•1 Diagnostics-CAN (500 kps)

•2 LIN-Networks

•K-Wire



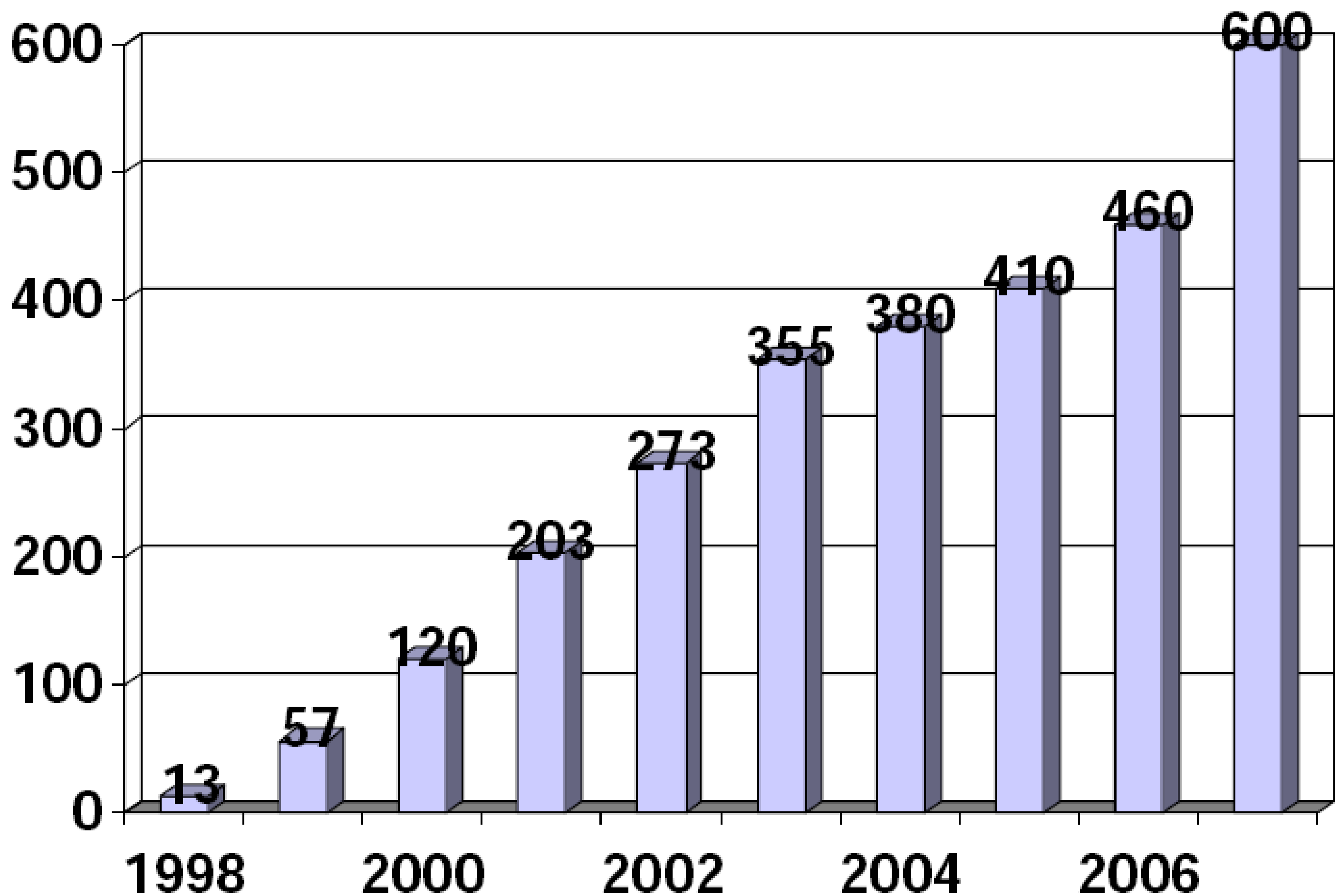
CAN History

- Development of CAN mainly driven by Mercedes-Benz for networking of versatile Electronic Control Units (ECUs)with the following requirements:
  - Error-resistance to cope with strong electro-magnet interference
  - Prioritized real-time capabilities with short latency (e.g. for safety critical applications)
  - Fast data rate (Class C network: 125 kbit/s –1 Mbit/s)
  - Expandability for versatile nodes
  - Cost-effectiveness for wires and nodes
- These requirements also hold for various other application fields in aviation and maritime industry, industrial and home automation, consumer electronics
- Widespread distribution of CAN nowadays

CAN Applications

- Automotive, aviation, space, maritime industry
  - Car, truck, bus; Airplanes; Rockets, space shuttles; Ships
- Medical equipment
  - X-Ray, Electro-Cardiograms (ECG)
- Industrial and home automation
  - Production machines
  - Lifts and escalators
  - Shutter, heating, light control
- Household appliances: washer, dryer
- Consumer electronics: model railway

Number of CAN Nodes (in millions)



Produced by Motorola, Philips, Intel, Infineon, etc.

CAN in ISO/OSI Reference Model

No. of layer	ISO/OSI ref model	CAN protocol specification
7	*Application*	Application specific
6	*Presentation*	Optional: Higher Layer Protocols (HLP)
5	*Session*	
4	*Transport*	
3	*Network*	
2	*Data Link*	**CAN protocol** (with free choice of medium)
1	*Physical*	

CAN PHY Layer

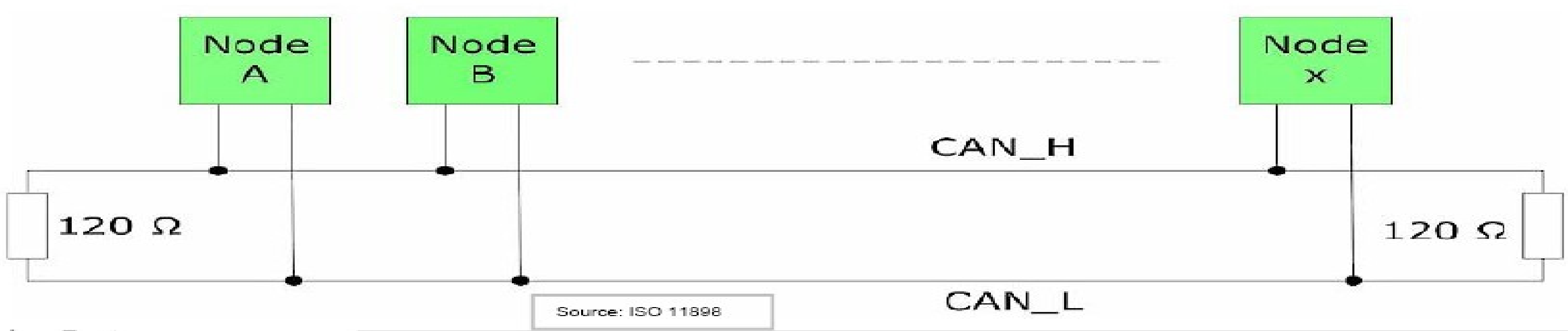
CAN Hardware

- Bus topology to reduce the number of wires
- Flexible in choosing transmission medium
- Automotive CAN according to ISO 11898-2/3 uses twisted pair with differential voltages on a bus topology (tolerant to single wire disturbance)
- Bus must be terminated with 120 Ω to:

  -remove signal reflections at the end of the bus

  -ensure the bus gets correct DC levels

- Max 30 connected nodes



Data rate

- The signal has to propagate to the most remote node and back again (round trip) before the bit is sampled
  - Bus length and data rate are correlated

$$\text{max. bus length} < \frac{\text{signal velocity} * \text{nom. bittime}}{2}$$

Data rate	Max. bus length*	Nominal Bit-Time
1000 kbit/s	40 m	1μs
500 kbit/s	130 m	2μs
250 kbit/s	270 m	4μs
125 kbit/s	530 m	8μs
50 kbit/s	1300 m	20μs
20 kbit/s	3300 m	50μs
10 kbit/s	6700 m	100μs

*approximation

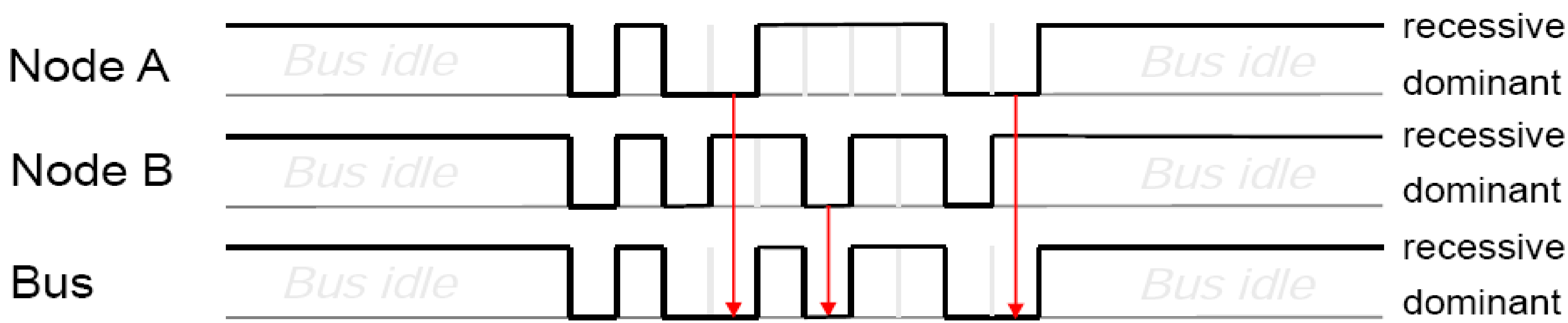
Coding

- Dominant and recessive coding:
  - Dominant: logic “0”
  - Recessive: logic “1”

Bus		Node B: dominant	Node B: recessive
Node A	dominant	*dominant*	*dominant*
Node A	recessive	*dominant*	*recessive*

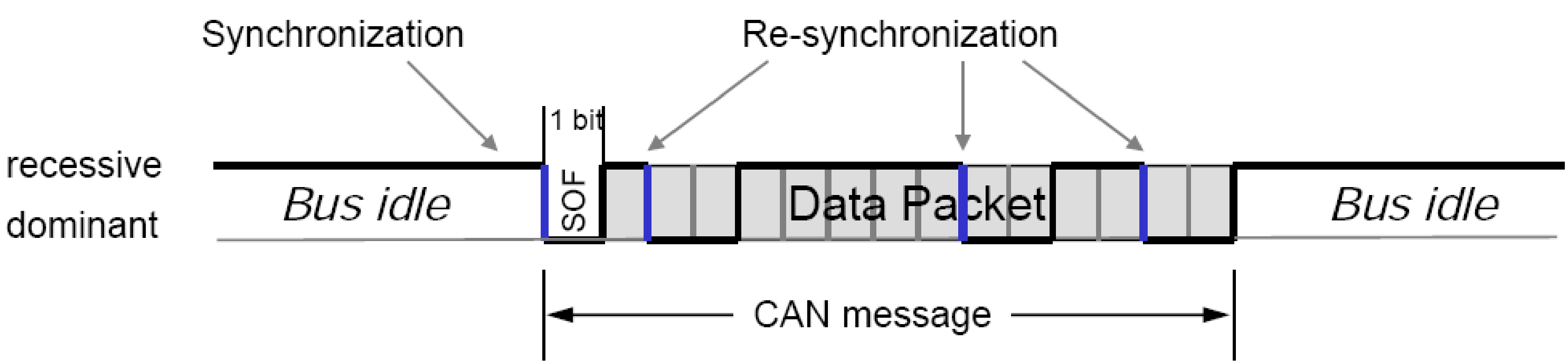
  -If more than one stations send a signal, the bus takes dominant state if at least one station sends a dominant signal. The bus takes recessive state only if both sends a recessive signal.

- Each node transmit and listen at the same time



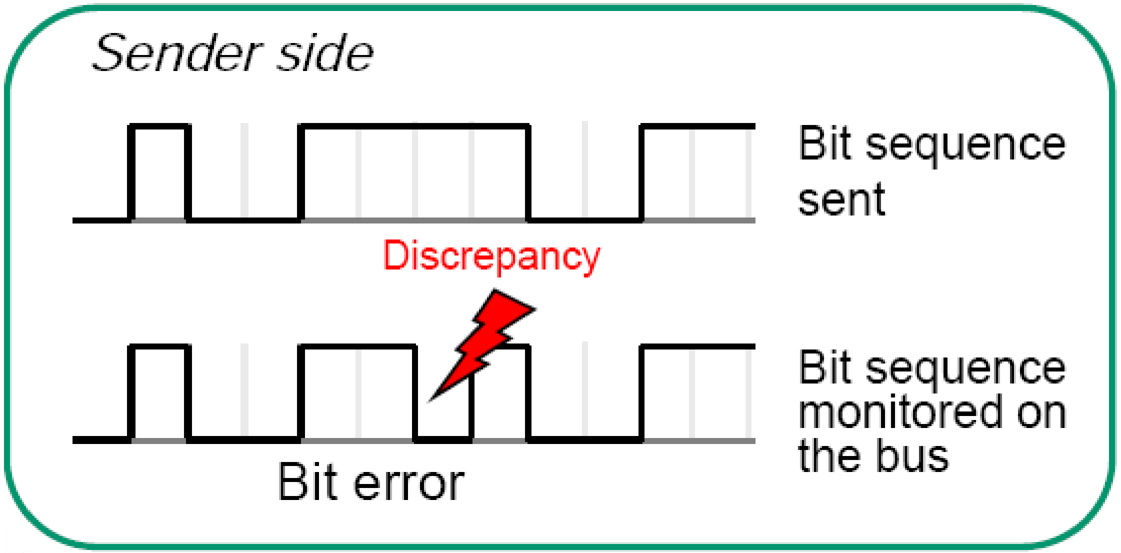
Synchronization

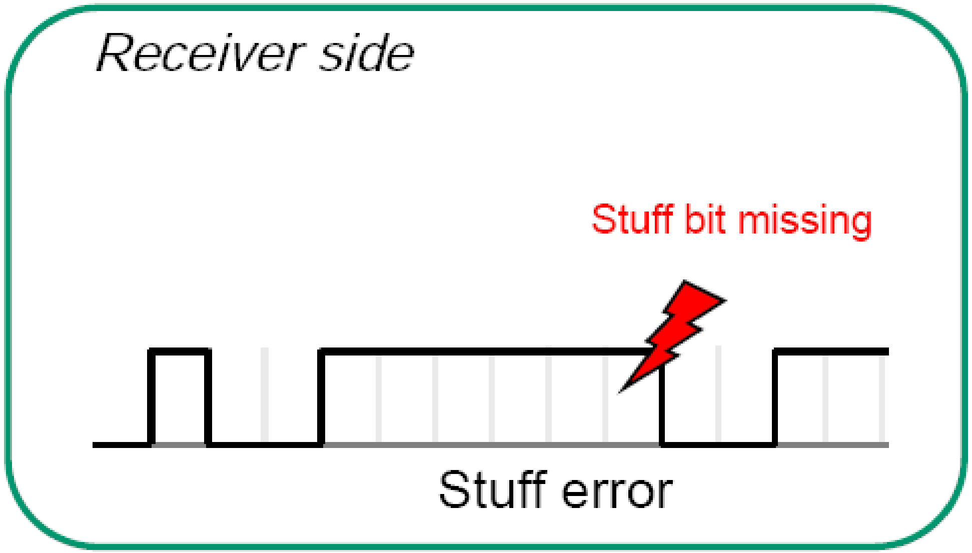
- No global time source, no dedicated clock signal
- Synchronization by edge detection in data signal
- Bit length known due to uniform clock rate for every node (e.g. 2 µs for 500 kbit/s)
- Hard synchronization with first recessive-to-dominant edge (=dominant Start Of Frame (SOF)bit) after bus idle
- Continuous re-synchronization at every recessive-to-dominant edge transition



Error Detection

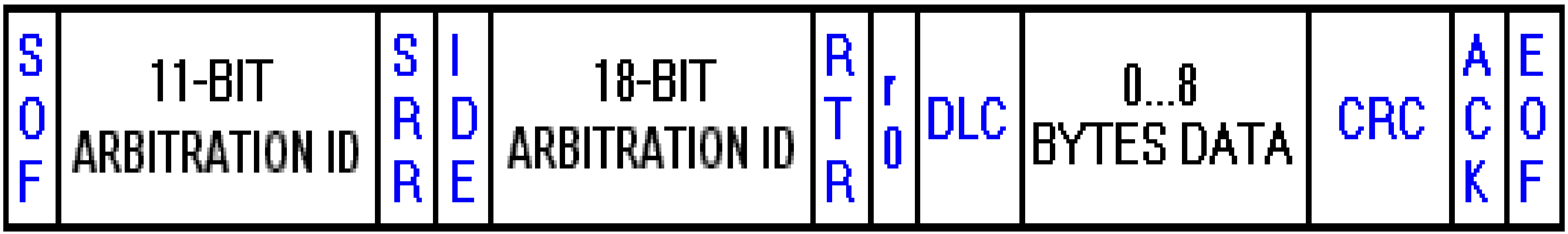
- At sender side: monitor bus during transmission
- At receiver side: detect errors by checking whether the bit sequence is in adherence with the bit stuffing rule





CAN Data Link Layer

CAN Frame



- SOF (start-of-frame) bit -- a dominant (logic 0) bit
- Arbitration ID -- identifies the message and indicates the message's priority

  -Standard format: 11 bit ID -> 47~55 bit data frame (+stuff bits)

  - Extended format: 29 bit ID -> 67-75 bit data frame (+stuff bits)

  - Every node on the bus receives all messages and filters according to ID
- IDE (identifier extension) bit -- allows differentiation between standard and extended frames

CAN Frame (cont'd)

- RTR (remote transmission request) bit -- serves to differentiate a remote frame from a data frame. A dominant (logic 0) RTR bit indicates a data frame. A recessive (logic 1) RTR bit indicates a remote frame.
- r0: reserved
- DLC (data length code) -- indicates the number of bytes the data field contains (0-8 bytes requires 4 bit length field)
- Data Field -- contains 0-8 bytes of data
- CRC -- cyclic redundancy check for error detection

  - 15 bit CRC with generator polynomial $x^{15} + x^{14} + x^{10} + x^{8} + x^{7} + x^{4} + x^{3} + 1$

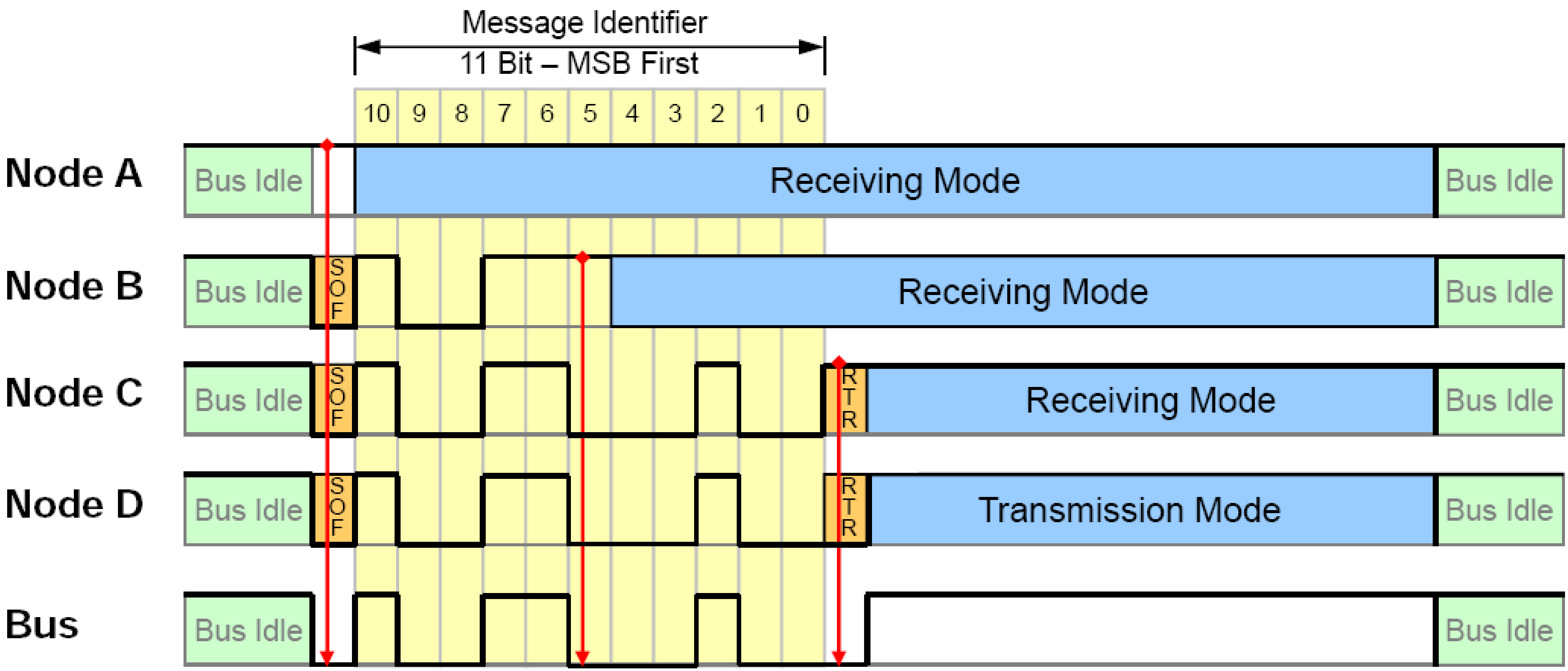
  - 1 bit CRC delimiter: single (always) recessive bit

CAN Frame (cont'd)

- ACK (ACKnowledgement) slot -- The transmitting node checks for the presence of the ACK bit on the bus and reattempts transmission if no acknowledge is detected
  - 1 bit ACK slot: dominant overwriting
  - 1 bit ACK delimiter: single (always) recessive bit
- CAN Signal – an individual piece of data contained within the CAN frame data field, containing up to 8 bytes of data
- End of Frame: 7 recessive bits
- Bit stuffing: sender inserts complementary bit (stuff bit) after 5 successive bits of same polarity.

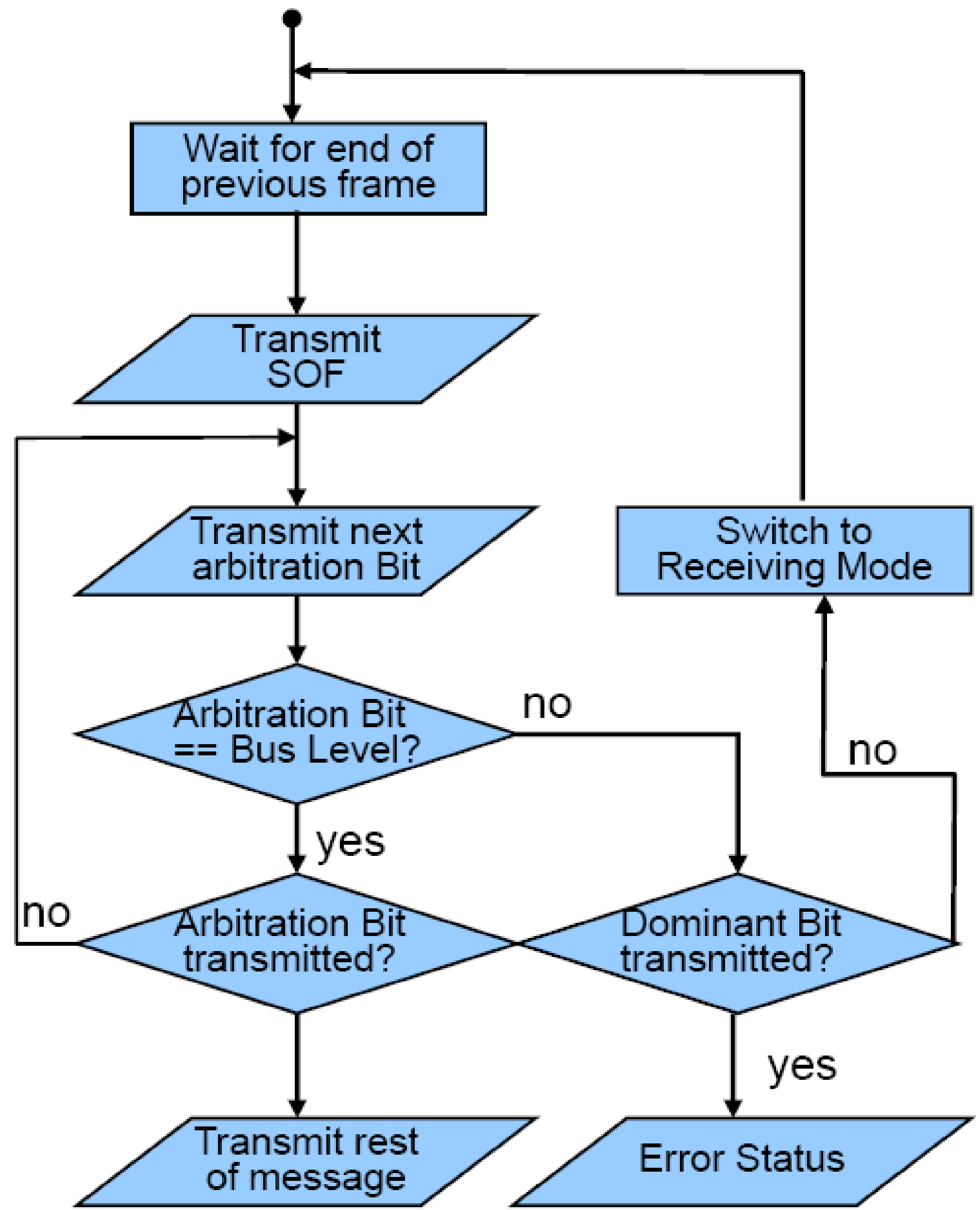
Contention-Free MAC

- CSMA/CR (Collision Resolution):
  - If two devices transmit simultaneously, the one with smaller arbitration ID gets the higher priority to transmit.



CSMA/CR

- Advantages:
  - -Allow different priority
  - -High bandwidth utilization
- Limitations?



Error Handling and Error Confinement

Error Handling

- Error frames are sent after an error is detected
- Error flag:
  - Active error flag: 6 consecutive dominant bits (breaking the stuffing rule!)
  - Passive error flag: 6 recessive bits (can be squashed by error frames sent by other nodes!)
- Error delimiter: 8 recessive bits
- Majority vote to detect “perpetrator”:
  - Majority of nodes send error frame Ÿ transmitter is perpetrator
  - Majority of nodes send no error frame Ÿ receiver is perpetratorn

Error Confinement

- Every node stores two kinds of errors:

  -Transmit error counter (TEC)

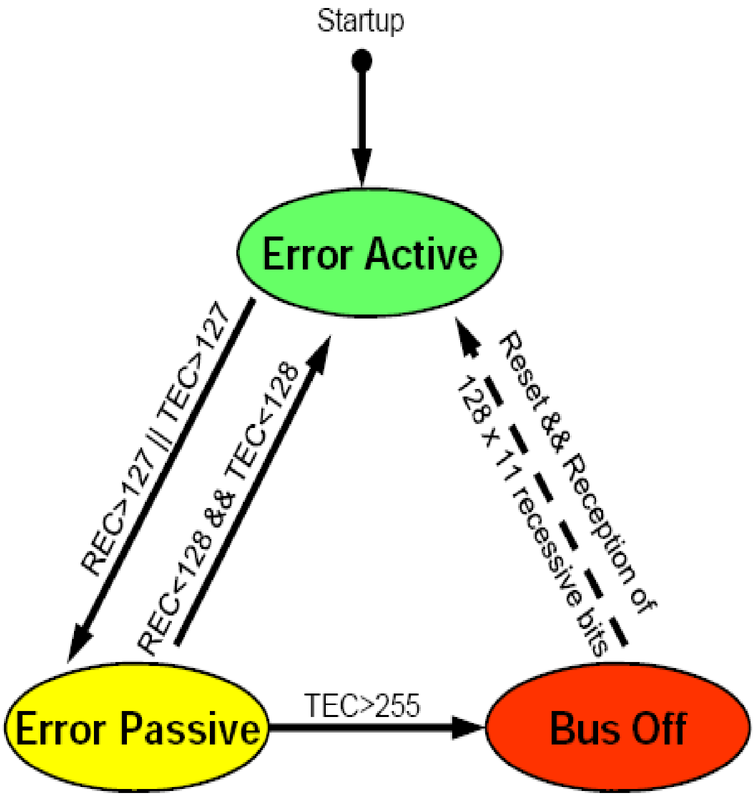
  - Receive error counter (REC)

- What a node does if the node is in one of the following states:

  - Error active: Transmission of Active Error Flags (dominant)if error is detected by this node

  - Error passive: Transmission of Passive Error Flags (recessive)if error is detected by this node

  - Bus off: No transmission on the bus



Residual Error Probability

- Example:
  - 1 Bit error every 0.7s
  - Bit rate: 500 kBit/s
  - Operation of 8 hours/day and 365 days/year
  - 1 undetected error in 1000 years