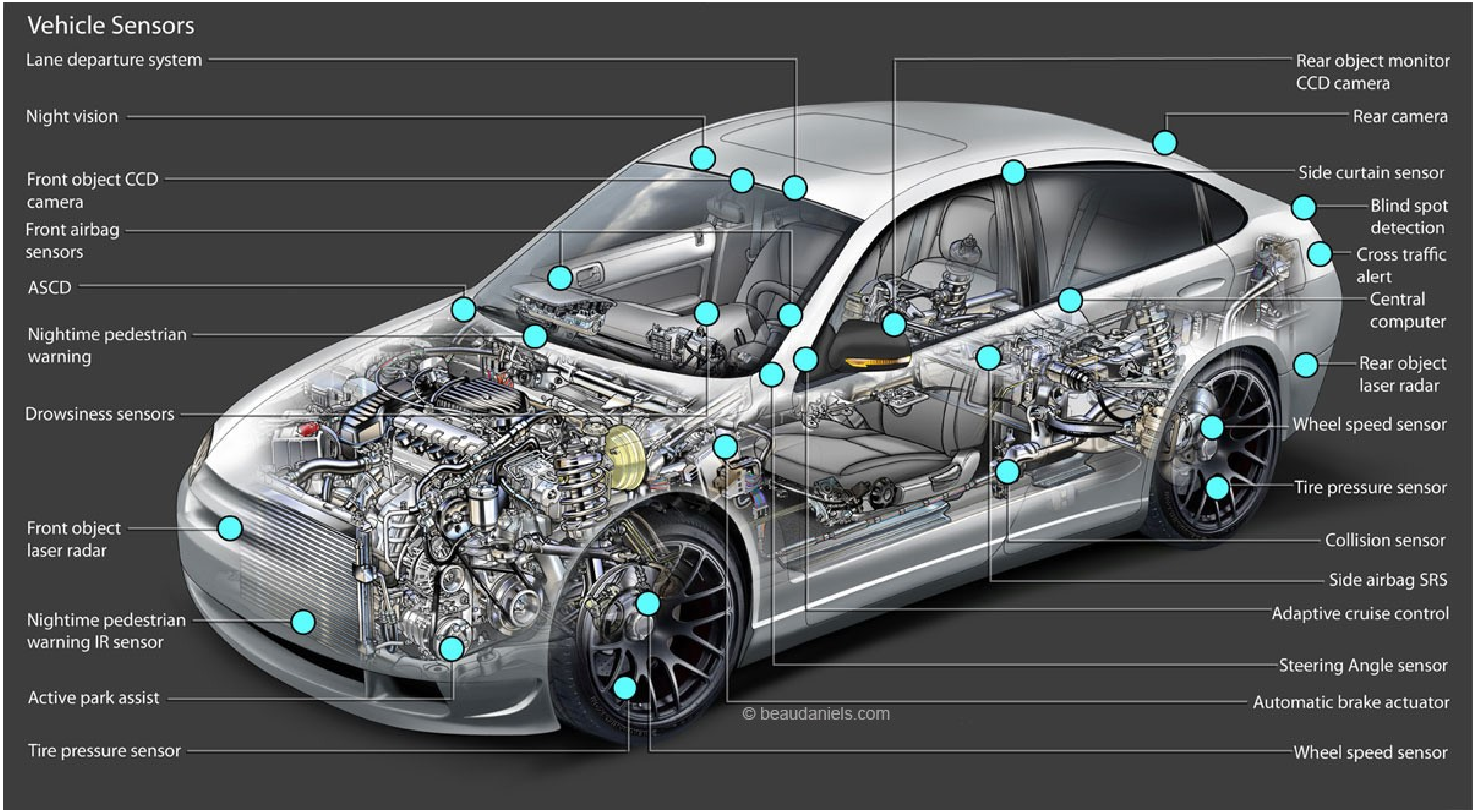
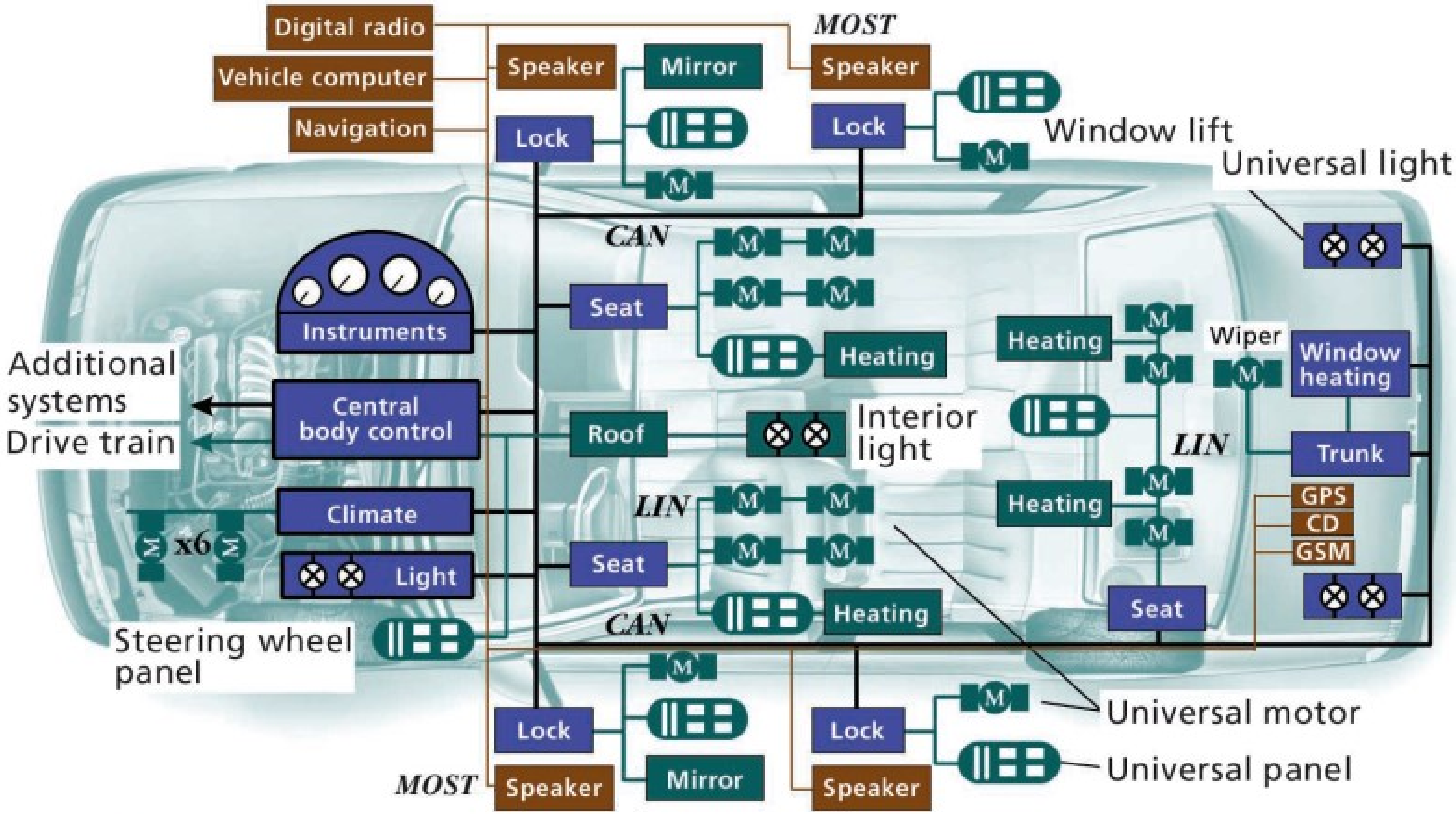
Sensors/Actuators in a modern car



The buses coordinating the sensors



CAN Controller area network
GPS Global Positioning System
GSM Global System for Mobile Communications
LIN Local interconnect network
MOST Media-oriented systems transport

Notable features:

- Lots of connections: need for less wiring
- Hostile envrionment: robustness, error isolation and repair
- Data bandwidth varies (a few numbers to video rates)
- Latency requirement varies
- Many of low latency needs are also critical needs
- Power requirement vary
- Most of the operation is done in parallel, some with hard deadlines
- System can be seen as hierarchy of components, more obvious in industrial environments
- Complex system: it needs
  - extensibility
  - extensive diagnosis
  - coping with diversity of components
  - safety certification

A distributed system most suited for this model:

Processing, power is distributed

- Lower requirement for data transfer
- Lower wiring
- All nodes need network interface
- Complexity decreases:
  - modularity for easier development, reuse
  - better diagnosis, error confinement
  - easier certified
  - flexible and extendible
  - cheaper, incremental, less troublesome development
  - lower human resource cost
- Downsides: System design should be done carefully.

Demands on the communication system:

- Selected network protocols should be cheap
- Should support wide range of bandwidth, time-critical requirements
- Multicast support should be there, specially for critical data
- Error detection, confinemnet and repair
- Hot plugging capabilities
- Synchronisation and temporal ordering should be maintained on the network
    - synchronous network with coordination between the nodes

Protocol categories:

- Event triggered (ET)
- Time-Triggered (TT):

Message types used:

Event-based messages	State-based messages
Captures asynchronous model of system	Time periodic / Synchronous
Describes the change in state. Error in communication results in loss of state information. Positive acknowledgement or retransmission. Point-to-point. More efficient usage of communication resources.	Constant rate. Event ordering is not a problem Multicast, helps triple modular redundancy (TMR). Unidirectional. Hot-plugging support.

Event triggered (ET) protocols

- Examples: CSMA/CD, CAN
- Events are asynchronous
- Error detection is by sender: acknowledgement needed (e.g. PAR), which blows up in multicast
- Maximum excution and reading time is large compared to average execution time
- Receiver can flow control to avoid overflow

Time Triggered (TT) protocols

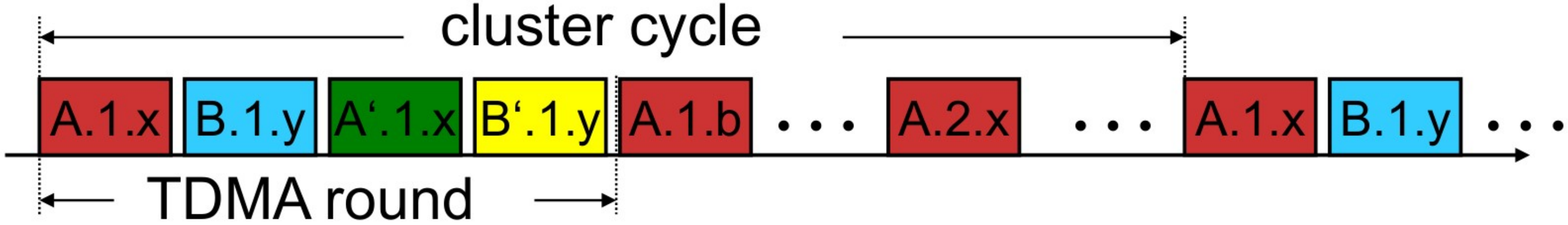
- Examples: FlexRay, TTE
- Global timeline of messages: known apriori
- Maximum execution time same as average execution time (low jitter)
- Error detection at the receiver, error contained due to apriori information.
- Easier for multicasting

Bus access protocols:

- ***CSMA/CD*** (e.g. Ethernet)
  - Send when no traffic on bus, if collision, then retransmit after random time interval.
  - Max. attempts fixed.
  - Small latency for low traffic, but ***unbounded latency***
  - Hot-plugging possible
  - Poor utilisation in high traffic.
- ***CSMA/CA*** (e.g. CAN)
  - Start sending priority bits on bus, sender(s) with lower prioity drop out.
  - Bit period depends on propagation delay (e.g. consider 40 m network length).
  - Bound time for high priority, may starve lower priorities

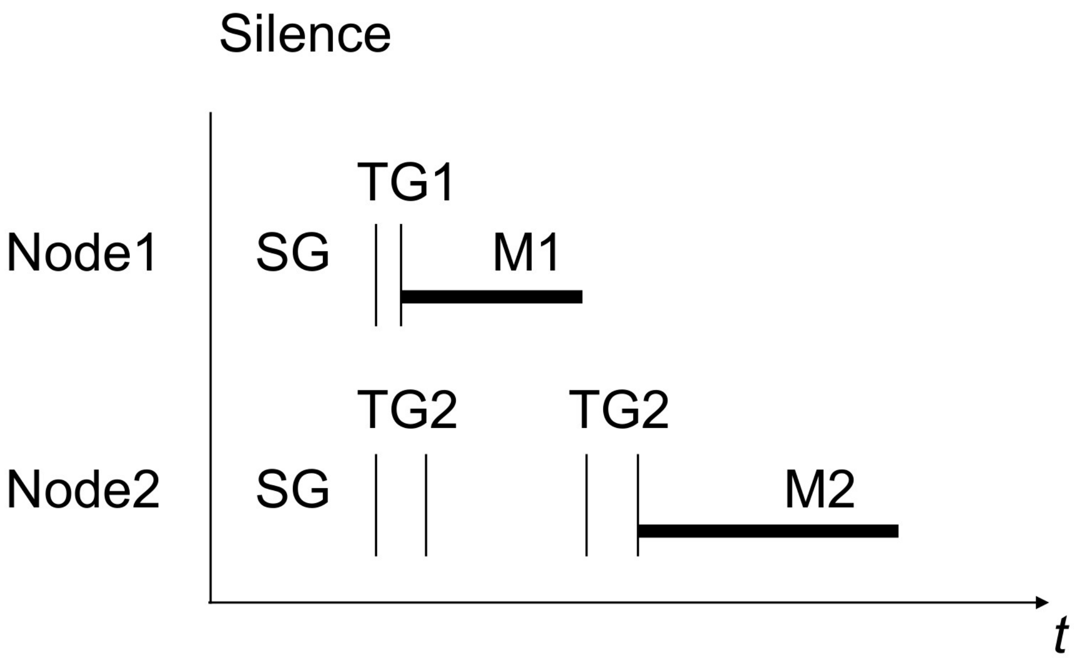
Bus access protocols:

- ***TDMA*** (e.g. TTP, FlexRay - static part)
  - Time slots alloted to nodes, apriori, e.g. use of Message Descriptior List in TTP controllers.
  - Need global time and a fault tolerant way to synchronise: can be done by knowing expected arrival time and actual arrival time.
  - Highly effcient in looped messaging environments, e.g. no need to transmit sender identity
  - Flow characteristics known beforehand.



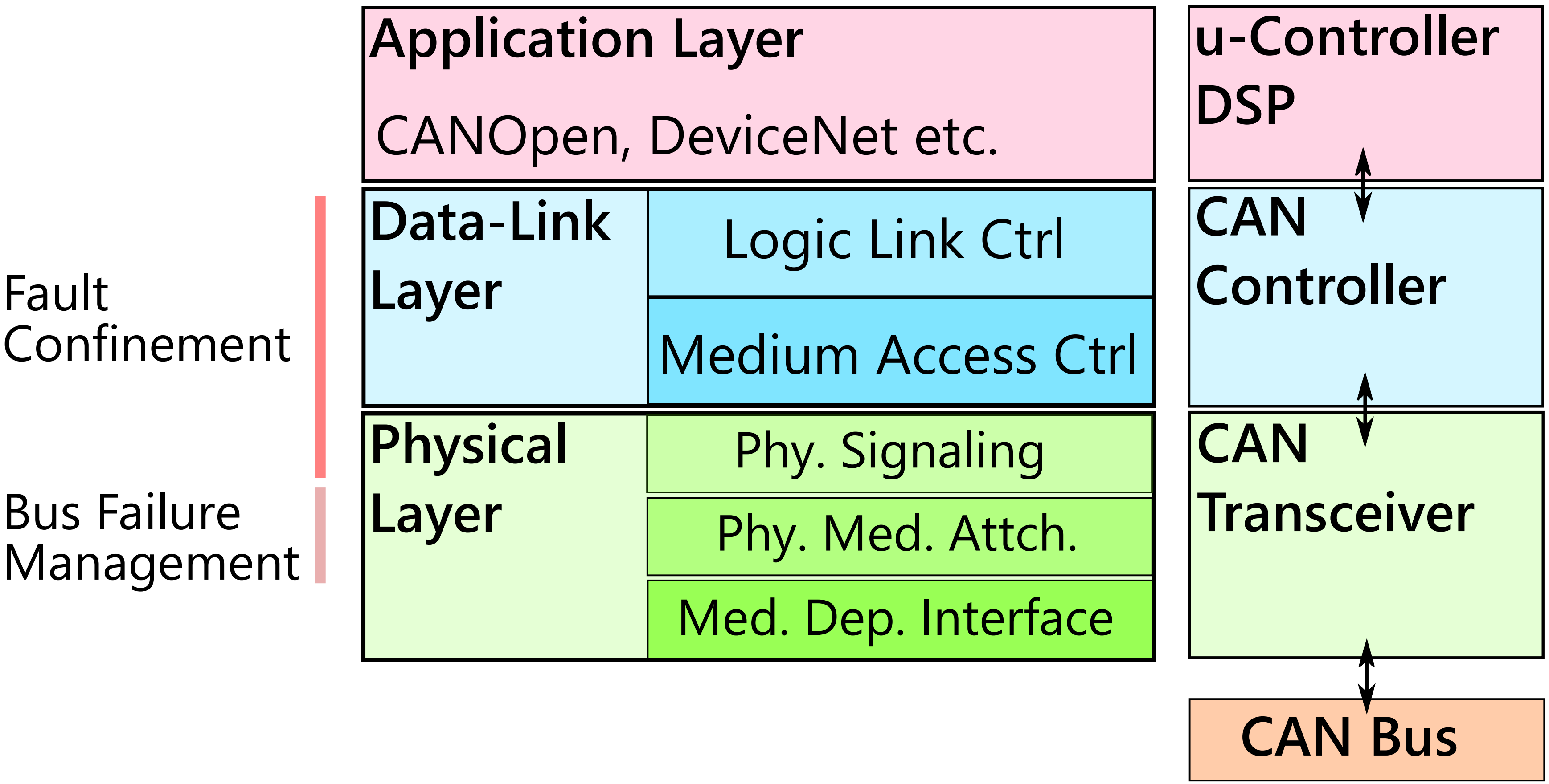
Bus access protocols:

- ***Mini-slotting*** (e.g. ARINC 629)
  - Time partitioned in slots (> max. propagation delay) which control access.
  - Send after a specific number of silent minislots occur (different for each node, apriori fixed)
  - ARINC 629 uses Synchronisation Gap (SG) > longest Terminal Gap (TG)



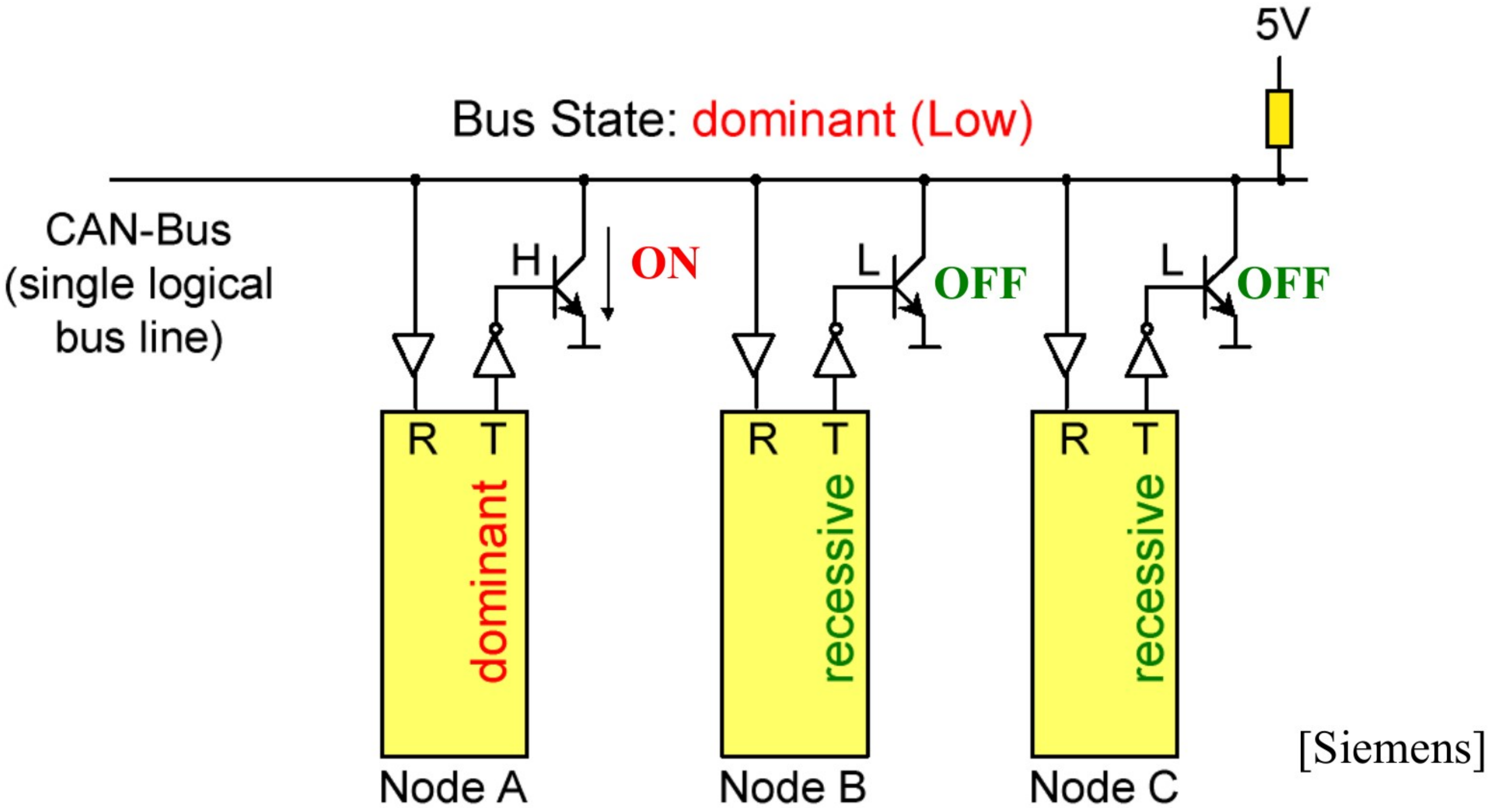
Specific Protocols: CAN

Multilayered, meant for low to medium bandwidth applications, broadcast data, working in noisy environment, with time critical information, and robust self diagnosis and error correcting capabilities.



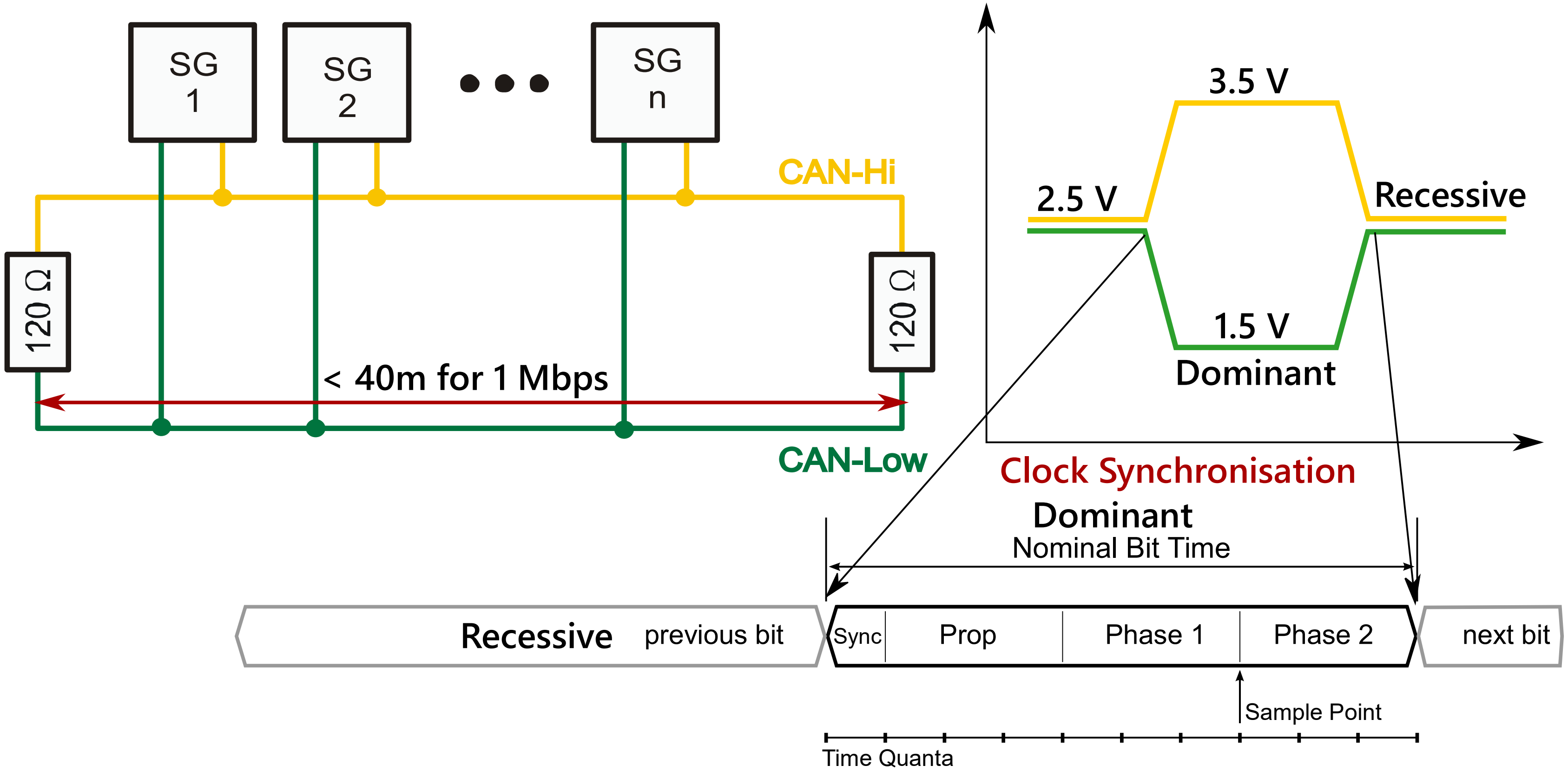
CAN Bus: Signalling

- Wired "OR"
- Bus floats to a common value (e.g. 2.5 V), the ***recessive*** bit
- unless pulled to a different value (1.5 V or 3.5 V), the ***dominant*** bit
- Sending a dominant bit forces bus to dominant state.
- Is this scheme independent of medium?



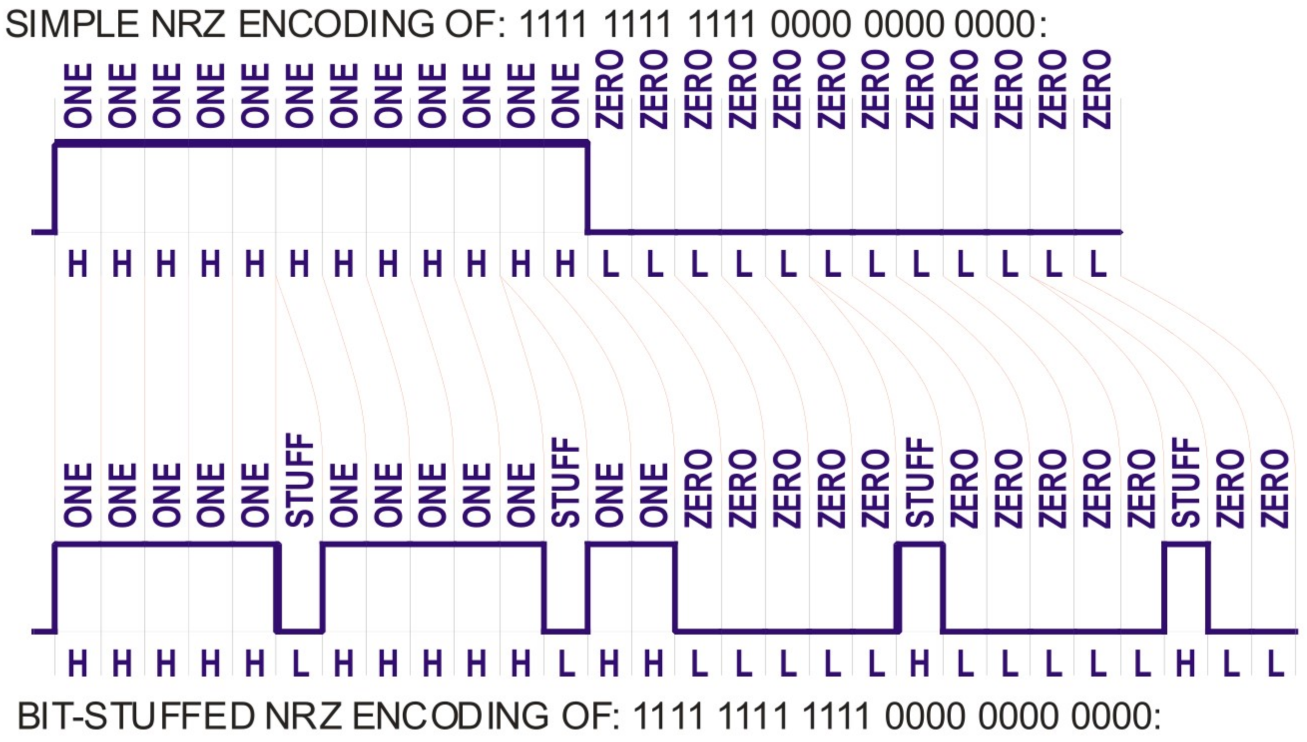
CAN Bus: Signalling

- Two wires are used for differential signalling.
- Clock synchronisation occurs during each transistion from recessive to dominant bit
- The bus length is restricted to 40m for 1 Mbps data rete and 30 nodes.



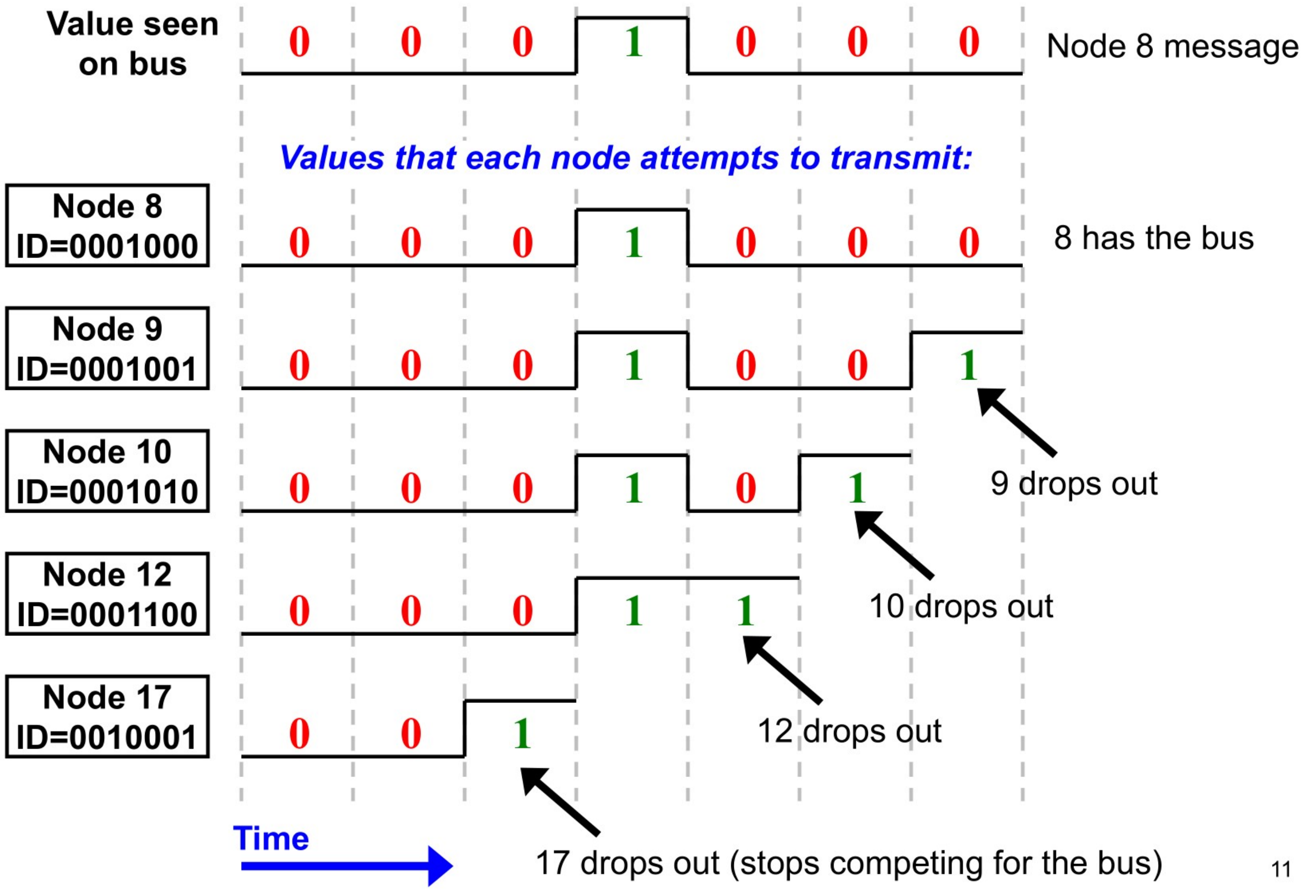
CAN Bus: Bit Stuffing

- No synchronisation done in a long series of ones or zeros: need edges to occur
- Easy way is to limit encapsulate 8-bits in SYNC/END pairs (RS-232). Not good.
- CAN uses bit stuffing instead: add opposite bits for series of 5 ones or zeros.



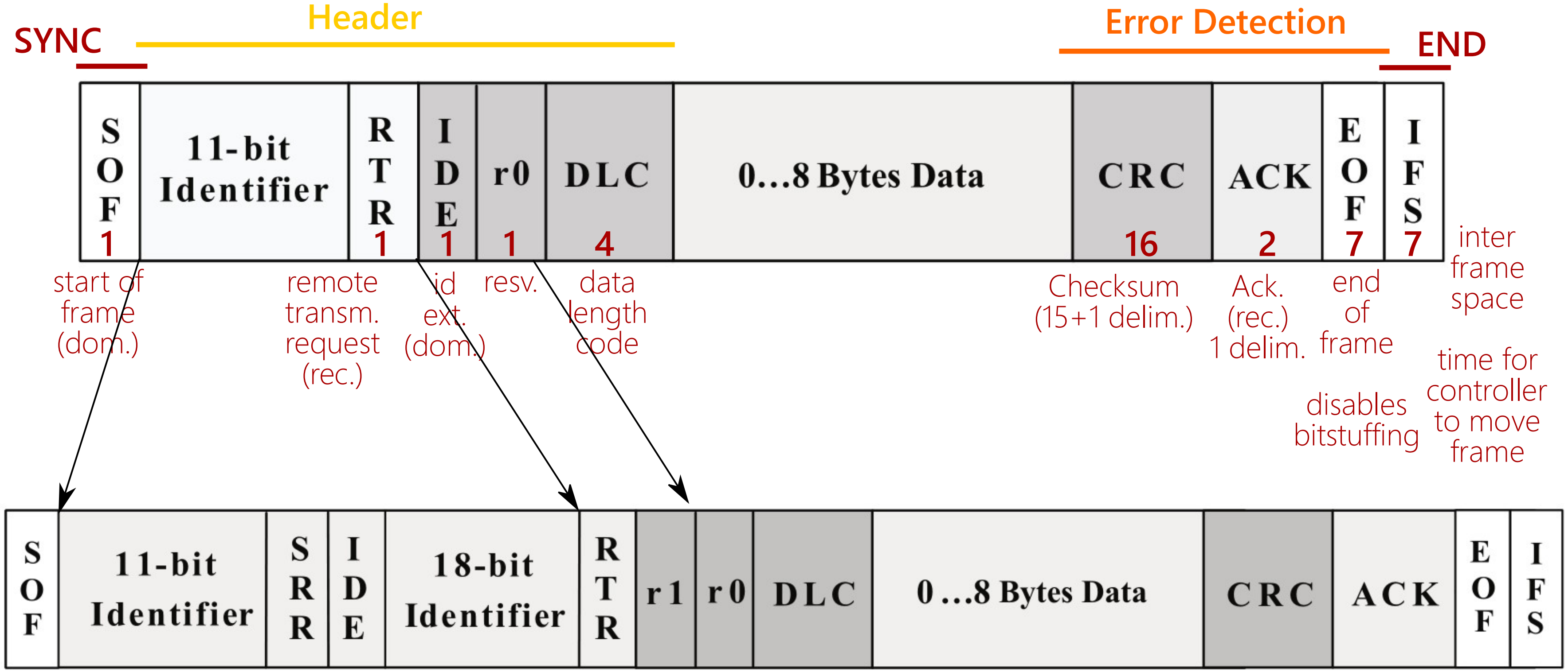
CAN Bus Arbitration: CSMA/CA

- Bus access is event driven, arbitration is by "binary countdown" and ***non-destructive***
- The device id. number determines its priority: lower id. is higher priority.
- Sending node ***must*** monitor its input all the time!
- Normally id. are assigned in a agreed upon pattern to enable assembling from different vendors.



CAN Bus: Frame Formats

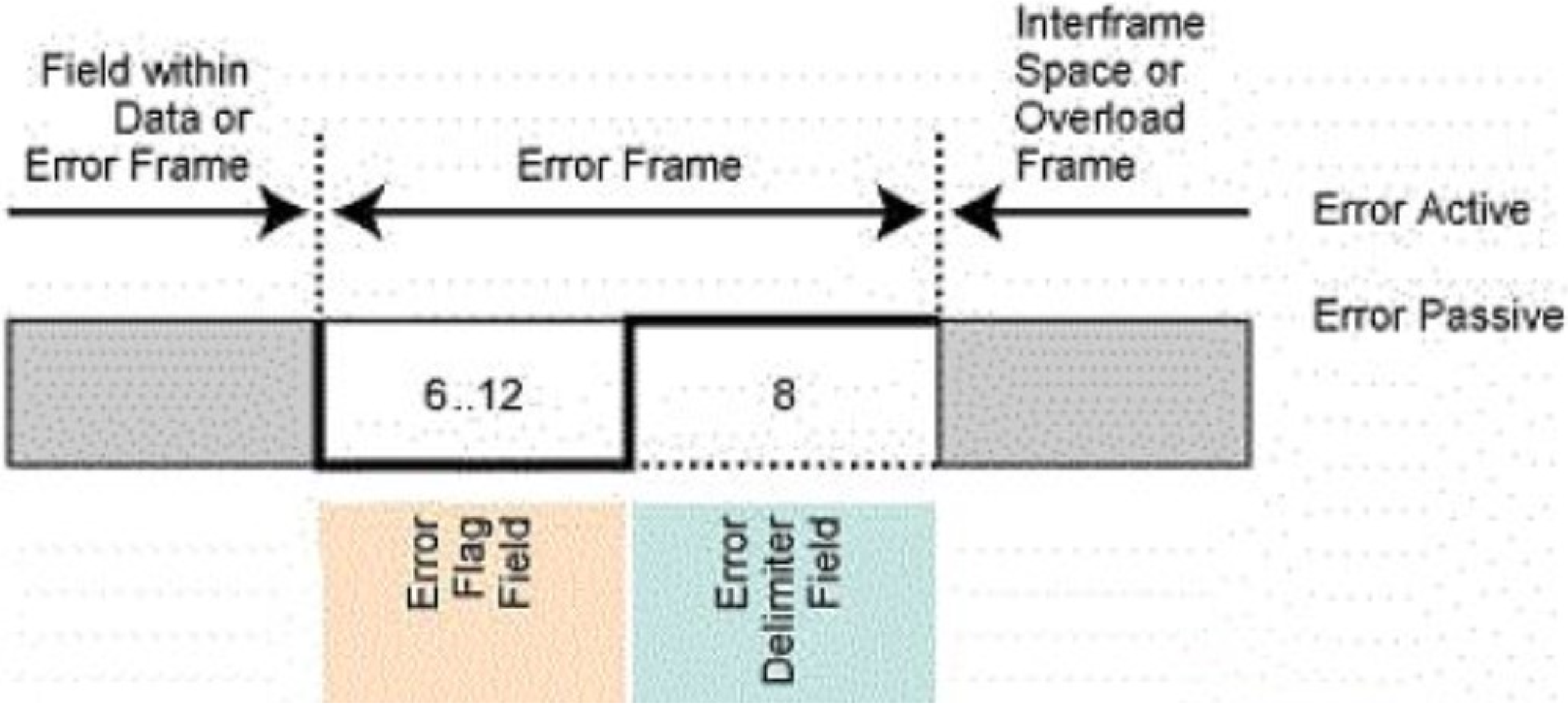
- Data is sent enclosed in Frames, each frame can have 0 to 8 bytes of data.
- Standard frmes have 11-bit id numbers, extended ones have 29-bit id numbers.



CAN Bus: Frame types

- Data Frame: was shown in last slide
- Remote Frame: same as Data Frame, RTR bit is rec. and no data.
- Error Frame: 6 dominant bits, violates bit stuffing, causes all nodes to send the same.
  - can be 12 bits long with all replies
  - followed by a 8-bit all recessive delimiter bits
  - retransmission of frame causing error is done after a bus idle period
- Overload Frame: Same as error frame, but sent by recevier which is too busy to process frames.

CAN Bus: Error Frame



- 6 dominant bits in a row: bit stuffing violated
  - further error frames from other nodes who see bit stuffing violated/
- Error Frame can start anywhere
- Non-deterministic behaviour

CAN Bus: Error Checking, Fault Confinement

- 5 methods of error checking: 3 at message level, 2 at bit level
- If any error is detected in a frame, an error frame is generated, sender has to retransmit original frame
  - if a recevier is continuously getting errors, its controller takes it off the bus
- Message level error checks: CRC, ACK, bits which must be rec. - EOF, ACK delim., CRC delim.
- Bit level error checks:
  - each bit is monitored by sender conflicts result in errors (except arb. bit)
  - bit stuffing during the frame is enfroced.

CAN Bus: bit-wise efficiency

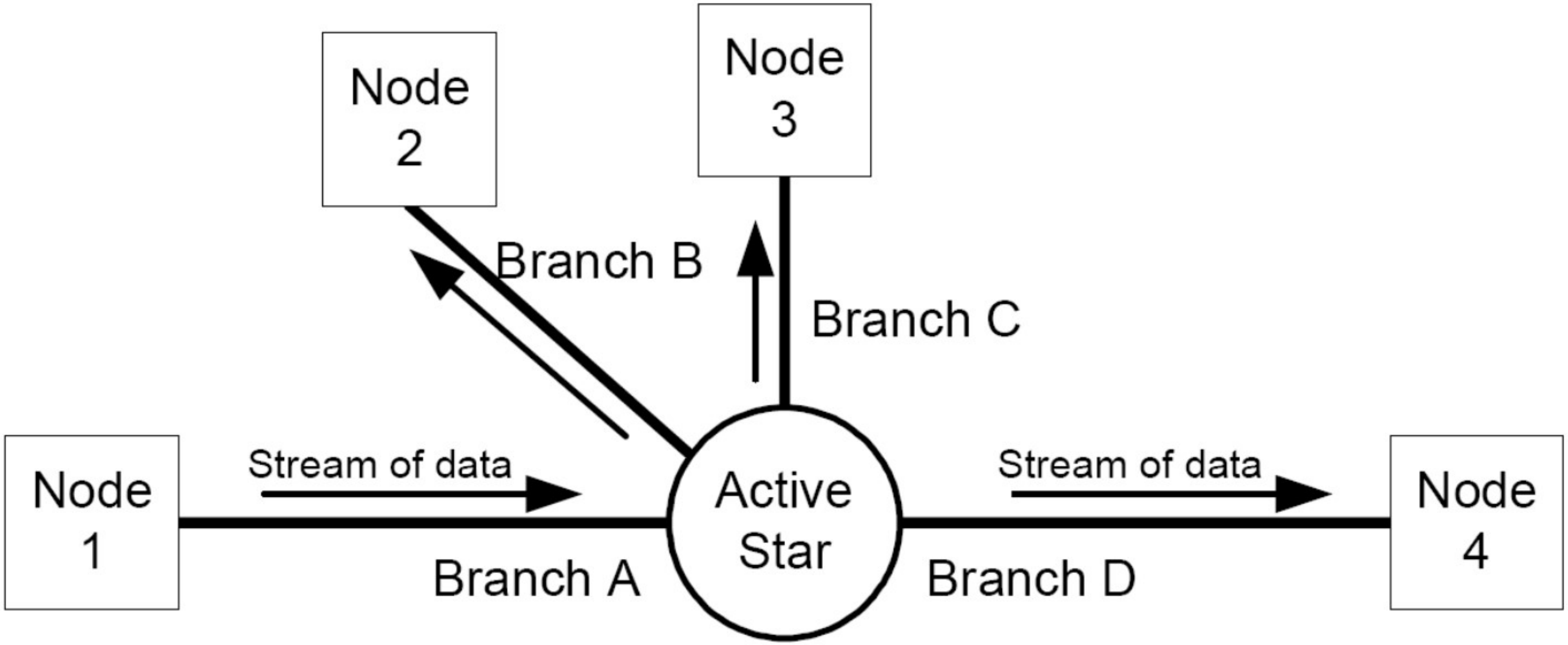
- Overhead is 49 bits for 0 to 8 bytes of data
  - 11 bit ID
  - 20 bit start/end and misc status
  - 16 bit CRC
  - 4 bit data length
  - 1 stuffing bit for every 4 bits except EOF and IFS
- For n bytes of data, total number of bits b = (floor((35 + 8n)/4) + 35 + 8n)
- Best Bit efficiency ~ 52% (n = 8)

Flexray (V2.1, 2004+)

- CAN not suitable for hard realtime and fast systems.
- Flexray provides deterministic data transmission
- Better fault tolerance (e.g. 2 redundant channels)
- Higher data rates and better bit-wise efficiences
- Independence of medium (both electrical and optical can be used)
- Industry backing

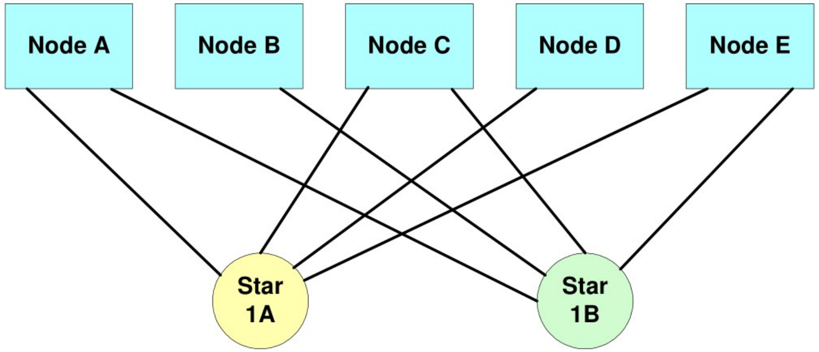
Flexray Network topology: Active Star

- Active star takes data from one channel and distributes it to all others (without storage)

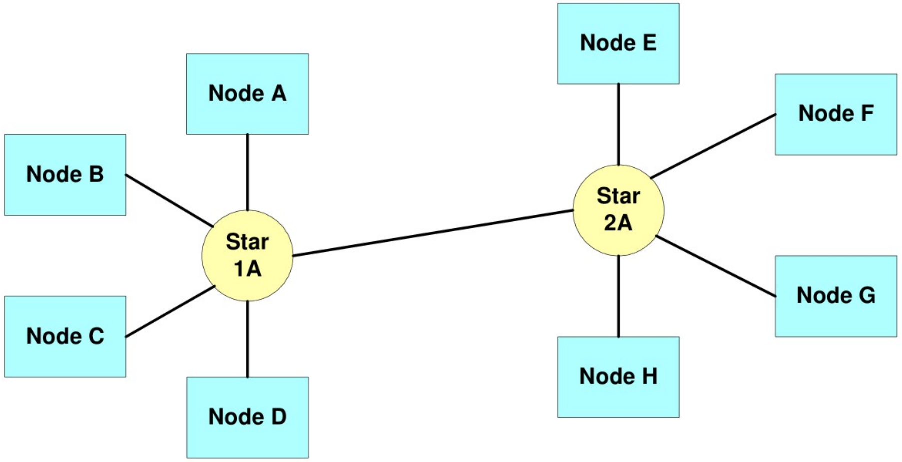


Flexray Network topology: Active Star

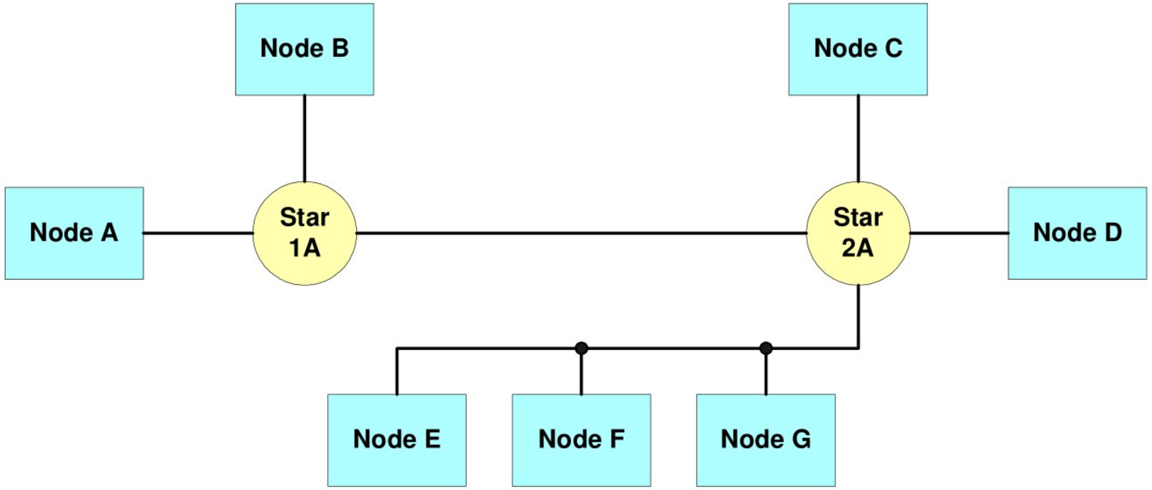
With redundant channels



Cascaded star single channels

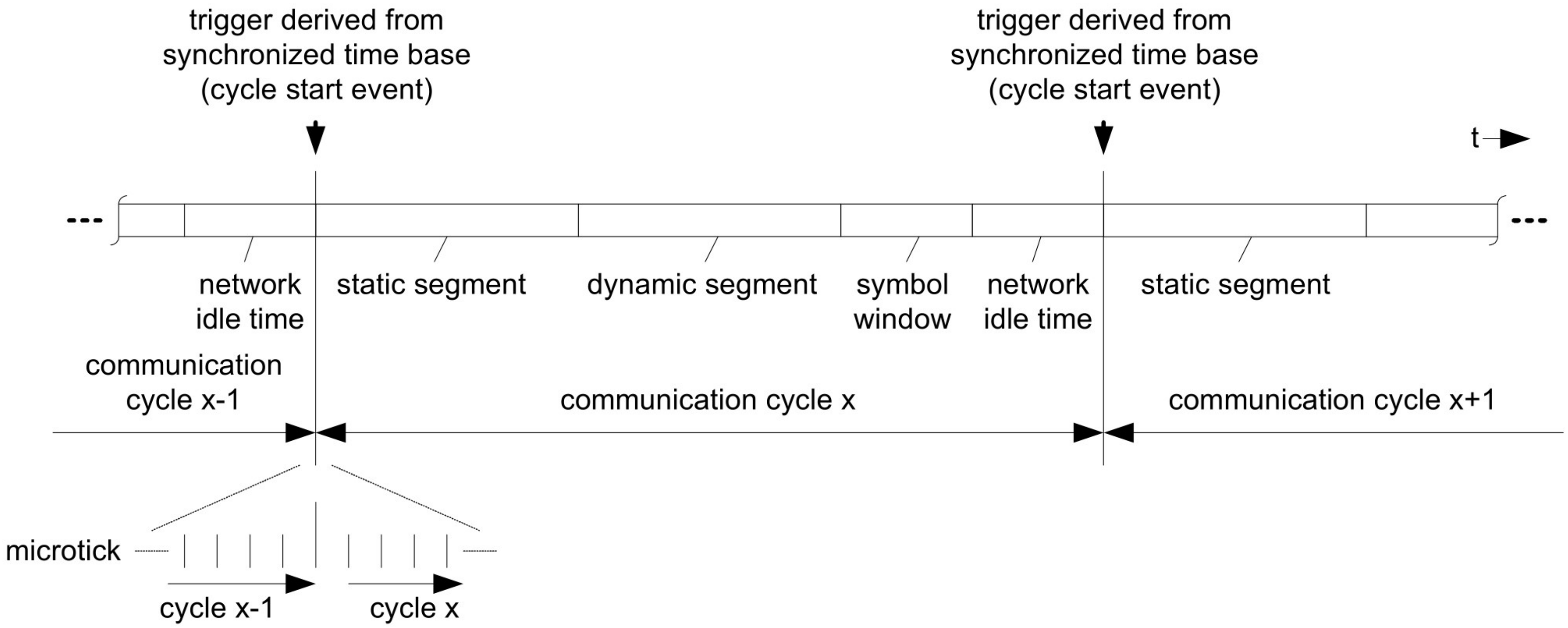


Single channel with hybrid topology:



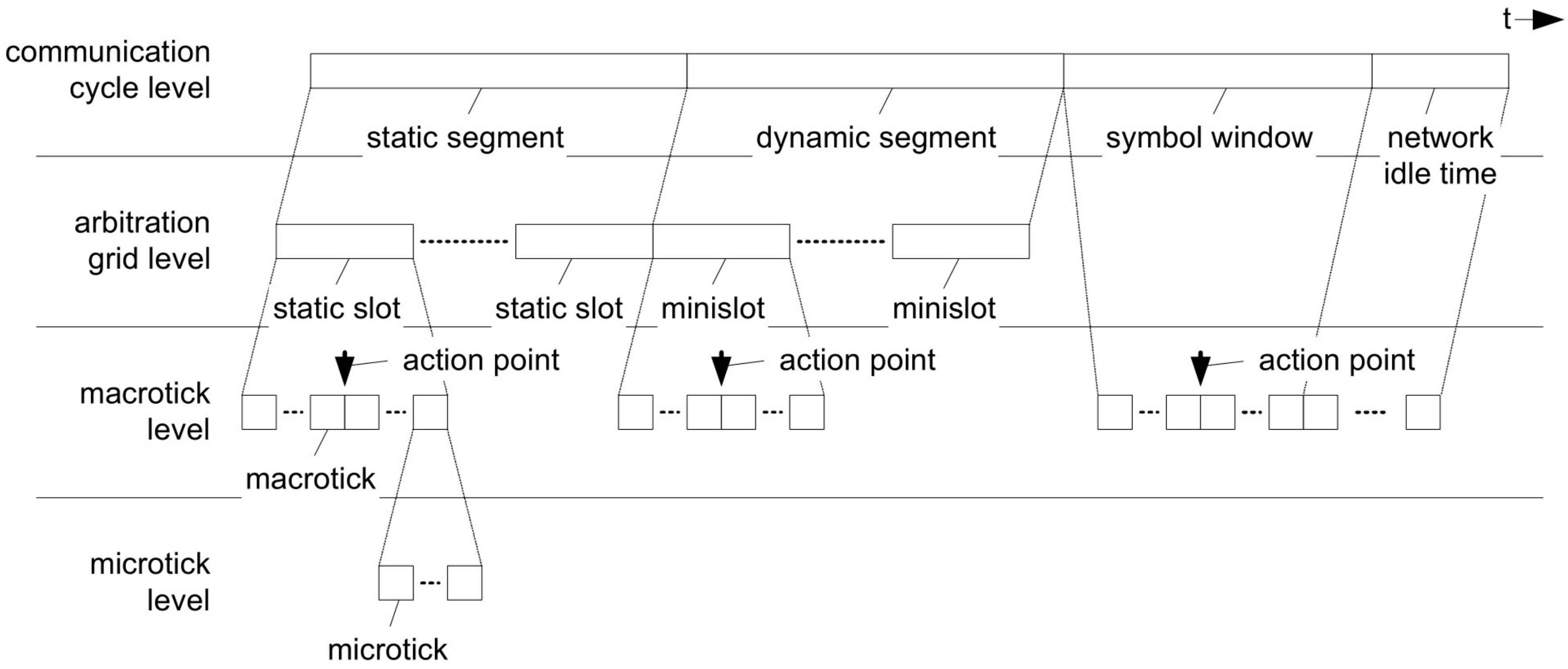
Flexray Medium Access

- The bus operates in continuous cycles based on a global clock.



Flexray Medium Access

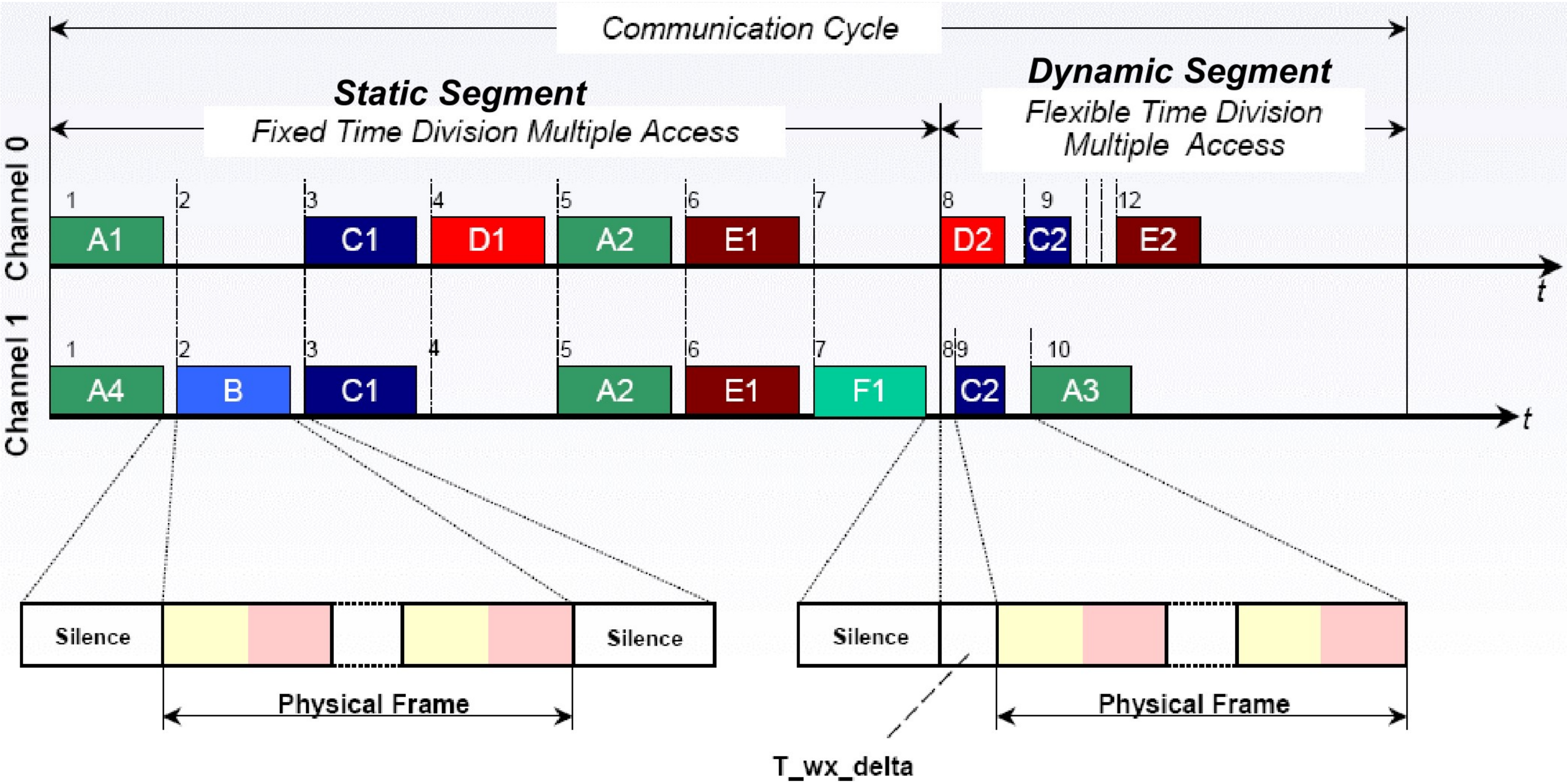
- A cycle is divided into 4 stages



- Microtick: a node's internal time, not synch. with rest of system
- Macrotick: cluster's global time, an integer multiple of microticks
- Macrotick boundaries are ***action points***: start or end of transmission

Flexray Medium Access

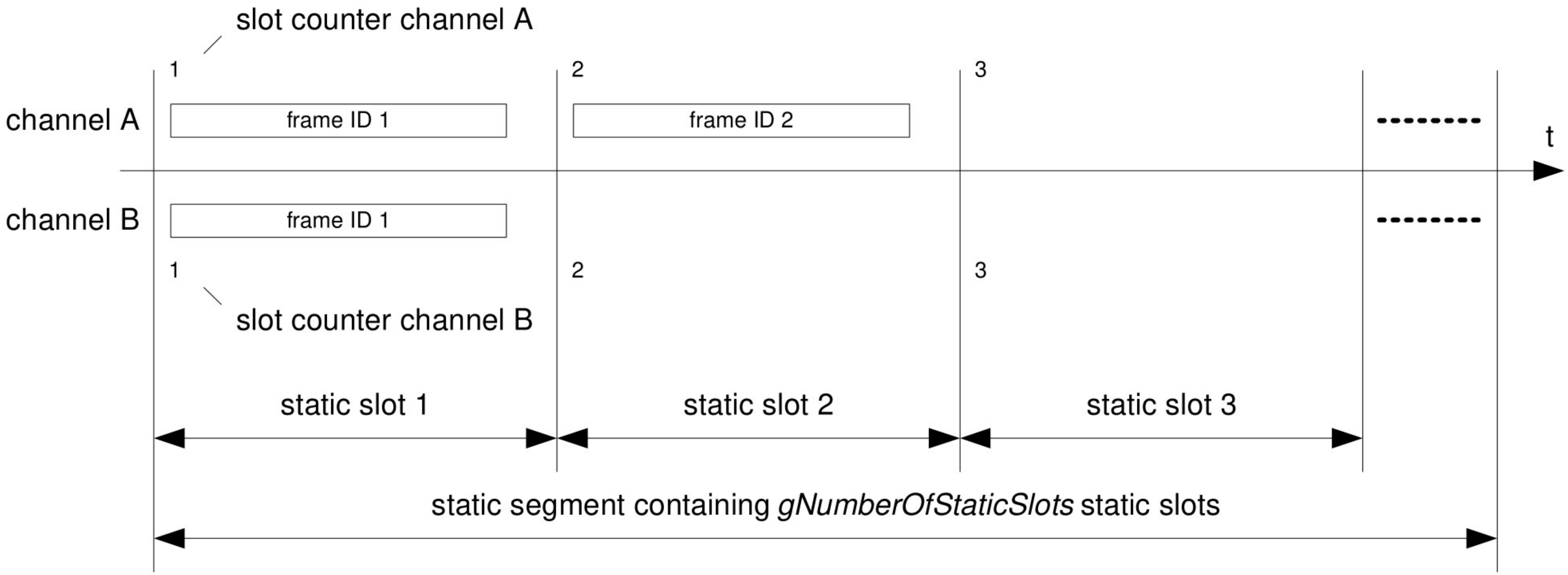
- The static segment uses TDMA, Dynamic segment uses time-slotting



- Note use of redundant information, and use of both channels for increased bandwidth

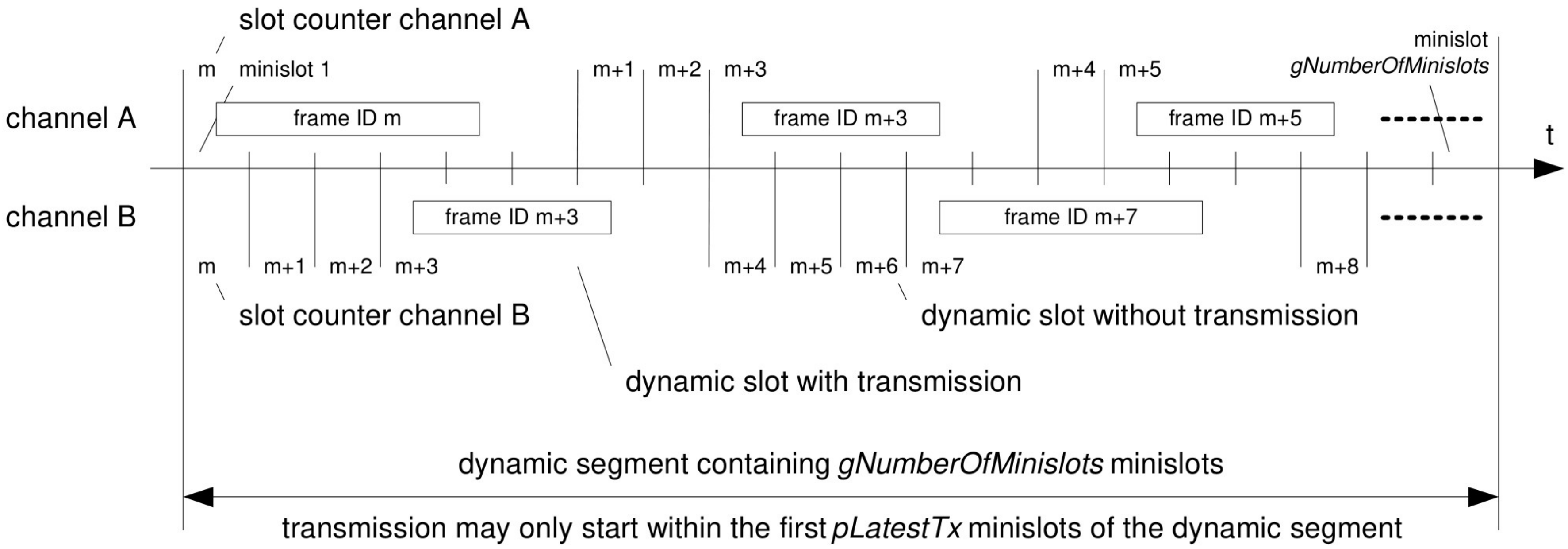
Flexray Static Segment

- TDMA slots are of same number of microticks and repeated in each static segment.
- Max. 1023 slots are allowed, given ascending frame ID numbers
- Frame ID is tied to the nodes (no need for bit arbitration)



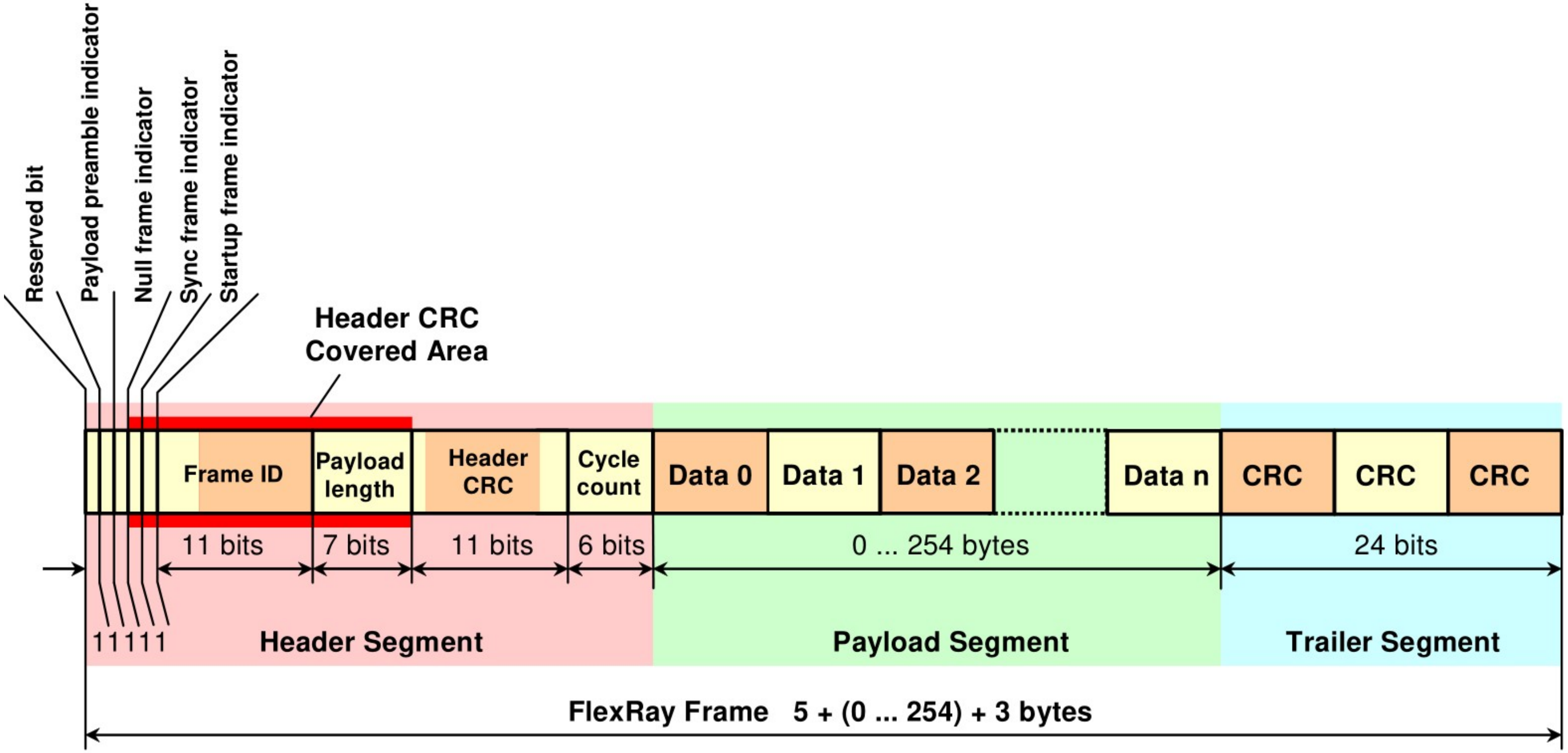
Flexray Dynamic Segment

- Frame ID is used for minislot numbering: First dynamic frame ID = last static Frame ID
- Dynamic segment is of fixed length
- Messages with lower frame ID is sent first
- Each frame ID can send one message per cycle, for more
- "Compressed" TDMA: deterministic arbitration
- Two channels can be used independently
- All nodes must listen to all communication to count minislots.



Flexray Frames

- Physical signals are very similar to CAN (differential).
- CRC added to header area for better protection against errors
- No need for stuffing as timing control is strict.



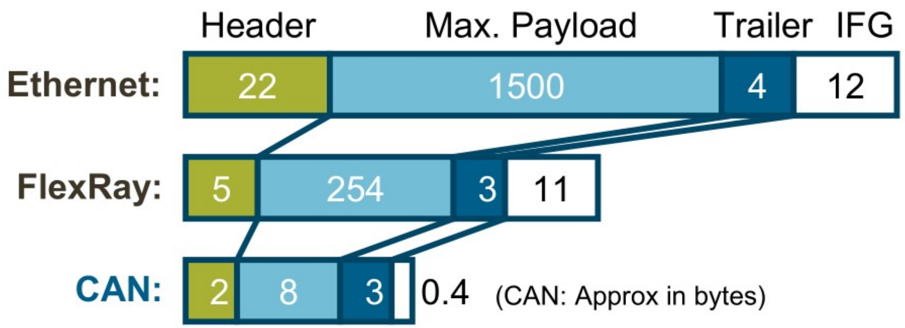
- bit-wise effciency ~ 99% at best.

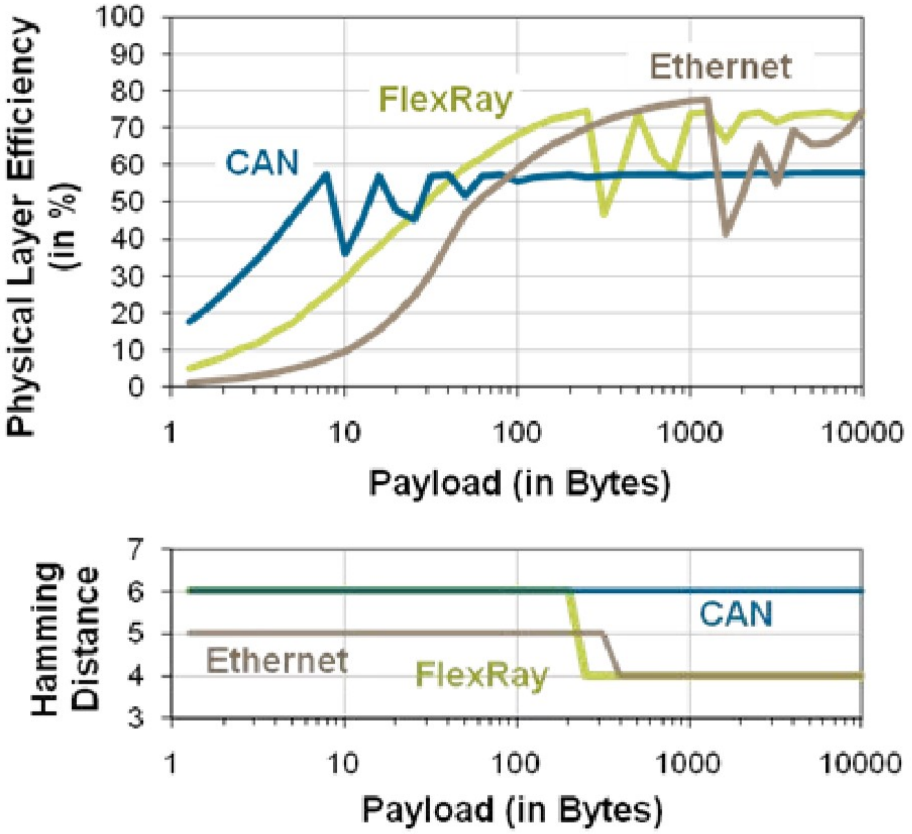
Comparisons

	CAN	FlexRay	(Fast) Ethernet
Access Scheme	CSMA/CR Carrier sense multiple access/collision resolution	TDMA Time division multiple access	CSMA/CD Carrier sense multiple access/collision detection
Focus	Event triggered, best for small payload	Time triggered, deterministic behavior, best for medium payload	Event triggered, best for high payload
Automotive Application	ECU-ECU, ECU-Sensors	Distributed control systems, Backbone	Backbone, Programming ECUs, Multimedia
Cabling, Topology	Twisted pair unshielded, bus	Twisted pair unshielded, bus/star	With special automotive bus driver: Twisted pair unshielded, star
Redundancy	No	Built in: two separate channels (using 2 x Twisted pair)	No (single channel)
Deterministic behavior	By extension: TTCAN	Built in	By extensions: TTEthernet, PTP, AVB

Comparisons: Frame Format

- At larger payloads FlexRay and Ethernet show better efficiency
- Both FlexRay and CAN are better equipped for detecting errors.





Comparisons: Net Data Rate

- Considering physical bit rate, frames, IFG, collisions
- Switched ethernet can be used to avoid the collision penalty for CSMA/CD (20% loss)