Combining CANopen and SAE J1939 networks

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Especially in mobile applications system designers face the requirement that data has to be shared between two CAN network protocols – SAE J1939 and CANopen. The SAE J1939 protocol is the standard for the power train ECUs (electronic control units) in a vehicle, e.g. motor control or transmission. For trailer add-ons or special I/O requirements CANopen modules are first choice because of their broad functional range and availability (COTS). Both CAN standards share the same physical layer, but different data frame formats and protocols are used.

Two approaches are possible to exchange data between J1939 and CANopen devices, either to use a gateway between the different CAN networks or to share the CAN physical layer between the J1939 ECUs and CANopen nodes.

Using a gateway

Within CANopen profile specifications, the device profile for truck gateways (CiA 413) was designed to build a bridge between the J1939 and the CANopen standard (figure 1).

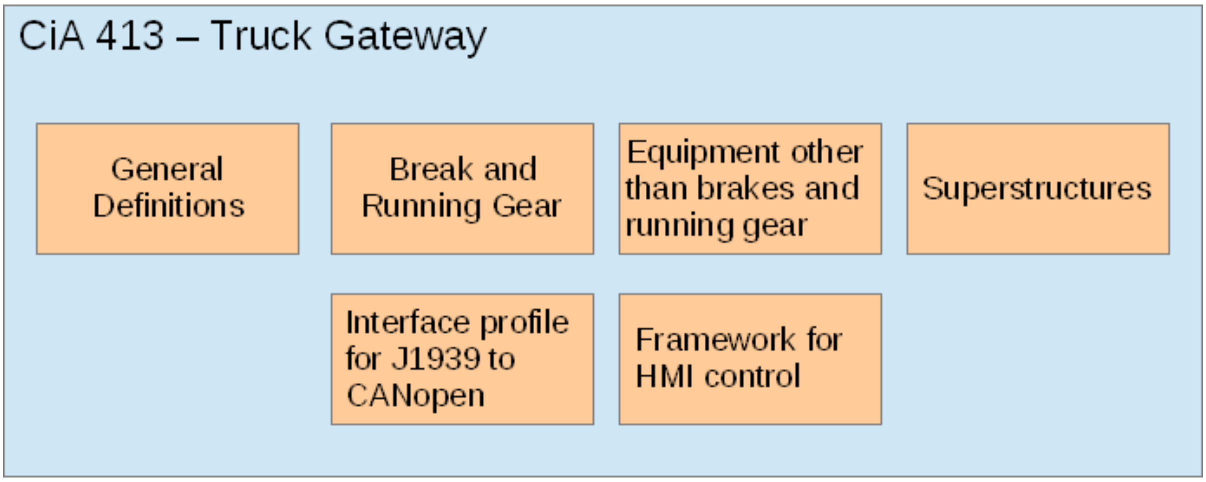


Figure 1: Truck gateway profile

Both standards have a different approach of data organization. In the J1939 standard, all possible process data gets a unique number, the “Suspect Parameter Number” (SPN). At least one SPN is then assigned to a specific “Parameter Group Number” (PGN), which is a CAN 2.0B data frame with a data length of 8 bytes.

The CANopen protocol standard uses an “Object Dictionary” for data organization. All parameters are organized in a table, where a cell is accessed via its unique row (object index) and column (object sub-index).

The CiA 413 profile family defines for the most important (but not all) existing SPN values of the Vehicle Application Layer J1939-71 /5/ a corresponding entry in the device profile area (index 6000h – 67FFh). This approach allows construction of gateways that support multiple device profiles (up to eight).

The device profiles can be of different type, so an inclinometer with digital outputs and truck gateway is possible.

Table 1 shows the general object dictionary structure in the index range 6000h to 67FFh.

Table 1: CiA 413 object dictionary structure

Index range	Function group
6000h to 60FFh	Brake and running gear equipment
6100h to 62FFh	Other than brake and running gear equipment
6300h to 63FFh	Superstructures
6400h to 64FFh	J1939 family networks
6600h to 6650h	Framework for HMI control

The objects of the CiA 413 object dictionary a typically mapped into Transmit- or Receive-PDOs, a default mapping is not provided.

Connection of the CAN-bus to the gateway has to be made via specific connectors. The 7-pin female connector shall be mounted in the chassis frame, the 9-pin female connector shall be located in the cabin. In addition to power supply and CAN signal lines the connectors provide a pin to enable the superstructure (table 2).

Table 2: CiA 413 connectors

Pin	Function	Remarks
1	VCC	Battery voltage, fused, 10A
2	GND	Battery ground
3	ENABLE	Enable when switched to GND
4	CAN_H	
5	CAN_GND	
6	CAN_L	
7	Reserved	
8	Reserved	
9	Reserved	

Usage of a gateway between the two networks has the advantage that the CAN bus-load is not increased in a significant way and bus errors can be resolved quite simple, since CAN error frames are not transferred. On the other hand, additional hardware costs have to be considered.

Sharing the physical layer

The CANopen standard CiA 301 allows various bitrates in the range from 10 kBit/s to 1 MBit/s. The J1939-11 specification stipulates 250 kBit/s and is used in the majority of applications. The J1939-14 standard specifies 500 kBit/s for the physical layer.

Thereby the bitrate for a shared physical layer is limited to the bitrates 250 kBit/s and 500 kBit/s. Fortunately both standards define the same sample point location at 87,5 % together with a SJW value of 1.

Care has to be taken when comparing the network topology parameters (table 3).

Table 3: Network topology parameters for 250 kBit/s

Parameter	J1939	CANopen
Bus length [m]	40	250
Drop line length [m]	1	11
No. of nodes	30	Depends on transceiver
Termination [Ohm]	120	120

The J1939 CAN physical layer documents define very tight limits compared to the CANopen CiA 301 standard. As long as the accumulated drop line length is not more than 55 meters (for 250 kBit/s) the CANopen parameters are closer to the theoretical values. Actual CAN transceivers allow up to 110 nodes to be connected to the same wires.

Mixing Standard and Extended Frames

Beneath the physical layer examination, we have to take a closer look on the data link layer. Both standards allow the use of Standard Frames (11-bit identifier) and Extended Frames (29-Bit identifier). For CANopen Standard Frames are the favorite choice, however many services can also be configured to send and receive data with Extended Frames (table 4).

Table 4: CANopen service configurations

CANopen Service	Extended Frame allowed
NMT	No
SYNC	Yes, index 1005h
EMCY	Yes, index 1014h
TIME	Yes, index 1012h
TxPDO	Yes, index 1800h .. 19FFh
RxPDO	Yes, index 1400h .. 15FFh
SDO	No
NMT error control	No

The J1939 specification covers only Extended Frames, but allows use of 11-Bit identifiers from other protocols /5/. The only limitation is the usage of Remote Frames, which are not allowed in J1939 networks. Hence the CANopen Node Guarding service as well as requesting PDOs via Remote Frames is not possible. This limitation is not remarkable, because both services are not recommended for actual network implementations.

The priority field inside the J1939 PDU identifier has no impact on the message sequence then.

CANopen “understands” J1939

Is it possible to use a CANopen device in a CAN network that runs with another protocol? The answer to that question is: Yes, unless you keep two limitations in mind:

- the Non-CANopen network shall not use the identifier value 0 (CANopen NMT).
- the Non-CANopen network shall not use the identifiers for SDO and NMT-EC services.

Both requirements are met by the J1939 protocol. But how can the CANopen device be set into Operational state in a network without NMT manager? Simply by configuration of the object 1F80h (NMT Startup). Writing and storing a value of 8 to this object will tell the CANopen device to enter NMT state Operational after the NMT state Initialization autonomously (self starting).

Mobile applications require in increasing number of sensor data, e.g. additional temperatures in a ne vehicle which are not measured by the existing J1939 ECUs. In most cases it makes sense to feed this information into the existing CAN network, which knows nothing about CANopen.

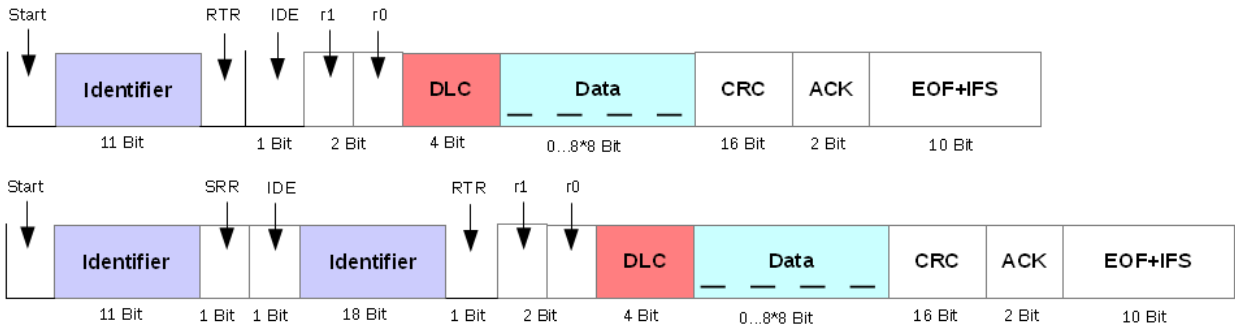


Figure 2: CAN data frames

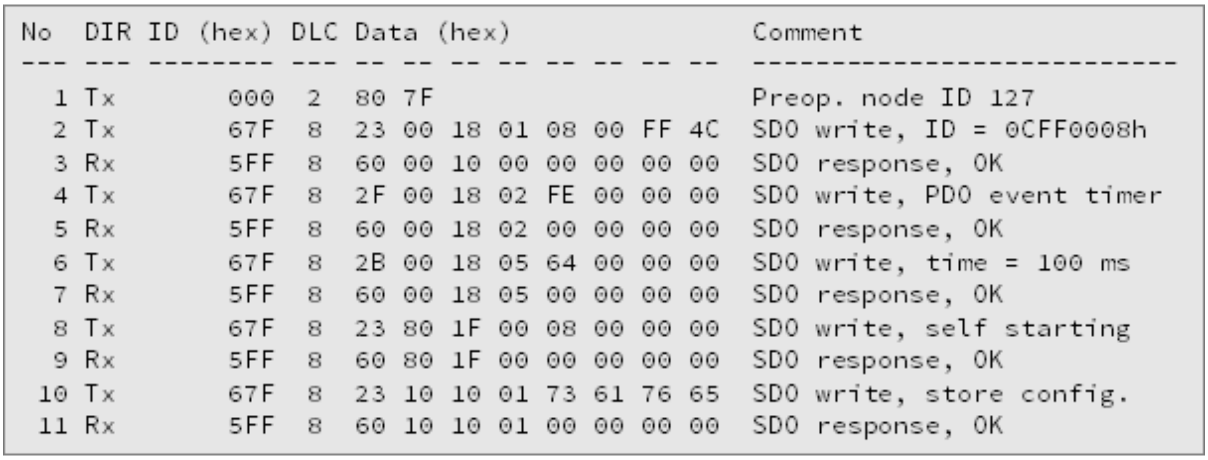
Mixing Standard Frames with Extended Frames has also an impact on the bus load. The IDE (Identifier Extension) bit is recessive for Extended Frames, so Standard Frames have always a higher priority and utilize the bus first (figure 2).

As an example, we want to acquire 4 temperatures with a COTS CANopen device, which shall be placed in an existing J1939 network.

Before connecting the CANopen temperature acquisition module to the CAN network of the vehicle, the following configuration must be applied to the CANopen device:

- Configure the Transmit PDO identifier to Extended Frame
- Configure the Transmit PDO to cyclic transmission, using the desired update rate
- Configure the NMT Startup object to self starting
- Store this configuration

For selection of the PDO identifier we use the PGN Proprietary B together with a non-conflicting source address value. The identifier can be calculated by the formular ID = 0x0CFF0000 + source address.



```
No  DIR ID (hex) DLC Data (hex)                 Comment
--- --- -------- --- -- -- -- -- -- -- -- --   ---------------------------
  1 Tx       000  2   80 7F                     Preop. node ID 127
  2 Tx       67F  8   23 00 18 01 08 00 FF 4C   SDO write, ID = 0CFF0008h
  3 Rx       5FF  8   60 00 10 00 00 00 00 00   SDO response, OK
  4 Tx       67F  8   2F 00 18 02 FE 00 00 00   SDO write, PDO event timer
  5 Rx       5FF  8   60 00 18 02 00 00 00 00   SDO response, OK
  6 Tx       67F  8   2B 00 18 05 64 00 00 00   SDO write, time = 100 ms
  7 Rx       5FF  8   60 00 18 05 00 00 00 00   SDO response, OK
  8 Tx       67F  8   23 80 1F 00 08 00 00 00   SDO write, self starting
  9 Rx       5FF  8   60 80 1F 00 00 00 00 00   SDO response, OK
 10 Tx       67F  8   23 10 10 01 73 61 76 65   SDO write, store config.
 11 Rx       5FF  8   60 10 10 01 00 00 00 00   SDO response, OK
```

Figure 3: CANopen module configuration example

Figure 3 depicts a configuration example for a CANopen module with node-ID 127. The identifier for the 1st transmit PDO is configured via index 1800h, sub-index 1 of the communication profile. The device is set to pre-operational state first. In the next step the 1st transmit PDO is configured as event triggered (messages 4 and 5) and the associated cyclic timer is programmed (messages 6 and 7). The data bytes 5 and 6 of message no. 6 define the timer repetition rate in multiples of 1 millisecond (64h = 100 ms). Please note that the value is transmitted LSB first. Now the device is configured to start PDO data transmission directly after power up (no NMT start command required). In the final step (messages 10 and 11) the configuration is stored in the device.

There is still one limitation when emulating the J1939 protocol with CANopen devices: they can not participate in the address claiming process. Hence duplicate source addresses (resulting in a unique identifer used by two devices) must be avoided by other means.

In order to fill this gap, MicroControl has added the address claiming procedure in the latest version of the CANopen protocol stack.

Conclusion

Two approaches for interconnecting J1939 and CANopen devices have been illustrated. Table 5 summarizes the pros and cons of each solution.

	Gateway	**Shared network**
Bus load	Neutral	Increased,
Error frames	Separate networks	Impact on all devices
Administration effort	High	Neutral
Complexity	High	Low
Exchange all data	No	Yes
Address claiming	Yes	No
Costs	High	Neutral

Table 5: Comparison of the two approaches

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