A personal review and an outlook

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The nonprofit CAN in Automation (CiA) users' and manufacturers' group started from its beginning the development of higher-layer protocols and additional physical layer recommendations, which were not covered by Bosch's CAN 2.0 A/B specification. Additionally, the association started the promotion of CAN technology in many different markets – first in Germany, then in Europe, and later in North America as well as in Far and Middle East. With the introduction of CAN FD, the next generation of CAN technology was born giving it another 20 to 25 years of lifetime. At least in 2020, we will see the first cars on the road using CAN FD networks. Other industries will follow or they will surprise me and adapt CAN FD earlier.

The CAN 2.0 A/B specification published by Bosch in 1991 described the data link layer protocol and the high-speed physical layer for bit-rates up to 1 Mbit/s. It did not specify the electro-mechanical parts of the physical layer in all details. For example, connectors and cables were not specified; just the impedance of 120 Ω was given as a recommendation. Also the bit-rates and location of sampling points were not speci-fied. Of course, this was not necessary, because the OEMs did this by themselves and gave the additional specifications to their Tier-1 suppliers.

However, in other markets the situation was different. The suppliers, in particular in industrial automation markets, provided for low-volume applications generic devices. This is why CiA released already a few weeks after its inauguration the CiA 102 specification with a list of recommended bit-rates including sample-point location. Additionally, the pin-assignment for the 9-pin D-sub connector was recommended. In parallel, some CiA members started to develop the CAN Application Layer (CAL) based on some pre-work done by the STZP, a German technology transfer center and Philips Medical Systems, a Dutch enterprise planning to use CAN networks in different departments.

From CAL to CANopen

CAL was specified in the CiA 200 series. It was a very academic approach. It covered just the OSI application layer and some parts of the transport layer. In general, CAN network implementations do not comply with the 7-layer OSI reference model. Already, the CAN controller chips implement besides a part of the OSI data link layer some sub-layers of the OSI physical layer. Nevertheless, the OSI model helps to understand layered protocol architecture for CAN-based networks.

CAL comprised several functions. The CMS (CAN message specification) defined the communication services, e.g. con-firmed and not confirmed messages. The NMT (network management) introduce an FSA (finite state automaton) and the NMT protocol. The DBT (distributor) managed the automatic assignment of CAN-IDs to the CMS protocols. The additional LMT (layer management) specified the auto-matic assignment of node-IDs to NMT slave devices.

CAL was – as already mentioned – an academic approach leading to resource-consuming implementations. It was practically used in some medical applications as well as in the textile industry. The CAL approach is a simple OSI (open system interconnection) 7-layer implementation.

In order to make products interoperable, you need also a communication profile for the lower layers. Additionally, it is necessary to standardize process data, configuration parameters, and diagnostic information. But this is outside of the OSI reference model.

In order to streamline implementations and to make CAL usable in assembly lines, Bosch started a research-project under the umbrella of the ESPRIT (European Strategic Program on Research in Information Technology) program financed by the European government. This ASPIC (Automation and Control Systems for Production Units using an Installation Bus Concept) research-project ended in 1994.

At this time in point, the results were given to CiA for further development and maintenance. Not all CAL protagonists were happy about this. Some of them wanted to continue developing proprietary communication profiles and device profiles based on CAL. Also companies offering the development of proprietary CAN-based higher-layer protocols were not in favor that CiA promoted the results of the European research project.

The CAL-based application layer and communication profile was published in the document CiA 301 version 1.0. Just two month later, the version 1.1 was released. In those times, the name CANopen was not given to this application layer and communication profile approach. The first real stable version was 3.0 (already titled CANopen), published in 1996. There are still today some products in duty implementing this version.

The next improvements came with version 4.0 released in 1999. It introduced four default PDOs and the Heartbeat protocol substituting the Node/Life guarding mechanism, which was based on CAN remote frames making more trouble than solutions. There were a few more improvements including the Identity parameter, which identifies a CANopen device uniquely in the world by means of 4 x 32-bit subparameters.

CANopen is more than just a CAN-based application layer and communication profile: It comprised many additional specifications, especially profile specifications. Already, when the research results were handed over to CiA, there were some first device profiles specified such as for modular I/O modules and electrical actuators. They are now known as CiA 401 and CiA 402. Today, the CiA 402 CANopen profile for motion controllers and drives is internationally standardized in the IEC 61800-7 series.

Device profiles describe the communication behavior of a single entity at its CANopen interface. Communication relations to other devices in the network are possible, but not by default specified. Communication with other CANopen devices needs to be configured or programmed application-specific. However, in some industries there is a demand to standardize all communication relations in a network system. In CANopen technology, this is called application profile. The first application profile, CiA 407, was developed for passenger information system in public transportation. The application parameters were based on the already established IBIS system. In the meantime, CiA 407 is standardized in the EN 13149 technical report (TR) series. Developed in Germany, it was first adapted in Finland and Czechoslovakia (Czech Republic and Slovakia). Other more successful CANopen application profiles include CiA 417 (CANopen Lift) and CiA 422 (C*le*ANopen) for refuse collecting vehicles (EN TR 16851).

In total, the CANopen profile specifications comprise more than 20000 DIN A4 pages. And there are new profiles under development and in the pipeline. Sometimes, the device suppliers are very slow in standardizing profiles. They are not really in favor that those products are interchangeable with those from competitors – even if this is just a partly interchangeability on the device's default behavior. But the interoperability with other CANopen product classes they appreciate very much. In applications, in which the system designers require standardized profiles, the development and the market penetration speeds up. A good example was the CiA 420 series, a set of CANopen profiles for extruder downstream devices. They were specified in close cooperation with the Euromap association of machine builders and factory suppliers for plastic processing. Academically, this set of specifications is an application profile with a defined CANopen manager entity, the extruder.

In general, device profiles provide interoperability between the other units and in particular to the so-called master entity. However, the plug-and-play capability is low. System configuration or programing of the application master is needed. Applica-tion profiles allow a higher degree of plug-and-play functionality compared to device profiles.

Other standardized CAN-based application layers

In the early 90ties, the so-called fieldbus was conducted: The “German” Profibus and “German” Interbus were fighting each other and together against the “French” FIP. Also in the CAN community, different application layers tried to gain acceptance and to win market shares. In Europe, CANopen was accepted increasingly, while in North America DeviceNet promoted by the ODVA association was the winner against Smart Distributed System (SDS) fostered by a Honeywell sub-division. In the CAN community, there was no “war”; it was more or less a peaceful co-existence: CiA even sold the DeviceNet specification on behalf of the ODVA.

In the passenger car industry, there was no application layer standardized at all. Every carmaker developed its own so-called communication matrix. In the heavy-duty vehicle industry, SAE took the lead and developed the J1939 approach, which was what I like to call an application profile. This means, the specification contained an application layer plus message content specifications such as signals or in J1939 terminology suspect parameters and parameter groups.

In the following years, additional higher-layer protocols were defined. Most of them were proprietary and in the long term not really successful. In industrial automation, CANopen and DeviceNet survived. CANopen was also adopted in many other application fields including healthcare, rail vehicles, maritime electronics, and elevators, for example.

Besides for truck and buses, J1939-based solutions were developed for agriculture and forestry machines (ISO 11783, also known as ISOBUS), for truck-trailer communication (ISO 11992), and for navigation equipment in marine applications (IEC 61162-3).

In the late 90ties, the automotive industry started to standardize higher-layer protocols for CAN, which was in the meantime the dominating communication system in passenger cars. The European government and the US administration forced the carmakers to standardize the CAN-based diagnostic interface, in order to give “free” garages and repair stations access to the in-vehicle ECUs’ error memory.

The very first common protocol for automotive applications was the CAN Calibration Protocol (CCP). Never internationally standardized it was a success. The second commonly used approach was the ISO transport protocol (ISO-TP) segmenting a 4095-byte payload and re-assembling it on the receivers’ side. The ISO-TP is internationally standardized in ISO 15765-2.

In the 90ties, the OEMs and Tier-1s were not that open to standardize more than the CAN physical and data link layer. This has changed: Today the content of diagnostic messages is partly standardized (e.g. Unified Diagnostic Services). Of course, governments regulate this, in order to protect OEM-independent garages and repair shops. The in-vehicle messages in passenger cars are still a “secret”. To be honest, the content of the messages is not that secret, anymore. Hackers reverse-engineered them and demonstrated how to control a car remotely.

We could standardize also the control and measurement messages. But not without secure communication methods, for example, authentication of the sender.

In CiA 447, the CANopen application profile for car add-on devices, a lot of those signals and messages have been stand-ardized. You can use these definitions also in the in-vehicle networks. CiA 447 net-works are used in special-purpose vehicles such as police cars, ambulances, taxis, and cars for disabled people requiring special equipment.

Only the standardization of the message content makes products interoperable and exchangeable, if they provide the same functionality. This is like in human communication: Standardizing a set of characters and some grammar rules is not sufficient to understand each other. You need vocabulary, which you have agreed on.

May be that in the future some industries are not more that afraid of "interoperable" product specifications anymore. The argument on third-party spare parts is no more cogently, if you can avoid unintended or illegal integration of products by means of authentication mechanisms.

Standardized remote access

By accident, CiA inherited the ModbusTCP-to-CANopen gateway specification from the Modbus association. CiA generalized it for any Ethernet-based networks in the CiA 309 series. This approach has been adapted by several industries, e.g. the CANopen subsea suppliers. CiA 309 allows remote access to CANopen networks via Ethernet. Some people call this IoT (Internet of Things). When CiA started in 2000 the development of the CiA 309 specification, the term "IoT" was not "invented".

Ethernet-based embedded networks are mainly used in automotive and industrial applications as backbone network or for some bandwidth hungry front-end communication. Ethernet and CAN will coexist for a long time. This means, we need gateways between the two most success-ful network technologies. In automobiles, the Time-sensitive Networking (TSN) seems to have a bright future. Also in in-dustrial control systems, some people are in favor of TSN, The OPC foundation al-ready maps its OPC UA application layer. We can learn from the above-mentioned gateway specifications and adopt them, where possible.

The future of CAN is bright

Already in the late 90ies, I was told that the CAN lifetime comes to its end soon. But in the first decade of this century, CAN has penetrated some more markets and is still doing so. This was the decade, in which CAN conquered the markets of mobile machines: construction and mining machines, agriculture and forestry ma-chines as well as container handling equipment such as harbor cranes and straddle-carriers. In the first years of this century, CiA members also started to de-velop the CANopen profiles for lift control-lers and refuse collecting vehicles. In these conservative markets with low innova-tion rates, it will take another two or more decades before CAN networks will be sub-stituted.

With the introduction of the CAN FD proto-col, the lifetime of CAN has been prolonged by one or two decades even in markets with shorter innovation cycles, for example the automotive industry and industrial automation. In particular, battery-powered systems benefit from CAN inter-faces with small footprints and low-power hardware (CAN controllers as well as CAN transceivers). Typical applications include Pedelecs and other light electric vehicles (LEV) as well as some service robots.

Service robots as well as cooperative robots on the factory floor are often very specialized with dedicated grippers, arms, and tools. This requires a modularized system design with interoperable products. For this you need standardized profiles. CiA has developed a number of CANopen profiles, and is willing to write specific ones for robot modules. The standardiza-tion of profiles is always a compromise: The system designers are in favor, but do not want to write them, and the suppliers like to keep as many as possible manufacturer-specific. The outcome depends normally on the "power" in the group standardizing the profile.

Because those robots are often battery-powered, network interfaces should support low-mode functionality. CAN hardware – protocol controllers and transceivers – provides this feature. There are also CAN transceivers with selective wake-up capability available, which reduce power consumption further.

CAN FD will be used also in many other application fields – in particular, in price-sensitive ones. Due to the high-volume in the automotive industry, CAN hardware is quite reasonable. Another selection criteria are the small footprints of the CAN hard-ware and the resource saving CAN higher-layer protocol stacks. This is required in all small machines including laboratory equipment, medical devices, and other front-end units – especially, sensors, but also miniature drives.

The reliability of the CAN FD transmission and the robustness of the physical layer, if properly designed, are other important criteria using CAN FD networks. The larger payload of up to 64 byte as well as the data-phase bitrate of more than 1 Mbit/s makes CAN FD even suitable for applications requiring functional safety and cyber security.

CiA is going to propose a common functional safety protocol for standardized higher-layer protocols such as CANopen FD and CiA 602-2 (J1939 on CAN FD). This approach could also be used for ISO 11992, the truck-trailer point-to-point network.

The re-invention of wheels

CiA is active in many different application fields. All of them claim that they have very specific requirements. This is true and it is not true. Of course, there are special requirements regarding the physical layer and the environmental conditions. Outdoor and indoor applications have quite different requirements regarding the temperature range. Also subsea sensor networks have to withstand saltwater for a long time.

Very extreme are the requirements in outer space applications. Even the CAN controller and transceiver chips have to be resistant against radiation. There are four companies offering such CAN transceiver chips. Seems to be an interesting market.

On the other hand, on the protocol level, the differences are not that huge. To transport an amount of data exceeding the length of CAN frames requires segmentation and re-assembling of data. For this purpose several transport layer protocols have been invented. But only one is really necessary.

It is a pity that the different application domains are not talking to each other. Life could be much simpler, if we would discuss and develop things jointly. Just a brief example: CiA members recommended in the CiA 601 series the CAN FD device and system design. In ISO 22900-2, a physical layer for CAN FD is standardized not considering any of the recommendations and rules of thumb given in the CiA documents.

The same happens every day on the application level. We invent multiple middlewares, device and application profiles, etc. Looking to autonomous moving things, there are cars, drones, service robots, agriculture and construction machines, etc. They all need the same basic func-tional elements such as object detecting sensors and navigation. Why we don't develop those things jointly? This would be synergy at work. The same is for cyber security and functional safety.

There are different functional safety protocols for CANopen, DeviceNet, ISOBUS, J1939, and ISO 11992. In some applications, especially in mobile machinery, there are several of them used. This makes integration of functional safe subsystem a challenge. It would be nice to develop a common protocol to be used in those commercial vehicles.

On the profile level, there are generic devices used in many application fields and very specific ones just needed for one dedicated application. It would make sense to standardize profiles independent of the communication technology. CiA is willing to support this. CiA is even willing to submit its CANopen profiles for use on other network technologies.

The re-invention of wheels happens, because there is no instance, which provides technology search services. It is even not a common engineer habit to search for existing solutions. An example: For automated driving you need to detect objects and obstacles. This is necessary for passenger cars, commercial vehicles including trailers, agriculture and construction machines as well as moving service robots and automated guided vehicles (AGV) such as forklifts. The automotive industry has developed several proprietary systems including communication solutions. Additionally, CiA members have specified the CANopen profile for item detecting devices intended for commercial vehicles and machines on wheels. The truck OEMs also need to communicate detected objects from the trailer to the towing vehicle. They like to use the CAN-based truck/trailer network standardized in ISO 11992-3. The application behind is an automatic lane departure control.

If there would be a database or any other kind of electronic representation on existing and under development standards and specifications, the re-invention of wheels could be reduced. (For searching patents, we have such resources).

Another example is the specification of CAN FD network designs. The ISO 11898 series standardizes the CAN FD data link layer and the medium dependent inter-face. But the network design is not stand-ardized. Each OEM will do it by itself. For diagnostics and aftersales purposes, there are regulations in the European Community, the USA, and in other countries to use ISO 15765-2 respectively ISO 22900-2. Unfortunately, these standards are not harmonized and don’t consider existing CiA (601 series) and SAE (J2284-4/5) recommendations.

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