AUTOSAR Runtime Environment and Virtual Function Bus

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Abstract. This paper presents a selected set of concepts of the AUTomotive Open System ARchitecture. Runtime Environment (RTE) and the Virtual Function Bus (VFB) are core parts of the AUTOSAR system design and facilitate relocatability of software components, one of the key features of AUTOSAR. The goal of this paper is to show how the RTE and the VFB work together in order to realizes relocatability and locationßtransparent interaction. A detailed view on the responsibilities of the Runtime Environment is shown as well as how artifacts from the level of the Virtual Function Bus are used for the generation of the RTE. Further, the concepts of runnables and the RTE mechanisms for their management will be shown in detail. Finally, an overview on hardware interaction mechanisms in the AUTOSAR architecture with respect to the Runtime Environment will be presented.

Stichworte: Automotive Open System Architecture, Runtime Environment, Virtual Function Bus, AUTOSAR, RTE, VFB, Runnables, Hardware Interaction

1 Introduction

The AUTOSAR [1] software architecture is an open standard automotive software architecture that has been developed by a joint group of automotive vendors and stakeholders in oder to create an integrated standard infrastructure for vehicle software development. It aims to improve the efficiency and quality of automotive software by means of a widely accepted standard while preserving the competitiveness of the participants products, i.e. *Cooperate on standards, compete on implementation*.

In order to achieve a high degree of transparency against the underlying hardware infrastructure, the AUTOSAR standard introduces two architectural concepts that facilitate infrastructure independent software development. Namely, these are the *Virtual Function Bus* (VFB) and the *Runtime Infrastructure* (RTE) that are closely related to each others and that shall be introduced in detail in the following.

The rest of this paper is structured as follows: First, a short introduction into the general ideas behind the concepts of RTE and VFB with respect to the AUTOSAR mission will be given. Afterwards, a more detailed view on the runtime environment will point out which kind of components can interact with the RTE and what has to be provided to realize this interaction. In section 4, the concepts of runnables will be introduced in more detail and different concepts of mappings of tasks to artifacts of the underlying operating system will be shown. Afterwards, in section 5, an example for the implementation of the RTE according to the Sender-Receiver communication pattern will be given. Finally, different mechanisms of how the RTE can interact with hardware components will be shown in section 6.

2 Fundamentals

One of the basic principles of the AUTOSAR software design is the relocatability of components among different architectures. In contrast to other embedded software architectures where each component is highly specialized on the underlying hardware infrastructure, OEMs and vehicle manufacturer can use the AUTOSAR approach to redeploy existing components to any kind of hardware infrastructure that supports the AUTOSAR standard.

In order to realize this degree of flexibility against the underlying infrastructure, the AUTOSAR software architecture follows several abstraction principles. In general, any piece of software within an AUTOSAR infrastructure can be seen as an independent component while each AUTOSAR application is a set of interconnected AUTOSAR components. Further, the different layers of abstraction allow the application designer to disregard several aspects of the physical system on which the application will later be deployed on, like:

- Type of micro controller

[1] Automotive Open System Architecture

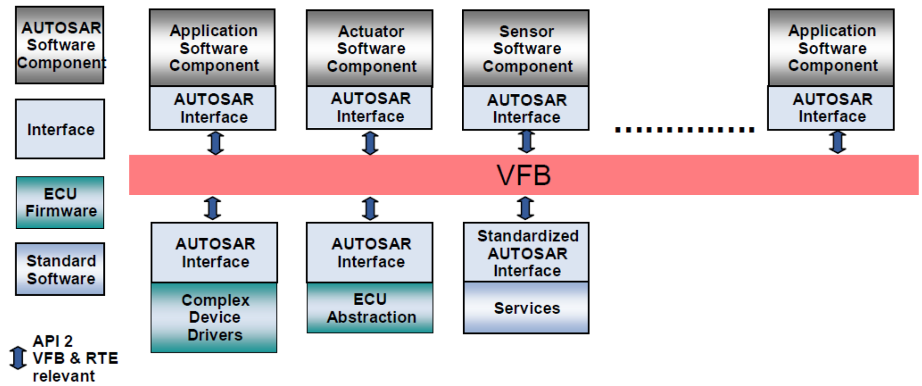


Fig. 1. Overview on the principles of virtual interaction using the AUTOSAR Virtual Function Bus

- Type of ECU hardware
- Physical location of interconnected components
- Networking technology / buses
- Instantiation of components / Number of instances

2.1 Virtual Function Bus

From a general perspective, the virtual function bus can be described as a system modeling and communication concept. It is logical entity that facilitates the concept of relocatability within the AUTOSAR software architecture by providing a virtual infrastructure that is independent from any actual underlying infrastructure and provides all services required for a virtual interaction between AUTOSAR components.

As illustrated in figure 1, the virtual function bus is a component interconnection concept that strictly separates the domain of application development and modeling from the infrastructure. It provides generic communication services that can be consumed by any existing AUTOSAR software component. Although any of these services are virtual, they will then in a later development phase be mapped to actual implemented methods, that are specific for the underlying hardware infrastructure.

2.2 Runtime Environment

In contrast to the purely virtual specification of the communication topology and interaction between components which is done via the virtual function bus, the runtime environment provides an actual implementation for these artifacts. It could also be said that the runtime environment provides an actual representation of the virtual concepts of the VFB for one specific ECU.

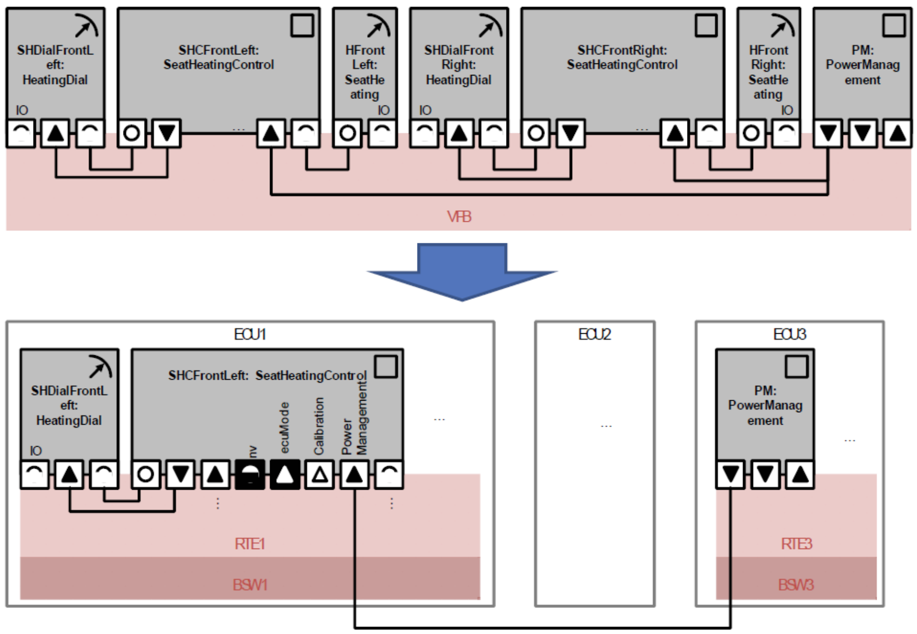


Fig. 2. Example VFB to RTE mapping where the virtual communication topology is mapped to three different ECU's [3]

Each ECU has its own customized RTE implementation which is generated during the ECU Configuration process of the AUTOSAR methodology [2]. The ECU mapping, i.e. the information about which component will deployed on which ECU, is part of the input of this configuration process.

Depending on the location of each component, the formerly virtual interaction can then be mapped to real interaction implementation. More precisely, components that are mapped onto one ECU will communicate through Intra-ECU-Mechanisms, like function calls while Inter-ECU communication will be realized using, e.g. a communication bus infrastructure. Since the RTE source code is usually generated, it can be tailored by the generator to implement exactly the communication paths required by its connected AUTOSAR components. Thus the RTE can be seen as a static implementation of specialized communication topologies.
Figure 2 illustrates an example transformation where the components that were virtually connected via one single virtual function bus are mapped onto three ECU's. Due to the mapping on different ECU's the different RTE's that are

[2] see [5] for more details on the ECU configuration process and the AUTOSAR methodology in general

Aspect	Virtual Function Bus	Runtime Environment
Application View	Common Application Programming Interface	
System View	- Centralized	- Distributed
Communication	- Ports - Semantics	- Intra/vs. Inter-ECU - COM Services
Invocation / Scheduling	- Implicit (via Port Semantic) - Runnable Description	- OS Task - Event Handling
Resource Allocation	- Specification of Requirements	- Allocation - Consistency

Fig. 3. Comparison of VFB and RTE with focus on selected common concepts

generated implement the communication between these components either via a local or via a remote connection.

2.3 Comparison of VFB and RTE

Although the concepts of virtual function bus and the runtime infrastructure are fundamentally different, they both share a common application programming interface. Since at the time the application modeler defines the interaction between its application and the virtual function bus, the application programming interface which is used at that time has to be used by the runtime environment as well in order to provide a working environment for the modeled application.
However, in other terms like system view or concepts of communication supported, the VFB and the RTE have a fundamentally different conceptual base. The table in figure 3 provides an overview on various aspects that are relevant for both, Virtual Function Bus as well as Runtime Environment.

3 Responsibilities of the Runtime Environment

The AUTOSAR Runtime Environment (RTE) is the central connecting element in an AUTOSAR ECU architecture. It realizes the interfaces of the Virtual Function Bus in order to enable interaction between any kind of AUTOSAR software components. Since the AUTOSAR standard incorporates several types of software components, the RTE implementation has to take into account various constraints and specialties that come with different types of software components. The following section will introduce specifics of the RTE interaction mechanisms and constraints that are introduced by the different types of software components attached to the RTE.

3.1 Overview

In figure 4, an architectural overview about the RTE and their respective interfaces to AUTOSAR components is illustrated. The interfaces that are used to connect any type of software component, are split into three categories:

– *AUTOSAR Interface* denotes software component interfaces that can be specified using the notation of VFB ports and communication semantics. It is used by Application Software Components and Sensor/Actuator components on the layer above the RTE as well as by the ECU abstraction and Complex Device Drivers on a layer below the RTE. Each component that is connected to the RTE via an AUTOSAR interface can provide and connect to ports and that way, interact with other components.
– *Standardized AUTOSAR Interfaces* are using the same type of interface definition derived from the VFB as the AUTOSAR interface but are standardized in the way that the interface specification of the components attached via such an interface is known in advance. This kind of interface is used for attaching AUTOSAR services that have a predefined and standardized functionality.
– *Standardized Interface* denotes other software component interfaces that can not be described using the VFB specification. Consequently, components attached to the RTE via a standardized interface cannot be used directly by other software components but are used by the RTE only. The operating system for instance has to provide a standardized interface to allow the RTE to consume services like component instantiation or task scheduling which must not be used by other software components.

In the following subsection, the different types of components that can be found in the model in figure 4 will be introduced shortly with respect to their impact on the RTE implementation.

3.2 AUTOSAR Software Components

An AUTOSAR software component in general is the core of any AUTOSAR application. It is built as a hierarchical composition of atomic software components and specified using the Software Component Template. Since the RTE generation process requires a wide set of information in order to create the neccessary methods, that information has to be provided within the Software Component Template and serves as input for the RTE generation:

– The *Hierarchical Structure* describes the composition of atomic software components that the AUTOSAR application software components consist of. This information will later be used by the RTE to create the required instances accordingly.
– *Ports and Interfaces* describe the provided and required ports for the software component and their respective communication semantics which will have to be realized by the RTE.

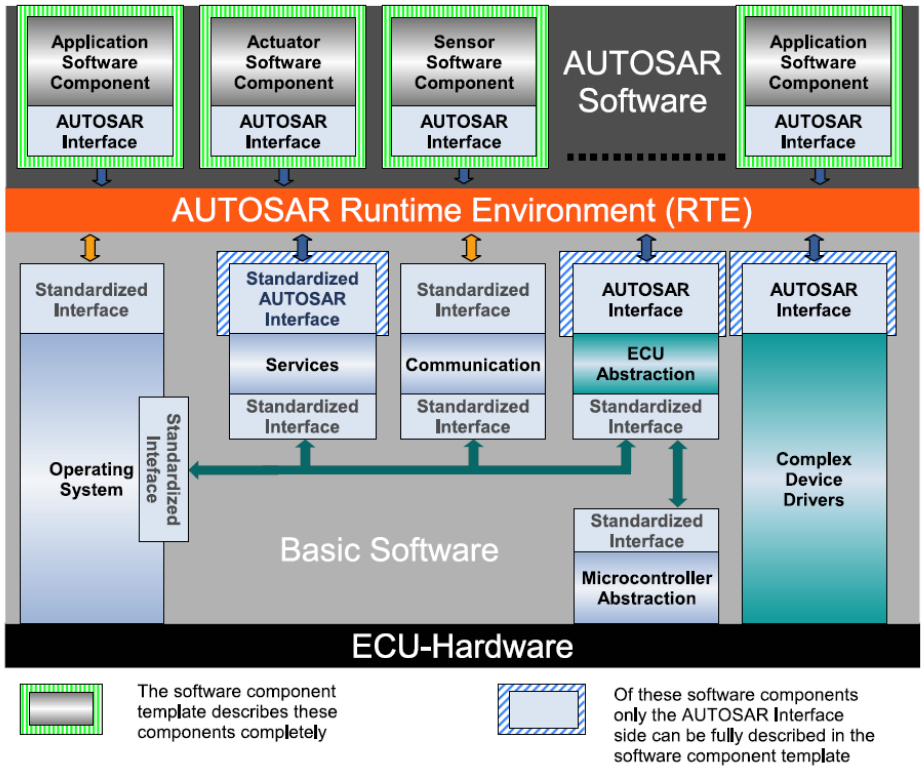


Fig. 4. Overview on the RTE integration into the AUTOSAR layered architecture [2]

- The *Internal Behavior* description provides details about Runnable Entities and RTEEvents (described in 4) that are required by the RTE for the purpose of scheduling and method invocation.
- Specifics of the *Implementation* can be provided for the RTE generation process in order to describe details about memory consumption, execution times, etc.

3.3 AUTOSAR Services

An AUTOSAR service can be described as a

> logical entity of basic software offering general functionality to be used by AUTOSAR Software-Components. [1]

Examples for such services are Memory Services (NVRAM Manager), Network Communication Management Services as well as Diagnostic Services and State

Management. Services are part of the AUTOSAR basic software and can be consumed by AUTOSAR Software components. They are attached to the RTE using standardized AUTOSAR Interfaces which allows other software components to connect to outgoing ports or provide input for incoming ports of AUTOSAR services. Further, the semantics of ports as defined by the Virtual Function Bus specification also apply for AUTOSAR services. In cases when an AUTOSAR software components from the application layer request service objects, it is the task of the runtime to map those calls to actual service object symbols on the local ECU.

Anyhow, since AUTOSAR services provide functionality closely related to the ECU on which they are deployed on, the RTE does not provide any mechanisms to access a service from a remote ECU. Further a service-to-service communication is not allowed by the AUTOSAR specification since this would violate the layered architecture. The fulfillment of these constraints has to be enforces during the RTE generation process.

3.4 Hardware-Related Components

The AUTOSAR layered architecture specifies an ECU abstraction layer that is supposed to decouple the software component development from the specifics of the underlying hardware by providing a high level interface to physical values of the actual ECU. The RTE then is responsible to provide the required communication channels between upper layer software components and the underlying hardware to enable the ECU specific interaction. Generally, components on the ECU abstraction layer are connected via AUTOSAR interface (see figure 4), which provides the full flexibility of the VFB communication capabilities that can be used for communication to and from the ECU abstraction. However, ECU abstraction mechanisms must only be accessed by suitable Sensor/Actuator software components that provide application layer interfaces to AUTOSAR application software components. Consequently, the RTE has to ensure that no direct access between general AUTOSAR software components and the ECU abstraction can occur. Further, since Sensor/Actuator components are specific for the underlying ECU, they cannot be connected to ECU abstraction components on remote ECU's which has to be enforced during the RTE generation processas well.

For more information on hardware interaction mechanisms with respect to the runtime environment, see section 6.

4 Runnables

Since AUTOSAR software components have no direct access to the underlying hardware or the operating system, the implementation of the atomic software components cannot reflect artifacts like *Threads* or *Processes*. Instead, each piece of functionality that has to be executed during runtime of the software component is wrapped into a so-called *Runnable*. The VFB-Specification defines a runnable as a

Sequence of instructions that can be started by the Run-Time Environment

Each runnable that a component provides can be invoked by the RTE and is executed within the context of the underlying operating system. An atomic software component can consist of an arbitrary number of runnables of which each might have its own execution semantics. During the process of ECU configuration, a mapping between operating system tasks and existing runnables is created that is later used by the RTE to define and perform scheduling and execution of the runnables according to their specification.

Depending on their implementation, runnables are categorized into two different sets that are then mapped on different types of operating system tasks:

– *Type 1* Runnables consist of a set of instructions that can be determined to terminate within a finite time. Thus, blocking RTE calls that contain *WaitPoints* cannot be contained in a type 1 runnable. Runnables that fulfill these constraints are usually mapped to basic operating system tasks.
– *Type 2* Runnables contain at least one wait point that causes the runnable to terminate only upon the appearance of an external event (e.g. the receive of a data value). Such runnables are mapped by the RTE to extended operating system tasks that support the state `Waiting`.

The following source listing shows a pseudo-code implementation of a runnable body. Each runnable is encapsulated into an accordingly named function body than contains the sequence of instructions the runnable is made of. In the given example, two statements are listed that read a value from an input port and subsequently writes a value to an outgoing port:

```
void SeatHeating_Runnable_run1(){
 ...
  RTE_Read_InPort_Value(.);
  // do something
  RTE_Write_OutPort_Value(.);
 ...
}
```

Listing 1. Example for the body of a runnables source code (Pseudo-Code)

4.1 Integration

The concept of runnables affects several aspects of AUTOSAR, like the operating system, the runtime environment as well as the virtual function bus. Each of them deals with runnables differently, depending on their view on the overall system. The goal of this section is to show the dependencies and points of intersection where the three participants OS, RTE and VFB are related in terms of their integration of runnables. Figure 5 illustrates this relation and will be explained in the following

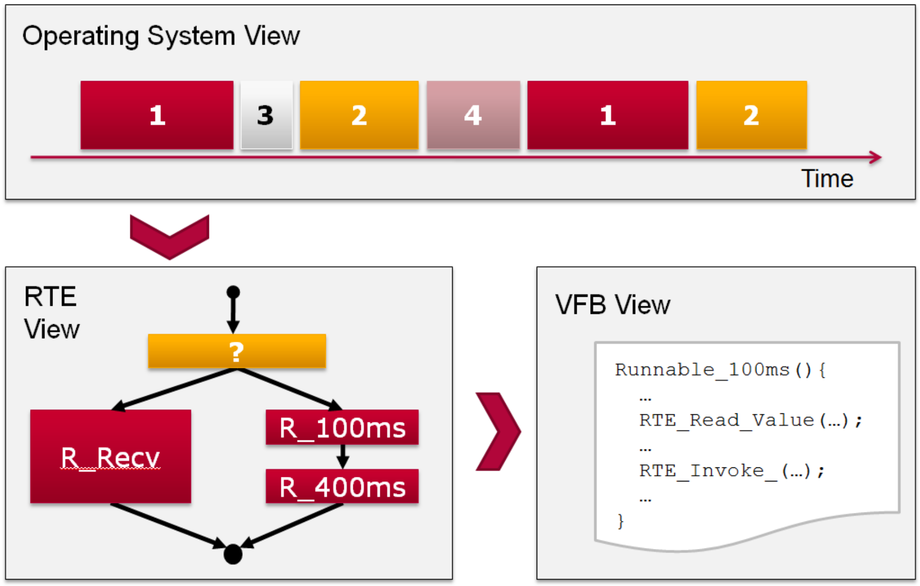


Fig. 5. Relationship between Operating System, Runtime Environment and Virtual Function Bus with respect to the integration of runnables

Operating System View An AUTOSAR-Compliant Operating System (e.g. OSEK OS which is referred to by the standard documents) does not know about the concepts of runnables at all. Instead, the operating system usually maintains a list of schedulable entities that are under management of a scheduling algorithm. Since runnable entities will be integrated by the runtime environment into operating system tasks, they will be executed anytime the corresponding OS task is scheduled. Section 4.3 will provide more details on how the mapping between operating system tasks and single runnables is performed.

RTE View The runtime environment maps runnables that can be executed together into one OS task. This task is then structured and controlled using RTE glue code that will control the correct execution of the runnables within the OS task. In figure 5, the boxes colored in red denote single runnables. The corresponding control flow that triggers the execution of such a runnable as well as the glue code (yellow box) is under control of the runtime environment.

VFB View On the level of the virtual function bus (i.e. during design time of the application), the integration context of the runnable as well as the environment in which it will be executed are not of concern. Instead, anything except the sequence of single instructions within the function body and the constraints on invocation for the runnable are disregarded.

4.2 RTE Events

Besides the specification of the instructions that a runnable consists of, the RTE further requires the runnable to declare upon which type of event the runnable is supposed to be executed. For that purpose, AUTOSAR defines a set of `RTEEvents` that can either activate or resume a runnable. Table 1 provides an overview on existing RTEEvents and their capabilities to activate or wake up runnables.

Activation in terms of runnables and RTEEvents denotes the invocation of a runnable instance that is mapped to an operating system task and consequently triggers its execution when scheduled by the operating system. The invocation itself is performed by the RTE implementation upon the appearance of the corresponding RTE event that is specified by the runnable. In general, all RTEEvents can be used to activate runnables.

Wake up Runnables of type 2 are defined to be capable of having a WaitPoint for synchronization purposes like the confirmation of the receive of data. Such WaitPoints are realized by blocking methods of the RTE API, e.g. `RTE_Receive()` or `RTE_Feedback()` which in turn use RTEEvents to determine when to return from a blocking API call. Obviously, only a subset of RTEEvent can be used meaningfully for the wake up of runnables like for instance `DataReceiveEvent`.

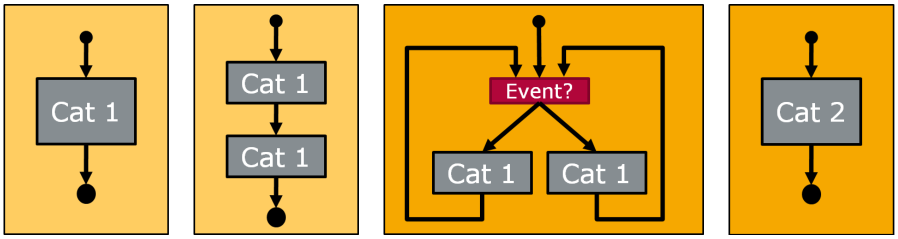
Event Type	Activate	Wake Up
`TimingEvent`	X	
`DataReceiveEvent`	X	X
`DataReceiveErrorEvent`	X	
`DataSendCompleteEvent`	X	X
`OperationInvokedEvent`	X	
`AsynchrnonousServerCallEvent`	X	X
`ModeSwitchEvent`	X	

Table 1. Listing of AUTOSAR RTEEvents and their capabilities to activate and/or wake up instances of runnables

4.3 Operating System Task Mapping

As mentioned beforehand, mapping of runnables to operating system tasks is performed during the RTE configuration process and performed on the basis of the ECU Configuration Description. At runtime, the RTE implementation then manages the activation and invocation of the runnables according to the RTEEvents and semantics specified.

The actual mapping between one or more runnables and their containing operating system task depends heavily upon the execution semantics of the



(a) A basic task containing a single category 1 runnable

(b) A basic task containing multiple category 1 runnables

(c) An extended task containing multiple category 1 runnables

(d) An extended task containing a single category 2 runnable

Fig. 6. Representative scenarios for the integration of AUTOSAR runnables into operating system tasks

runnables and cannot be fully exploited within this document. More precisely, since the mapping depends on information like type of the runnable (either category 1 or 2) as well as their activation and execution behavior (e.g. cyclic execution every Nms, etc.) a wide set of possible runnable configurations exists. However, in the following, several scenarios will be presented that shall give an overview on possible integration of one and more runnables within an operating system task. Figure 6 provides a graphical overview on the control flow of the scenarios described below.

Scenario 1 A very common and comprehensive scenario is illustrated in figure 6(a) where a single category 1 runnable is mapped into one operating system task. A common example for such a scenario is a runnable with a time triggered execution (e.g. every 100ms) that provides and receives information via Sender/Receiver ports.

Scenario 2 An extension of scenario 1 would be the sequential execution of several category 1 runnable that share a common cycle time (see figure 6(b). Since it is ensured that both runnables have a finite termination time (category 1 constraint) their sequential execution can be ensured to terminate timely. Consequently, a basic task that triggers the execution of both runnables in a sequence can be realized by the RTE.

Scenario 3 If multiple category 1 runnables might be executed on the basis of the appearance of one or more RTEEvents, this could be realized by means of an extended task as shown in figure 6(c). Here, an extended task is running in an endless loop, continuously checking for the appearance of a new RTEEvent that is used to decide which of the two category 1 runnables need to be executed. An example for such an event might be a TimeEvent that is evaluated and according to the suitable cycle time triggers the execution of one of the runnables.

Scenario 4 The integration of category 2 runnables into extended operating system tasks is generally realized as shown in figure 6(d). Since every category 2 runnable contains one or more wait points it is not possible to determine a finite termination time. Consequently, a sequence of category 2 runnables could not be guaranteed to ever terminate. For that reason a category 2 runnable is generally integrated as a standalone runnable in a single extended OS task.

5 RTE Implementation

The virtual function bus specification as introduced in [6] defines two communication patterns that can be used by an AUTOSAR software component: *Sender-Receiver* and *Client-Server*. Both patterns have in common that, although their usage is specified on the level of the virtual function bus, their implementation is provided by methods of the implementation of the runtime environment.

In order to provide a better understanding of the relations between the runtime environment and the interaction among AUTOSAR software components, the following section will give an in-depth introduction to the implementation background of the runtime environment. For the sake of simplicity, this will be done using the example of the Sender-Receiver pattern. However, the concepts in general do apply to Client-Server as well.

5.1 Fundamentals

In the following part, a generic example will be used that is illustrated in figure 7 using the modeling notation of the AUTOSAR Virtual Function Bus specification. It shows a simple communication architecture between one sender component that is providing an outgoing send port which is connected to two receiving software components. Since on the VFB level there is no statement about the actual location of the software components, it will be shown in the following how the generated RTE implementation might look like, depending on which kind of deployment and configuration has been chosen.

5.2 Send/Receive Modes

Besides the distinction between the two general communication modes Send/Receive and Client/Server, ports usually come with additional information on the read and write semantics of values on such ports. Depending on these semantics, the RTE generation will later on create different implementations in order to reflect the expected behavior that is associated with the corresponding port semantics.

In terms of Sender/Receiver ports, four different modes of data receive have to be distinguished:

- *Implicit Receive* denotes a semantic where the RTE provides only a copy of the respective value to the calling instance. That way it can be ensured that the value remains constant during the complete life cycle of the runnable and will not be changed by a remote instance.

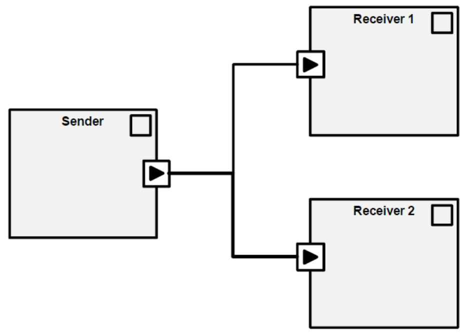


Fig. 7. VFB Model for a sender-receiver communication topology

API	Description
Explicit Read/Write	
`RTE_Read_...()` `RTE_Write_...()`	Read / Write Data Value (Last-Is-Best Semantic)
`RTE_Invalidate_...()`	Invalidation of previously sent value / reset to initial
`RTE_Receive_...()` `RTE_Send_...()`	Send or Receive Data Value Receive: Blocking using WaitPoint until data value is received (`DataReceiveEvent` / `DataReceiveErrorEvent`) Send: Non-Blocking, delegation to AUTOSAR COM
`RTE_Feedback_...()`	Wait for completion of data send (RTE_Send) (`DataSendCompleteEvent`)
Implicit Read/Write	
`RTE_IRead_...()` `RTE_IWrite_...()`	Implicit Reading / Writing

Table 2. Listing of AUTOSAR RTE API method prefixes for the various send and receive communication modes

- *Explicit Receive* provides a non-blocking read operation on the actual variable containing the latest valid value
- *Wake up of wait point* is used by components to request the receive of a new value for the given variable and cause the RTE to wake up the component if the receive operation has completed successfully.
- *Activation of runnable entity* is used for runnables that wish to be invoked upon a new DataReceiveEvent and can then choose to either invoke implicit or explicit receive operations to actually retrieve the new value.

A complete list of the interfaces provided by the runtime infrastructure for the various communication modes can be found in table 2

5.3 Implementation

In the following subsection the different API calls and the generated RTE source code that realizes these API calls will be introduced. Since the RTE generator is not a standardized component of the AUTOSAR architecture but its implementation may vary depending on the vendor, the following source listing cannot be understood as actual running sources but only as an illustration of the underlying concepts. Thus, any of the following source listings are considered pseudo-code and do not attempt to represent runnable source code of an actual programming language.

5.3.1 API usage

Since AUTOSAR components cannot access features of the ECU communication facilities directly, the RTE provides an API that will at runtime realize the physical communication according to the ECU configuration. However, the syntax of the API follows a general concept that allows it to derive the names of the corresponding API functions. The basis for each of these function names is defined by the kind of communication mode and its corresponding API prefix (see table 2 for examples) followed by the name of the port and the respective value to be transmitted. That way, a receive port named `PassengerDetected` that provides a single value called `val` could be read via the RTE API call `RTE_Read_PassengerDetected_val()` for instance.

Integrated into the body of a runnable, a sender and a receiver implementation could be realized as listed in 2.

5.3.2 Sender Implementation

The details of the implementation of the `RTE_Send_...()` methods that are provided to the sender component by the RTI depend on the actual ECU configuration and consequently may vary. Generally, there are two kind of possible interaction types that have to be considered by the RTE: *Intra-ECU* which denotes the communication between two software components residing on the same ECU and *Inter-ECU* which denotes the situation when two software components reside on different ECU's that are connected via a bus network.

In the first case, since the RTE implementation is singleton instance that connects instances of the software components, the send operation may be implemented as a simple write statement to a variable in a shared memory location. The second case instead has to realize a remote communication in order to transmit the sent value to its destination port. For that purpose, the RTE implementation will consume a communication service object that is made available at runtime. In the following listing this is denoted with means of a C++ macro that is assumed to realize the according function call with the given parameters. Both implementations can be found in listing 3

5.3.3 Receiver Implementation

Depending on the receive semantic that is used by the receive-port, the RTE implementation on the receiving side of the communication channel has to provide implementation for the interfaces listed in table 2. In listing 4, two examples are given that represent two possible combination of port semantics.

The first is the case of explicit reading in an intra-ECU communication example where the caller directly reads the local variable that contains the most recent value on the incoming port (if any). The second receive port implementation represents a Intra-ECU communication scenario that is implemented using a blocking API `RTE_Receive...()` that additionally implements a queue for incoming values.

6 Hardware Interaction

As mentioned previously, an AUTOSAR software component is not allowed to access elements of the underlying ECU hardware layer directly. Instead, the layered software architecture includes components to decouple the application logic from the internals of hardware functionality in oder to enable relocatability. At the level of the RTE, these components can then provide AUTOSAR Interfaces for software components that provide normalized, hardware independent information that abstracts from actual physical values. The ECU Abstraction layer as well as Complex Device Drivers are such components that are accessible via the RTE and provide access to/from the underlying hardware.

6.1 ECU Abstraction

The ECU Abstraction layer provides a unified interface for AUTOSAR software components to access electrical values of the underlying ECU independently of the actual ECU hardware architecture. The ECU abstraction itself is closely coupled to the Microcontroller Abstraction (MCAL) that provides access to the actual physical signals of the micro controller. The MCAL is a hardware specific component that is available on each standard micro controller and provides to the basic software access to hardware information without directly accessing the microcontrollers registers. Among other, MCAL provides access to Digital I/O, Analog/Digital Converter, FLASH, EEPROM, etc. Figure 8 illustrates the interaction mechanisms between ECU abstraction, MCAL and the underlying hardware. In the example, the ECU abstraction implements the command `ECU_Set_I()` in three different ways, depending on the instruction set of the MCAL.

6.2 Sensors and Actuators

Sensor- and Actuator-Hardware can only be accessed using the interfaces provided by the ECU abstraction. For the purpose of relocatability of AUTOSAR software components, access to Sensor- and Actuator hardware via the ECU abstraction is restricted to Sensor and Actuator components only. Sensor and Actuator are atomic software components that provide an application layer interface to AUTOSAR software components and implement the control over the

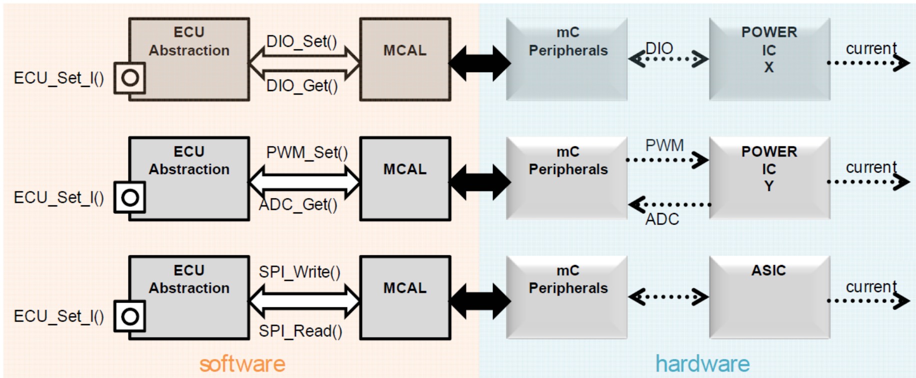


Fig. 8. Communication path from the ECU abstraction to the hardware

physical Sensor- and Actuator-Hardware. Since S/A software components are specialized for a concrete S/A-Hardware they can only be used on an ECU that provides the corresponding hardware.

6.3 Complex Device Drivers

Since the AUTOSAR layered software architecture restricts direct access to hardware from upper layers, an additional concept is provided in order to bypass that restriction for resource critical and/or Non-AUTOSAR compliant software components. The *Complex Device Driver* provides an AUTOSAR Interface to the application layer and has direct access to values on the physical layer. This is usually used for the implementation of complex sensor or actuator drivers that need direct control over the underlying hardware.

6.4 Architectural benefits

The separation of application logic from details of the underlying hardware has several advantages compared to an integrated approach. First, the relocatability of AUTOSAR software components can be achieved transparently since the application source code does not concern any specifics of ECU hardware. Further, this separation of concerns allows OEMs to develop components of each layer independently. That way, ECU manufacturers can manage the development of controllers that are specific for their hardware while the application layer software components can be designed independently by a vehicle manufacturer for instance. Additionally, this layered design allows to interchange components of the architecture without affecting components from the layers above. Changing the micro controller for example would only affect the MCAL while everything from ECU abstraction upwards could remain unchanged.

7 Conclusion

Goal of this paper was to introduce into the concepts of the AUTOSAR Virtual Function Bus and the Runtime Environment. It was shown how the virtual function bus enables the description of a virtual application infrastructure that allows the AUTOSAR software components to be design without regarding the actual physical infrastructure that they will reside on. Afterwards, the relation between the virtual infrastructure and its actual implementation by the runtime environment was outlined. Thereby, special attention was payed to the details on how the generated RTE source code realizes the different communication topologies and their semantics.

Furthermore, this paper introduced into the relation of the runtime environment to other artifacts of the AUTOSAR layered software architecture such as communication services and the operating system. Details were shown how the description of runnables are mapped to operating system tasks and how their execution is managed by the runtime environment. Finally, an overview was given on how hardware interaction is realized and how this affects the way in which AUTOSAR software components are developed.

References

1. AUTOSAR GbR. Autosar glossary, 2008.
2. AUTOSAR GbR. Specification of rte, 2008.
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5. Regina Hebig. Autosar methodology. Technical report, Hasso-Plattner-Institute for IT Systems Engineering, 2009.
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8 Appendix

```
// Sender implementation
void RTE_RunnableSender100ms_run1(){
 ...
  RTE_Send_PassengerDetected_val(.);
 ...
}
// Receiver implementation
void RTE_RunnableReceiver100ms_run1(){
 ...
  v = RTE_Receive_PassengerDetected_val(.);
  int i = new int();
 ...
}
```

Listing 2. Usage of the RTE API within a sender and receiver-communication channel

```

// Intra-ECU communication
void RTE_Send_PassengerDetected_val_1(bool val) {
  // write RTE-Global Variable
  passengerDetected = val;
}

// Inter-ECU communication
void RTE_Send_PassengerDetected_val_2(bool val) {
  // access COM-Service object to trigger send
  COM_SEND_DATA(receiver2, val);
}
```

Listing 3. RTE Send API implementation for Intra- and Inter-ECU communication

```

// Intra-ECU communication
bool RTE_Read_PassengerDetected_val1(bool val) {
        return passengerDetected ;
}

// Inter-ECU communication
bool RTE_Receive_PassengerDetected_val2(bool val) {
        if(inQueue_PassengerDetected.isEmpty())
                waitForIncomingData();
        return inQueue_PassengerDetected.poll();
}
```

Listing 4. RTE Receive API implementation for Intra- and Inter-ECU communication