The Connected Car

5

This chapter introduces the key technologies essential for the evolution of connected cars. Section 5.1 introduces cyber-physical systems (CPS) and describes engineered systems that integrate computing and networking technologies. The cyber part of CPS is deeply embedded in and interacts with physical processes, the physical components. Section 5.2 presents the concept of the Internet of Things (IoT) with regard to its communication capabilities anytime, from anywhere, with everything and key object radio-frequency identification (RFID) technology, which enables objects, things, or entities to be connected wirelessly. Section 5.3 focuses on telematics, infotainment, and the evolution of the connected car, taking into account technology maturity levels, driving factors, and business models of connected cars. Section 5.4 refers to platforms and architectures with regard to connected cars as well as the connected car reference platform and the connected car in the cloud. Section 5.5 introduces autonomous vehicles with regard to the respective guidelines for the testing and deployment of autonomous vehicles published by the National Highway Traffic Safety Administration (NHTSA). In Sect. 5.6, the GENIVI Alliance®, essential for the telematic and infotainment components, is introduced. Section 5.7 introduces several case studies of specific themes essential for the evolution of the connected car, such as the BMW ConnectedDrive Store, the Mercedes COMAND® Online, and HERE, which provides digital mapping for fully autonomous driving. Section 5.8 contains comprehensive questions for verifying the knowledge gained and finally followed by references and suggestions for further reading.

5.1 Cyber-Physical Systems

The integration of embedded systems, physical systems where the computer is completely encapsulated by the device it controls, and the interaction with physical processes via networked computing, led to the emergence of a new generation of

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engineered systems, the cyber-physical systems. Cyber-physical systems (CPS) are complex, multidisciplinary, physically aware, next generation engineered systems (Möller 2016). CPS integrate computing and networking technologies, the cyber part, which are deeply embedded in and interacting with physical processes which add new capabilities to physical systems, the physical components. The term physical components in this book refers to automotive E/E components, such as electronic control units (ECUs) and others.

5.1.1 Introduction to Cyber-Physical Systems

In 2006, the National Science Foundation (NSF) in the USA identified CPS as one of the promising research themes of the future. In the following year, based on the recommendation of the US President's Council of Advisors on Science and Technology (PCAST) (PCAST 2007), a research program was established by NSF entitled Cyber-Physical Systems, through which about 65 projects have been funded. In a subsequent PCAST report in 2010, further research needs for CPS were identified; and the related NSF program was initially extended until 2013. A special interest organization has been set up in the USA, the Cyber-Physical Systems Virtual Organization (CPS-VO), to foster collaboration among CPS professionals in academia, government, and industry.

In 2012, a study funded by the German Federal Ministry of Education and Research (BMBF) was published by the German Academy for Science and Engineering (acatech) on the topic "Information and Communication Technology (ICT)," which was tied to the megatrend, Internet of Things (IoT), addressing the future opportunities and challenges of the technology trends of CPS (Geisberger and Broy 2012).

Furthermore, the European Union's joint technology initiative, Advanced Research and Technology for Embedded Intelligence Systems (ARTEMIS), has invested in research and development (R&D) efforts on the next generation of engineered systems with a public-private partnership (PPP) between European nations and European industry. ARTEMIS supports the vision of a digital transformation where all systems, machines, and objects become smart and physically aware and have a presence in the cyber-physical space, exploiting the digital information and services around them and communicating with each other as well as with the environment. In addition, the European Commission covers CPS as an advanced computing research and innovation theme in their Horizon 2020 Programme (URL1 2017).

According to these studies and programs, CPS have an essential role in industry and society leading to breakthroughs in all relevant areas and bridging the wide range of fields of action in which CPS can be applied. CPS are composed of:

- *Cyber components:* Represent the next generation of embedded devices, processing information, and communicating wirelessly with their distributed environment.

- *Interfaces:* Deal with communication networks and other components, such as interconnected sensors, actuators, analog-to-digital converters (ADCs), and digital-to-analog converters (DACs). ADCs and DACs are responsible for converting continuous-time analog signals to discrete in-time digital signals and vice versa, respectively. Furthermore, interconnected devices bridging cyber components with physical components whereby sensors, sensor nodes, sensor networks, and actuators convert other forms of energy or information to electrical signals and vice versa, respectively.
- *Physical components:* In this book they represent vehicle electrical/electronic (E/E) components and architectures.

5.1.1.1 Wireless Sensor Networks

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical and/or environmental conditions to cooperatively send measured data through the network to a main location. Today's modern WSNs are bidirectional, which means they also enable control of the sensor activity. Therefore, WSNs can also be introduced as ubiquitous communication networks to access relevant remote information and tasks, anywhere and anytime, following the IoT paradigm (see Sect. 5.2).

WSNs are used in many industrial and consumer applications, such as industrial process monitoring and control and machine health monitoring. Against the background of the manifold applications, different combinations of network functions and services are required, which results in a wide variety of WSNs based on the infrastructure, network range, frequency range used, bandwidth, and power consumption. Despite the disparity in the objectives of sensor applications, the main task of WSNs is to sense and collect data from a target domain, process the data, and transmit the information back to specific sites where the underlying application resides. Conducting this task efficiently requires the development of an energy-efficient routing protocol to set up paths between sensor nodes and the data sink.

WSNs are built of nodes, from a few to several hundreds or even thousands, where each node is connected to one or sometimes several sensors. Each such sensor network node typically has several parts, as shown in Fig. 4.6. The topology of the WSN can vary from a simple star-based network topology for monitoring and security applications to an advanced multihop, wireless mesh network, where the propagation technique between the hops of the network can be routing or flooding (Dargie and Poellabauer 2010; Sohraby et al. 2007).

With regard to WSN, described in Sohraby et al. (2007), which is taken as the basis for the design for routing protocols for WSNs, the following must be considered:

- Possibility of packet loss and delay
- Power and resource limitations of the network nodes
- Time-varying quality of the wireless channel

To address these design requirements, several routing strategies for WSNs are available:

- *Data-centric approach:* Disseminates interest within the network. This approach uses attribute-based naming, whereby a source node queries an attribute for the phenomenon rather than an individual sensor node. The interest dissemination is achieved by assigning tasks to sensor nodes and expressing queries relative to specific attributes. Different strategies can be used to communicate interests to the sensor nodes, including:
  - Anycasting
  - Attribute-based multicasting
  - Broadcasting
  - Geocasting
- *Flat network architecture:* Includes minimal overhead to maintain the infrastructure and the potential for discovery of multiple routes between communicating nodes for fault tolerance.
- *Location-to-address sensor node:* Location-based routing useful in applications where the node position within the geographical coverage of the network is relevant to the query issued by the source node. Such a query may specify a specific area where a phenomenon of interest may occur or the vicinity to a specific point in the network environment.
- *Network structure:* Imposes a structure on the network to achieve energy efficiency, stability, and scalability. Network nodes are organized into clusters in which a node with higher residual energy takes the role of a cluster head. The cluster head is responsible for coordinating activities within the cluster and forwarding information between clusters. Clustering has the potential to reduce energy consumption and extend network lifetime.

In Sohraby et al. (2007), several routing algorithms that have been proposed for data dissemination in WSNs are described. In addition, the design trade-offs and performance of these algorithms are also discussed.

In general, routing algorithms are based on various network analytical and graph-theoretical concepts as well on operations research (OR), including:

- Maximum flow
- Minimum span problems
- Shortest route

Routing is closely associated with dynamic programming and the optimal control problem in feedback control theory. The shortest path routing schemes find the shortest path from a given node to the destination node. If the cost, instead of the link length, is associated with each link, these algorithms can also compute minimum cost routes. Algorithms that are centralized find the shortest path from a given node to all other nodes; if decentralized, they find the shortest path from all nodes to a given node. There are certain well-defined algorithms for shortest path routing, including:

- *Bellman-Ford algorithm:* Routing algorithm used for routing in mesh networks to determine the shortest route with the least number of hops through the network. The distance metric is based on the number of hops measured.
- *Dijkstra algorithm:* Finds the shortest paths between nodes in a graph, for example, road networks; has polynomial complexity.

Routing schemes based on competitive game theory notions have also been developed as described in (Lewis 2004).

Furthermore, large-scale communication networks contain cycles (circular paths) of nodes. Nodes as shared resources can handle multiple messages flowing along different paths. Therefore, communication nets are susceptible to deadlock, wherein all nodes in a specific cycle have full buffers and are waiting for each other. Then, no node can transmit because no node can get free buffer space, so all transmission in that cycle comes to a halt.

Livelock is the condition wherein a message is continually transmitted around the network and never reaches its destination. Livelock is a deficiency of some routing schemes that route messages to alternate links when desired links are congested without taking into account that the message should be routed closer to its final destination. Many routing schemes for routing with deadlock and livelock avoidance are available, as described in (Lewis 2004).

Flooding is a common technique frequently used for path discovery and information dissemination in wired and wireless ad hoc networks, as described in (Sohraby et al. 2007). The routing strategy is simple and does not rely on costly network topology maintenance and complex route discovery algorithms. Flooding uses a reactive approach whereby each node receiving a data or control packet sends the packet to all of its neighbors. After transmission, a packet follows all possible paths. Unless the network is disconnected, the packet will eventually reach its destination. Furthermore, as the network topology changes, the packet transmitted follows the new routes.

To prevent a packet from circulating indefinitely in the network, a hop count field is usually included in the packet. Initially, the hop count is set to approximately the diameter of the network. As the packet travels across the network, the hop count is decremented by one for each hop that it traverses. When the hop count reaches zero, the packet is simply discarded. A similar effect can be achieved using a time-to-live field, which records the number of time units that a packet is allowed to live within the network. At the expiration of this time, the packet is no longer forwarded. Flooding can be further enhanced by identifying data packets uniquely, forcing each network node to drop all of the packets that it has already forwarded. However, such a strategy requires maintaining at least a recent history of the traffic to keep track of which data packets have already been forwarded.

5.1.1.2 Shared Sensor and Actuator Networks and Control Systems

In shared sensor and actuator networks (SANs), resource scheduling is an important feature for CPS operation. In this regard, actuation coordination is essential to decide which actuators must be scheduled to perform a particular action or how to manage control actions properly. Various parameters must be considered during control task allocation to a particular actuator (Mo et al. 2014), such as:

- Actuator capabilities
- Energy consumption of each actuator
- Physical system requirements
- Real-time capability
- Task completion time

Regarding actuator scheduling, an important difference between CPS and most cyber systems is the reversibility or preemption of actuator operations. While rollback operations and preemption are available in most cyber systems, e.g., databases or bus access protocols, physical operations executed by the actuators typically cannot be reversed (Gunes et al. 2014). If an actuation is performed based on erroneous data, it is often challenging if not impossible to roll back the activity, as discussed in (Yan et al. 2012) in more detail. Additionally, challenge of non-reversibility affects real-time scheduling in cases where several jobs are managed on a shared platform. Even hard real-time tasks may be blocked by low-priority processes if a shared actuation resource access cannot be preempted or rolled back (Gunes et al. 2014; Springer et al. 2014).

With regard to control laws and the theory behind control systems, which are the basis for state-of-the-art continuous-time, dynamic control systems, these systems have a crucial role in CPS design (Gunes et al. 2014). Conventionally, control policies are completely separate from the system infrastructure and implemented after developing the system prototype (Erdem et al. 2010). Such an approach is not feasible for meeting the demands expected from CPS because of their complex and dynamic nature. To meet those demands and perform complex control laws, the physical system itself and its dependency relationship with those control laws must be well defined and modeled (Zhou and Baras 2013).

In cases where the feedback loop is closed over wireless sensor and actuator networks (WSANs), control design can be applied making the control system insensitive to network uncertainties, such as time-varying delays (Koutsoukos et al. 2008). Fidelity-aware utilization control, which integrates sensor data fusion (SDF) within the feedback loop, can be adopted in wireless cyber-physical surveillance systems (WCPSS) to optimize system fidelity and adaptively adjust the control objective of microcontroller utilization in the presence of environmental variations, such as noise characteristics and others characteristics (Chen et al. 2011). The importance of control theory in CPS design has been addressed by a number of studies (Gunes et al. 2014; Lee and Seshia 2011; Radhakisan and Gill 2013; Rajkumar et al. 2010).

In case where feedback control of a system is closed through a shared network, the control system is called a networked control system (NCS), in which the control input/output is passed through interconnected system components, such as (Gupta and Chow 2010):

- Actuators
- Controllers
- Sensors

Another type of control system is the so-called supervisory control and data acquisition (SCADA) system (Barr 2004), which represents control systems utilized to monitor and control processes. A SCADA system gathers data in real time from sensors in local and remote locations and transfers the data to the central computers in order to control equipment/conditions and take necessary actions (URL2 2017). CPS entail requirements far beyond the expectations of legacy control systems, such as SCADA (Gunes et al. 2014). With regard to their complexity, CPS go beyond traditional engineered systems employed in industry which requires a much closer networking of the appropriate systems and software engineering disciplines. Therefore, the design of CPS requires a significant amount of reasoning with regard to unique challenges and complex functionality, reliability, and performance requirements, such as real-time capability (see also Sect. 5.1.3.4).

The decreasing cost of computation, networking, and sensing provides the basic economic motivation for embedding networking and information and communication technology (ICT) into every industry and application domain. Moreover, the exponential growth in computing power has brought extremely sophisticated computers at reasonable prices to the market. The same trends have vastly improved sensing and actuation technologies. Thus, computers and communication have become the universal system integrator that keeps large systems together, thereby enabling the composition of the respective CPS components and infrastructures. Thus, CPS have an advanced technology and complex system architecture that connects computing and networking with the physical and cyber, or virtual, environment within one paradigm. Hence, it provides services such as:

- Control
- Information feedback
- Real-time monitoring

Other CPS characteristics are essential to merging the interaction of the physical and the cyber components by integration and collaboration of computation, communication, and control (the so-called 3Cs) (Ning 2013).

5.1.1.3 Technological Innovations

Against the background of technological innovations, it can be stated that CPS and the IoT (see Sect. 5.2) have many similarities. Both are actuating, computing, sensing, transmitting information, and using interaction technologies to merge their cyber and physical components; but some differences can be recognized. The IoT emphasizes the connection of things with networks, while CPS emphasizes the integration of information on computational and physical elements (Li et al. 2011).

CPS incorporate the following with situational adequacy and ergonomic issues:

- Actuating through actuators, actuator nodes, and actuator networks
- Algorithms to adopt the behavior of networked systems
- Human-machine interfaces (HMI)
- Interoperability standards (see also Sect. 5.1.3.3)
- Ontologies to interlink the CPS applications (see also Sect. 5.1.3.1)
- Sensing through sensors, sensor nodes, and sensor networks

Comparing embedded systems with CPS shows the integration of computing and networking with physical and virtual processes with the objective to convey how to interact with the physical components to monitor and control the physical processes. Thus, CPS have many benefits, like:

- Allow individual machines to work together to form complex systems that provide new capabilities
- Make systems safer and more efficient
- Reduce the cost of building and operating these systems

The design of such systems requires an understanding of the dynamics of hardware, software, networks, and physical and cyber processes (Pellizzoni 2015), allowing new and advanced systems with complex dynamics and high reliability to be created. Thus, the consolidating technological advances are that embedded computing systems (ECS) created networked embedded computing systems (NECS) which progressed to CPS and which finally converge to the Internet of Everything (IoE), Data and Services, as shown in Fig. 5.1, based on the report of Geisberger and Broy (2012). Figure 5.1 illustrates the technical evolution from embedded computing systems, through networked embedded systems to CPS and finally the Internet of Everything, Data and Services (Geisberger and Broy 2015).

The last two decades have launched a change in technological innovations that is driving a digital transformation of the industry. This change is not a matter of choice; it is driven by fundamental, long-term technological and economic trends which will continue. Thus, the challenge for CPS is to translate these technological and economic drivers into activities which will transform the industry and the manufacturing of products (Möller 2016).

At the systems level, CPS are mapping physical objects and corresponding virtual objects that communicate via ubiquitous information networks, whereby algorithms and services, as well as dynamic integration of services and service providers, and particularly information exchange, will cross borders. At the cyber level, data collected in arbitrary and alterable information networks, 3D models and simulation models, documents, relations, work conditions, and more will become available anywhere and anytime through ubiquitous or cloud computing (Möller 2016).

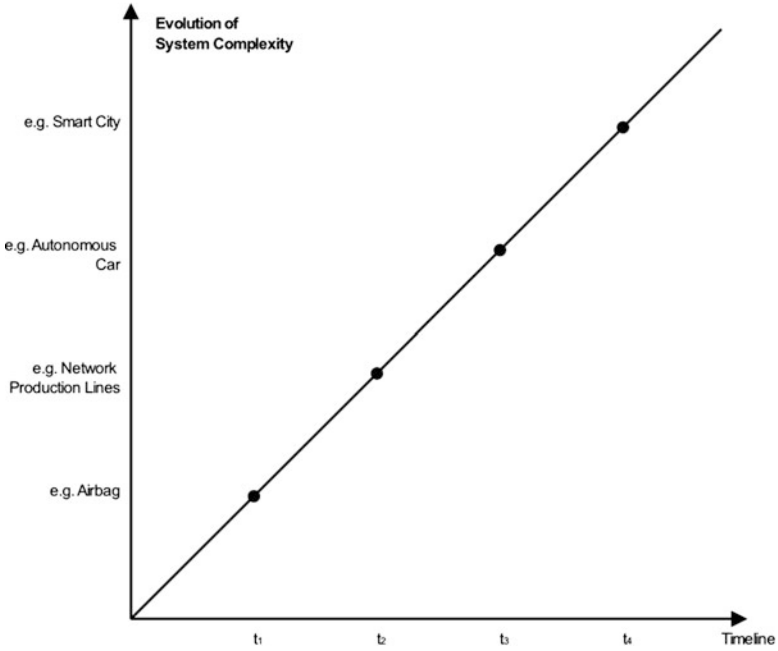


Fig. 5.1 Evolution of ECS into the IoE (Möller 2016)

Ubiquitous computing is everywhere at the same time, meaning it is omnipresent and makes computing an embedded, invisible part of everyday life. Tiny computing devices, which vanish into the environment are required to introduce ubiquitous computing, thereby creating a completely new paradigm of a computing environment for heterogeneous sets of devices, including invisible computers embedded in everyday things/objects such as automation devices, home devices, mobile devices, personal devices, security devices, vehicles, and wearable devices situated in various environments.

Cloud computing is a metaphor for the utility and consumption of computing resources. It involves deploying groups of remote servers and software networks that allow centralized data storage and online access to computer services or resources.

The main consolidation of a typical CPS can be seen in the integration of the dynamics of physical processes with those of the software and networking, providing abstractions and modeling, design, and analysis techniques for the integrated whole (URL3 2017), as shown in the CPS concept map in Fig. 5.2.

From Fig. 5.2, it can be seen that CPSs are primarily considered as an engineering discipline, focused on technology with a strong foundation in mathematical abstractions. The technical challenge is to conjoin abstractions that have evolved for modeling physical processes, such as differential equations, stochastic processes, and more, with abstractions that have evolved in computer science with regard to algorithms and programs, which provide a procedural epistemology (Abelson and Sussman 1996).

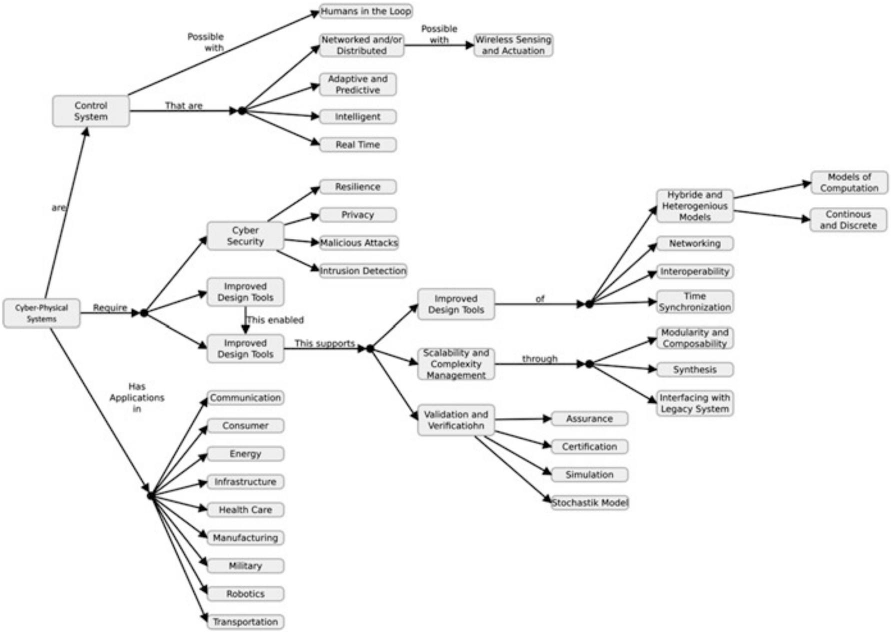


Fig. 5.2 CPS concept map (Möller 2016)

The former abstractions focus on the dynamic evolution of a system state over time, whereas the latter focus on the processes for transforming data. Computer science abstracts away core physical properties, particularly the passage of time that are required to include the dynamics of the physical world in the domain of discourse (URL3 2017). Thus, CPS have foundational characteristics such as:

- Capacity, with regard to information theory
- Formal methods, with regard to computer science
- Information processing, with regard to sensor networks
- Middleware, with regard to software engineering
- Real-time communication, with regard to networking
- Performance, with regard to control engineering

5.1.2 Cyber-Physical Systems Design Recommendations

Current industrial experience provides only limited knowledge of how to combine computers and physical systems. Therefore, continuing to design systems based on this limited knowledge (methods and tools) is not efficient; the risk of unsafe and unpredictable systems can be estimated. These shortcomings become extremely important in CPS design because these systems are heterogeneous, comprised of multiple types of physical systems and multiple models of computation and communication. Therefore, heterogeneity in CPS design results in system-specific design flows which are inappropriate for design automation. Increasing design complexity and the lack of effective, specialized design automation tools can limit design productivity and increase time to market. This means that there is a need to realign the abstraction layers in the design flows and build a new infrastructure for agile design of CPS, as described in the following text and based on Möller (2016).

The challenges in the design of CPS result in the abstraction of levels which can be introduced as part of a stack-based process to abstract away the low-level architecture details and make the underlying system components more effective and transparent to the designer. Therefore, components at any level of abstraction should be made predictable and reliable. So far, this is technologically feasible if the number and capabilities of the available system components can be queried and software developed for code portability between the cyber and physical parts. If it is not technologically feasible, then the next level of abstraction must compensate with a robust principal component analysis. But abstractions do not directly encapsulate the essential characteristics which means it is hard to predict whether or not the cyber part will meet requirements of the physical (Pellizzoni 2015).

A successful system design follows these principles, assuming that it is technically feasible to build predictable and reliable components. It is much harder to make wireless links predictable and reliable due to the increasing needs of interactive network traffic. This may result in delays which raises the fundamental question of how to support delay guarantees over an unreliable medium, such as the wireless one. This is an important issue for automakers because a premium car has >150 sensors and more than 100 switches that are connected by wiring on the order of >1500 m, for making the wiring harness. This is very costly, very heavy, and very complicated and can result in multiple and complex electromechanical failures in the harness. Therefore, automotive engineering tries to solve the fundamental question of how to overcome delays over the wireless medium. One possible option is to compensate one level up, using robust coding and adaptive protocols.

Another obvious fundamental question is whether it is technically feasible to make software-engineered systems predictable and reliable. At the foundations of computer architecture and programming languages, software is essentially perfectly predictable and reliable, as it is limited to what is expressed in simple programming languages. With regard to imperative programming languages with no concurrency, such as C, designers can count on a computer to perform exactly as specified with essentially 100% reliability.

A problem arises when scaling up from simple programs to software-engineered systems, particularly to a CPS. The fact is that even the simplest C program is not predictable and reliable in the context of a CPS because the program does not express any aspect of the behavior that is essential to the CPS. It may execute perfectly, exactly matching its semantics, and still fail to deliver the behavior needed by the CPS. For example, it could miss timing deadlines. Since timing is not in the semantics of C, whether a program misses deadlines is, in fact, irrelevant in

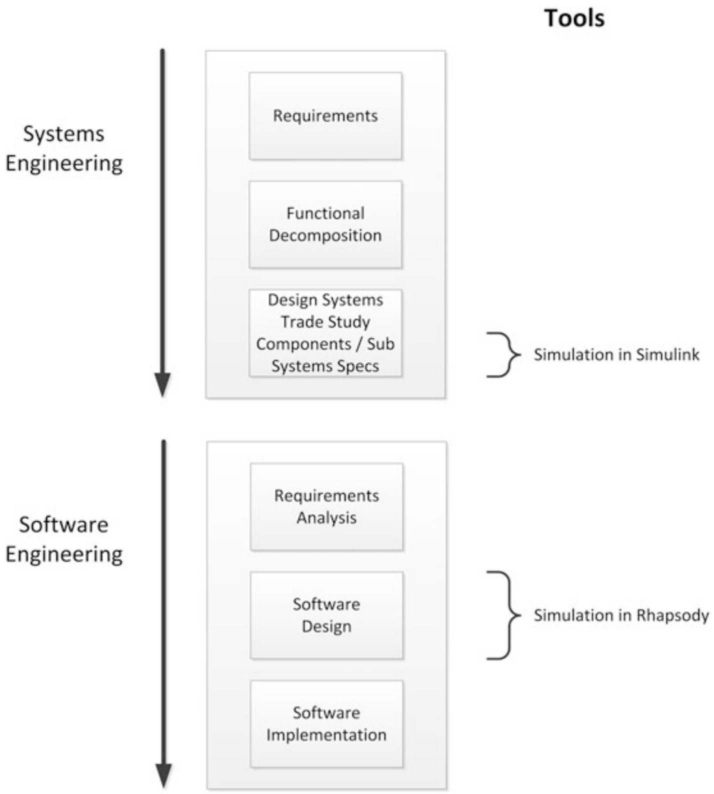


Fig. 5.3 Systems *and* software engineering approach in cyber-physical systems design (Möller 2016)

determining whether it has executed correctly. It is, however, very important to determine whether the system has performed correctly (Lee 2008). Thus, CPS design requires an adopted systems *and* software engineering approach with regard to their intrinsic complexity, as shown in Fig. 5.2.

As shown in Fig. 5.3, two essential engineering sectors in CPS design are integrated: systems *and* software engineering. The systems engineering approach can be characterized as follows:

- A systems engineering approach is a basic necessity for the planning, coordination and implementation of large complex projects as these projects are more difficult to manage and mistakes in early phases can lead to massive problems in the execution phase.
- Current systems engineering frameworks do not enable conceptualization and design which takes into account the deep interdependencies among engineered

systems and the natural world. Thus, there is a clear need for a new cyber-physical systems engineering framework (CPSEF) for the development, implementation, and operation of highly efficient CPS capable of handling the complexity of today's and tomorrow's many application domains. An interdisciplinary approach for developing and implementing complex technical systems in major projects in systems engineering is required.
- Mastering the engineering of complex and trustworthy CPS is crucial to planning, implementing, and sustaining business models.
- Ongoing integration of software-intensive, embedded computing systems and global communication networks (GCNs) in CPS is considered to be the next big step in the technological progress in ICT with a great deal of change in business potential and introduction of novel business models for integrated products and services.

The software engineering approach can be defined as:

- An approach concerned with all aspects of software production
- An approach to systematic, quantifiable design, development, operation, and maintenance of software
- Use of sound engineering principles in order to economically obtain software that is reliable and works efficiently on real machines

The Institute of Electrical and Electronic Engineers (IEEE) Computer Society and the Association for Computing Machinery (ACM) are the main US-based professional organizations of software engineering which have published guidelines to the profession of software engineering. The IEEE *Guide to the Software Engineering Body of Knowledge—2004 Version* defines the field and describes the knowledge IEEE expects of a practicing software engineer.

Today, CPS present a range of challenges which call for better and more effective architectural design environments with regard to the:

- Complexity of CPS, which results from parallel and distributed development, usually using different tools and methods
- Diverse sets of different algorithms with unique challenges
- Desire to reuse existing and future intellectual properties
- Electronics and software content that can be intricate
- Increased need to manage requirement changes during the development cycle
- Needs for integration and testing that can become costly and time consuming

With regard to specific constraints, Systems Modeling Language (SysML) and Unified Modeling Language™ (UML) (URL4 2017) have been designed as architectural frameworks and have been validated across numerous industries with their separate views for functional, physical, and software architectures as well as their requirements capture and elicitation, and have been expanded by Rhapsody which integrates a rich set of external components, such as:

- *Code:* C, C++, Java, or Ada
- *Tools:* Simulink®, Statemate®, and SDL Suite

A very important intrinsic characteristic in CPS design is the interface. The CPS interface inherits all of the elements from the cyber and physical parts and adds new elements that bridge the gap between computational and physical systems. To model the interactions between the cyber and the physical worlds, two directed connector types are essential: the physical-to-cyber (P2C) and the cyber-to-physical (C2P) connectors. Thus, simple sensors can be modeled as P2C connectors; and simple actuators can be modeled as C2P connectors. One of the major difficulties in providing tool support for architectural design and analysis is the need to tailor those capabilities to the application domain.

5.1.3 Cyber-Physical Systems Requirements

Gathering and analyzing CPS requirements require a perspective that is sensitive to scope and interplay between the cyber, the physical, and the behavioral aspects of the system to emphasize disciplined approaches to design. This includes functional decomposition, abstraction, and formal analysis from a systems engineering perspective, as shown in Fig. 5.3. To keep the complexity of a design in check, it is necessary to employ mixtures of semiformal and formal approaches to CPS development. At the semiformal level of CPS design, the goals and possible scenarios are allocated at the system analysis level by SysML and UML. The task allocated at the formal analysis level is design space exploration and, at the system analysis level, the detailed simulation analysis. Simulation analysis is an essential task, with regard to the lack of an integration science with the needed mathematical foundation.

5.1.3.1 Requirements Characteristics

The semantics of the heterogeneous data sources in CPS are captured by their ontologies representing terms and relationships, an important method that builds sharable and reusable knowledge repositories and supports their interaction (Zhai et al. 2007). Hence, ontology can be defined as an abstract representation of real-world objects of the CPS under investigation, which means that the ontology constitutes a domain-specific model defining the essential domain concepts, their properties, and the relationships between them, represented as a knowledge base. Therefore, an ontology (O) organizes domain knowledge in terms of concepts (C), properties (P), and relations (R).

$$O = (C, P, R)$$

In other words, an ontology (O) is a triplet where C is a set of concepts essential for the domain, P is a set of concept properties essential for the domain, and R is a set of binary semantic relations defined between concepts in C. A set of basic relations is defined as $R_b = \{\approx, \uparrow, \nabla\}$ with the following interpretations (Zhai et al. 2007):

- For any two ontological concepts, c_i, $c_j \in C$, $\approx$ denotes the equivalent relation, meaning $c_i \approx c_j$. If two concepts, c_i and c_j, are declared equivalent in ontology, then instances of concept c_i can also be inferred as instances of c_j and vice versa.
- $\uparrow$ is the generalization notation. In cases where the ontology specifies $c_i \uparrow c_j$, then c_j inhibits all property descriptors associated with c_i; and these need not be repeated for c_j while specifying the ontology.
- $c_i \nabla c_j$ means c_i has part c_j. If a concept in ontology is specified as an aggregation of other concepts, it can be expressed by using ∇.

5.1.3.2 Requirements Engineering

Requirements engineering can be introduced as the process of defining, documenting, and maintaining requirements, which are documented physical and functional needs that a particular design of a system must be able to perform. The fields concerned with requirements engineering are systems and software engineering as described in Möller (2016). The activities involved in requirements engineering vary widely, depending on the type of system being developed and the specific style guide practices of the organization involved. These may include (URL5 2017):

- *Requirements elicitation:* Practice of collecting requirements of a system from users, customers, and other stakeholders; sometimes also called requirements gathering.
- *Requirements identification:* Concerned with analyzing, eliciting, elaborating, structuring, specifying, negotiating, documenting, and modifying requirements to propose future direction for successful and efficient work.
- *Requirements analysis and negotiation:* Tasks determining the needs or conditions to meet for a new product, with regard to possibly conflicting requirements of the various stakeholders.
- *Requirements specification:* Documenting the requirements in a requirements document.
- *System modeling:* Developing models of the system, often using a notation such as the:
  - UML®.
  - UML Profiles Requirements Validation: Check that the documented requirements and models are consistent and meet stakeholder needs.
- *Requirements management:* Managing changes to the requirements as the system is developed and put into use.

UML is a general purpose modeling language designed to provide a standard way of visualizing the system design. UML describes the order in which actions are carried out. All actions taken together describe a process. UML activity diagrams consist of nodes and edges. Certain events occur on the node. Edges connect nodes. Tokens are spread out over the entire activity diagram.

When project information is spread across multiple documents, it is difficult to assess the completeness, consistency, relationships between requirements, design, engineering analysis, verification, and validation information. It is also difficult to establish the end-to-end traceability needed to support change impact assessments.

In order to address the document-centric limitations, more advanced systems engineering processes are transitioning to a data-centric approach, which allows all systems engineering team members to access any project and/or related data. Thus, the data-centric approach is a major part of the Cradle® software tool, a requirements management and systems engineering tool which can easily be used for CPS design purposes. Cradle integrates the entire project life cycle into one, massively scalable, integrated, multiuser software product. It identifies the data to be captured, as shown by Baker (2015) in Fig. 5.4 and explained by Möller (2016). The term *mission* used in Fig. 5.4 is synonymous with the term *use case*.

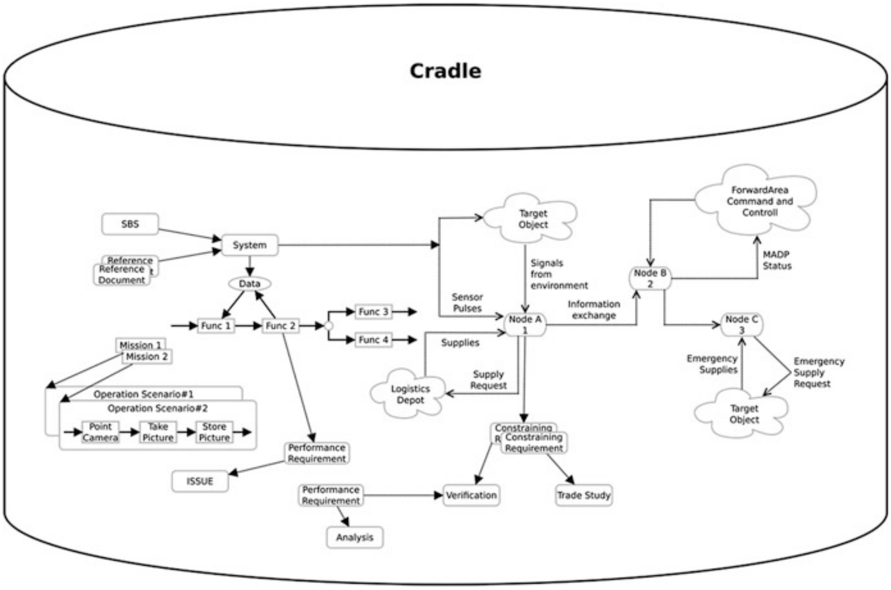


Fig. 5.4 Project data repository for the data-centric approach in the Cradle® software tool (Möller 2016)

Cradle software tool can be used to manage requirements definition and management activities for system development and modification. Cradle groups the requirements definition and management activities into eight stages, as shown in Fig. 5.5.

5.1.3.3 Interoperability Requirement

Interoperability describes the ability of systems working together, which means to interoperate. The term was initially defined as allowing a seamless information exchange for services in ICT and systems engineering. A more general definition refers to social, political, and organizational factors in regard to their impact on system performance. From a more technical perspective, interoperability is the task of building coherent services for systems when individual system components are technically different and managed by different software systems. Interoperability can be introduced as (URL6 2017):

- *Syntactic interoperability:* Necessary condition in the case of two or more systems capable of communicating and data exchange with regard to specified data formats and communication protocols. Extensible markup language (XML) or structural query language (SQL) standards are tools for syntactic interoperability.
- *Semantic interoperability:* Ability to automatically interpret the information exchanged meaningfully and accurately in order to produce useful results as defined by the end users of the systems which is important for vertical integration. To achieve semantic interoperability, two or more systems must refer to a common information exchange reference model.

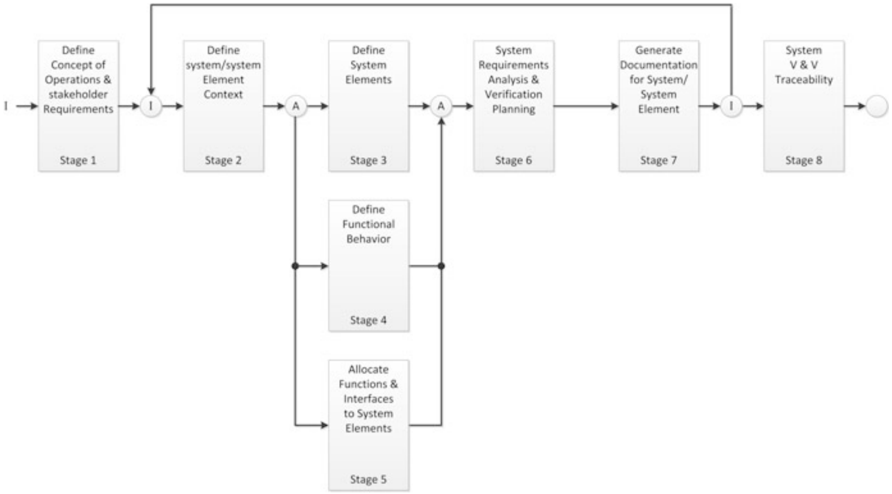


Fig. 5.5 Eight stages of requirements definition and management activities of the Cradle software tool (Möller 2016)

Interoperability must be distinguished from open standards. Open standards are being defined by a group of individuals that includes representatives from vendors, academicians, and others holding a stake in the development. The technical and economic merits, demerits, and feasibility of a proposed common protocol are discussed and debated. After the doubts and reservations of all members are addressed, the resulting common document is endorsed as a common standard. This document is subsequently released to the public; henceforth, it becomes an open standard. It is usually published and is available free of charge or at a nominal cost to any and all comers, with no further encumbrances. Various vendors and individuals can use the standards document to make products that implement the common protocol defined in the standard and are thus interoperable by design with no specific liability or advantage for any customer for choosing one product over another on the basis of standardized features (URL6 2017).

5.1.3.4 Real-Time Requirement

A real-time system is required to complete its tasks and deliver its services on a timely basis, which means that the time taken for the system to respond with an output from the associated input is within a sufficiently small acceptable timeline. Real-time systems include digital control, command and control, signal processing, and more. The Oxford Dictionary of Computing gives the following definition of a real-time system:

> Any system in which the time at which output is produced is significant. This is usually because the input corresponds to some movement in the physical world, and the output has to relate to that same movement. The lag from input time to output time must be sufficiently small for acceptable timelines.

The Predictably Dependable Computing Systems project (Randell et al. 1995) gives the following definition:

> A real-time system is a system that is required to react to small stimuli from the environment (including the passage of physical time) within time intervals dictated by the environment.

Fortunately, it is usually not a disaster if the system response is not in time. These types of systems can be discerned from those where failure to respond can be considered just as bad as a wrong response. It is this aspect that distinguishes a real-time system from others, where response time is important but not crucial. Consequently, “the correctness of a real-time system depends not only on the logical result of the computation but also on the time at which results are generated”. Practitioners in the field of real-time computer system design often differentiate between hard and soft real-time systems (Burns and Wellings 2001; Liu 2000).

- *Hard real-time systems (HRTS):* Systems where it is absolutely imperative that responses occur within the specified deadline.

- *Soft real-time systems (SRTS):* Systems where response times are important, but the system will still work correctly if deadlines are occasionally missed. Soft real-time systems can themselves be distinguished from interactive ones in which there are no explicit deadlines (Burns and Wellings 2001).

The use of the term soft does not imply a single type of requirement but incorporates a number of different properties, such as:

- Deadline can be missed occasionally: typically with an upper limit of misses within a defined interval
- Service can occasionally be delivered late: typically with an upper limit of tardiness

As mentioned, real-time embedded control systems are used for process control, complex applications with regard to communication, command and control in the military domain, as well as in the control of aircraft, automobiles, autonomous robots, chemical plants, medical equipment, power distribution systems, and more.

The reliability requirement of real-time systems is to translate the need to meet critical task deadlines with a very high probability. Hence, the following question needs to be answered, "How can tasks be scheduled such that deadlines continue to be met despite processor permanent, transient, or software failures (Chen et al. 2011)?

5.1.4 Cyber-Physical Control Systems

Control refers to the directed influence of an engineering system, such as a CPS, whose properties correspond to the observed characteristic transfer elements. Moreover, in CPS-based control systems, the system's output not only depends on the unilateral impact of the arrangement of the reference input (set value) but also depends on the disturbances occurring. The reference input acts as a control input for the output transfer characteristic according to physical laws and links and/or timing so that the desired systems behavior is determined. Although, the system's output has no influence on the reference input (missing feedback), the system's output may differ due to external disturbances from the desired target value. Hence, a CPS-based control system can be an open-loop type system consisting of a number of transfer-block-based characteristics connected in series. This control principle in its conceptual annotation is shown in Fig. 5.6.

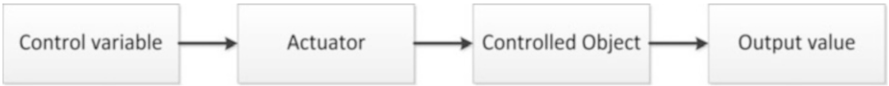


Fig. 5.6 Block diagram structure of a control system (Möller 2016)

In reality, disturbances frequently occur at different times and with different levels of strength. They have the potential to significantly displace the control system's output from the reference input. Against this background, it is useful to capture the system's output by a separate transfer block.

In case of deviations of the system's output from the reference input, the influence of the disturbance on the system can be compensated for through the principle of feedback control. With a simple open-loop control system, one cannot act against foreseeable disturbances. Hence, a system characteristic is required which in the simplest case has transfer characteristics for observing the system's output and comparing it with the reference input to calculate the identified error between them, forcing the system's output to follow the reference input. This principle is the closed-loop control system in which the system's output, whose dynamic depends on the chosen system's specific model, is forced to follow a reference input while remaining relatively insensitive to the effects of disturbances.

In the case of a difference between both signals, the summing point of the feedback loop generates an error signal which is transferred to the controller input. The controller acts on the error with regard to a control strategy and manipulates the system to make it track the reference input. Moreover, this closed-loop feedback forces the system's output to follow the reference input with regard to present disturbance inputs. Thus, closed-loop control contains more transfer elements than open-loop control. The transfer elements of closed-loop control are (Möller 2016):

- *Plant or process:* System to be controlled.
- *System output:* Particular system aspect to be controlled.
- *Reference input:* Quantity desired for the system's output.
- *Actuator:* Device used to control input to the plant or process.
- *Controller:* Device used to generate input to the actuator or plant to force the system's output to follow the reference input. Therefore, the controller contains the control strategy to make the desired output track the desired reference input.
- *Disturbance:* Additional undesirable input to the plant imposed by the environment that may cause the system's output to differ from the expected output with regard to the reference input.

To this point, these transfer elements are the same in an open-loop control system. The closed-loop control system has the following additional transfer elements:

- *Sensor:* Device to measure system output
- *Error detector:* Determines the difference between the measured system output and reference input

Therefore, a closed-loop controller continuously detects and compares the potential difference between the reference input and the system's output by making use of the sensor and error detector. The resulting error value of the error detector is read by the controller's input which then computes a setting for the actuator to manipulate the plant of the closed-loop, cyber-physical control system. The controller uses the feedback from the error detector to force the system's output back to the reference value based on the chosen control law. The actuator modifies the input to the plant with regard to the requirements based on the error detector output and the controller transfer function.

A block diagram of a closed-loop control system is shown in Fig. 5.7, with its conceptual annotation referring to the transfer elements described above. The parameters and symbols are summarized in Table 5.1 (Möller 2016).

The block diagram of Fig. 5.7 depicts the structure of the control systems as an interconnection of blocks and symbols representing certain basic mathematical operations in such a way that the diagram corresponds to the system's mathematical model. The interconnecting lines between blocks represent the variables describing the system's behavior, such as input and state variable. For a fixed linear system with no initial energy, the output $y(t)$ is given by

$$y(t) = G(t) \cdot u(t)$$

where $G(t)$ is the block transfer function and $u(t)$ is the input. Hence, a block diagram is merely a pictogram representation of a set of algebraic equations, allowing blocks

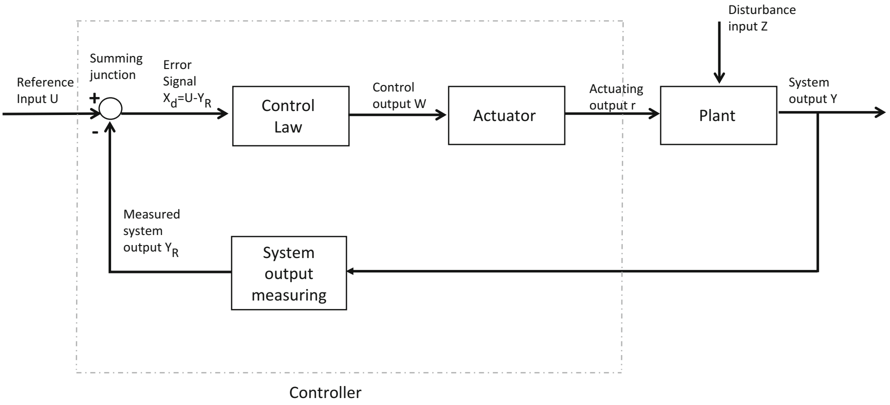


Fig. 5.7 Closed action of the control loop in block diagram form (Möller 2016)

Table 5.1 Denomination of closed-loop control system symbols

Symbol	Denomination
$u(t)$	Reference input or set value
$x_d(t)$	Error detection or control deviation
$y(t)$	Control output or correcting input
$r(t)$	Actuating output
$z(t)$	Disturbance input
$x(t)$	System output or control variable
$x_R(t)$	Measured system output or measured control variable

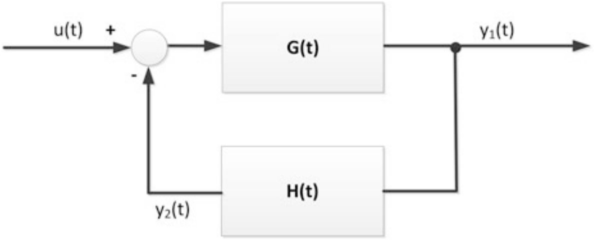


Fig. 5.8 Feedback loop (Möller 2016)

to be combined by calculating the equivalent transfer function and, thereby, simplifying the diagram.

The block diagram of a feedback system that has a forward path from the summing point to the output and a feedback path from the system's output back to the summing junction (closed-loop) is shown in Fig. 5.8.

The block diagram shows the simplest form of a feedback control system. The transforms of the control system's input and output are $u(t)$ and $y_1(t)$, respectively. The transfer function is introduced as the forward loop gain or forward transfer function and as the feedback loop gain or feedback transfer function.

Let the model of a feedback system be given in terms of its forward and feedback transfer functions, $G(t)$ and $H(t)$. It is often necessary to determine the closed-loop gain or closed-loop transfer function

$$F(t) = \frac{y_1(t)}{u(t)}$$

$$H(t) = \frac{y_2(t)}{y_1(t)}.$$

This function can be derived from the block algebra equations for the closed-loop system by solving them for the ratio

$$\frac{y_1(t)}{u(t)}.$$

The block diagram structure corresponds to the following set of equations:

$$\begin{aligned} v(t) &= u(t) - y_2(t) \\ y_1(t) &= G(t) \cdot v(t) \\ y_2(t) &= H(t) \cdot y_1(t). \end{aligned}$$

Combining these equations to eliminate $v(t)$ and $y_2(t)$ yields

$$y_1(t) = G(t) \cdot [u(t) - H(t) \cdot y_1(t)]$$

which can be rearranged to give

$$[1 + G(t) \cdot H(t)]y_1(t) = G(t) \cdot u(t).$$

Hence the closed-loop gain or closed-loop transfer function

$$F(t) = \frac{y_1(t)}{u(t)}$$

is

$$F(t) = \frac{G(t)}{1 + G(t) \cdot H(t)}.$$

It is clear that the sign of the feedback signal at the summing point is negative. If the sign at the summing point is positive, then the closed-loop gain or closed-loop transfer function will become negative. A particularly simple case occurs when one assumes the feedback transfer function is unity, i.e. $H(t) = 1$. This control system is called a unity feedback system, yielding

$$F(t) = \frac{G(t)}{1 - G(t)}.$$

In practice, specific feedback transfer functions are used when designing cyber-physical control systems. Their closed-loop transfer function characteristics can be described by Möller (2016):

- Transient behavior or static characteristic curves
- Mathematical methods

The mathematical notation of the respective feedback law for the dynamic behavior of cyber-physical closed-loop control system transfer functions depends on the chosen characteristic of the specific controller block. In practice, the following elements are of importance:

- Proportional control
- Integral control
- Derivative control

5.1.4.1 Proportional Control

The proportional control (P feedback) is the most straightforward feedback, where the output of the controller varies directly as the input (or system error) $x_d = u - x_R$ which results in (Möller 2016)

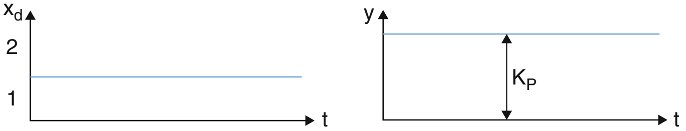


Fig. 5.9 Unit step of an ideal proportional controller; left side step input, right side step input multiplied by gain factor K_p

$$y(t) = K_P \cdot x_{\mathrm{d}}(t)$$

where K_P is the gain factor of the proportional control. Increasing K_P will increase the closed-loop gain of the control system and can, therefore, be used to increase the speed of the control system response and to reduce the magnitude of any error. The cyber-physical control system with proportional feedback is referred to as a system zero order or a system without a memory element. The graph in Fig. 5.9 shows the response of the proportional control using the step response as input with a fixed gain of K_P.

The proportional control alone, however, is often not good enough because increasing K_P not only makes the system more sensitive but also tends to destabilize it. Consequently, the amount by which K_P can be increased is limited; and this limit may not be high enough to achieve the desired response. In practice, when trying to adjust K_P, conflicting requirements may occur. On one hand, it is intended to reduce any steady-state error as much as possible; but to attempt this by increasing K_P is likely to cause the response to oscillate, resulting in a prolongation of the settling time. On the other hand, the response to any change of the input signal should be as fast as possible but with little overshoot or oscillation. Fast control system response can be achieved by increasing K_P, but the increase is likely to destabilize the control system.

To solve the conflicting requirements with regard to the control system gain, a P controller is required that has a:

- K_P value that is high in order to reduce the control system error
- K_P value that is high to ensure a rapid response
- K_P value that is low enough to ensure that the dynamic response does not overshoot excessively and that any tendency to oscillate is damped fast enough

To fulfill these requirements, the P controller has to be expanded by adding, to the proportional part, one or two other control terms, such as integral control, differential or integral and differential control.

5.1.4.2 Integral Control

The prime purpose of adding an integral control part to a controller is to remove any steady-state error. The integral controller is usually used together with proportional and derivative control and in cases where the speed of response and instability are not a problem.

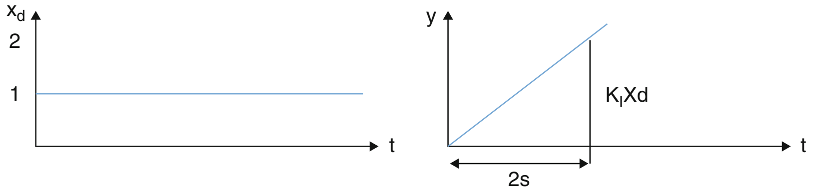


Fig. 5.10 Unit step of an ideal integral controller

An integral control dependence exists for which the output signal x and time integral of input x_d are proportional. Time integration of the control deviation e with the system's output or the actuated variable y acts with a reset time T_N. The reset time is called the integration factor or integration time constant. This means that for a reset time of $T_N = 2s$ at time $t = 0$, the output value y after 2 s has reached the value of the constant input x_d. In the case of an integral controller, the actuator variable r, apart from the initial value, is proportional to the time integral of the control deviation (Möller 2016)

$$y(t) = 1/T_N \cdot \int_{t_0}^{t_1} x_\mathrm{d}(t)dt.$$

If the input to the integral control element is zero, the output value does not change. By choosing a constant input value unequal to zero, the integral controller output changes with a constant increase. The integral controller has no steady-state error like the proportional controller. The integral controller is relatively slow in comparison to the proportional controller. By choosing a reset time T_N (proportional factor $K_I = 1/T_N$) that is too large, there is, however, an overshoot of the control variable; the controller becomes extremely unstable. Technically, the digital version of an integral controller is implemented by summation over a time interval. The graph in Fig. 5.10 shows the response of the integral controller for a unit step response at time $T_N = 1$ with $K_I = 1/T_N$ and $x_\mathrm{d} = 1$.

5.1.4.3 Derivative Control

Derivate control is used in the controller to speed up the transient response of cyber-physical control systems. Derivative action is always accompanied by proportional control. Integral control is used only if necessary. Embedding derivative action in the controller has a stabilizing effect on the cyber-physical control system by virtue of the addition of phase lead to the closed-loop control system by reducing the phase lag of the gain factor of the derivative control.

For a derivative controller, the output u is proportional to the time derivative of the input signal x_d. Therefore, the actuating variable y is proportional to the rate of change of the control deviation x_d which yields (Möller 2016)

$$y(t) = T_V \frac{dx_d}{dt}.$$

In the case of sudden changes in the system's output (control variable), the actuated variable y increases immediately and, thereafter, goes back to its original value. Ideally, a derivative controller follows the Dirac pulse as a step response whose graph is an infinitely high, infinitely thin spike at the origin, with the total area under the spike, and physically represents the density of an idealized point mass or point charge.

A pure derivative controller cannot be realized in practice because the differentiation eliminates the set point. Therefore, the derivative controller is used in combination with the proportional controller, or integral controller, to achieve a quick response to sudden changes in a system's output (control variable) x.

Technically, the digital version of a derivate controller is implemented by differentiation over a time interval. The constant T_V is called derivative action time. The graph in Fig. 5.11 shows the unit step response of a derivative controller, for a gain factor of $K_D = T_V = 1$.

5.1.4.4 Proportional, Integral, and Derivative Control

These controls, as mentioned earlier, are widely used for controlling the response of cyber-physical control systems (CPCS). The derivative action is used to increase the speed of response, while the integral part prevents steady-state errors from occurring in the flow rate or actuator position.

The integral behavior of the proportional-integral-derivative (PID) controller is usually used when the controller is trying to maintain the system's output at its nominal working range and where changes in the system's output only occur as a result of changes in the load.

In a case where the input to a PID controller is changed significantly, the integral part of the controller is usually turned off or suppressed until the system's output is close to its nominal working range. If the integral part is not suppressed, then the large change in the input to the PID controller causes large oscillations to be superimposed onto the response of the cyber-physical control system. Hence, the oscillating response interacts with the two other control elements, the proportional and the derivative; the result is a very cyclic response of the cyber-physical control system with a very long settling time.

A general constraint for using integral control is that it should only be used if steady-state errors exist that cannot be tolerated in the cyber-physical control system

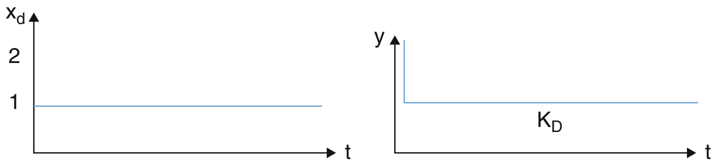


Fig. 5.11 Unit step of an ideal derivative controller; left side step input, right side step input response at time T_N with K_I and $x_d = 1$

strategy. Even the contribution of the integral behavior used should be just enough to remove the steady-state error without causing the steady response to oscillate. Where steady-state errors either do not exist or can be tolerated, then a proportional-integral-derivative controller will be sufficient.

The PID controller combines all three control laws, the proportional, the integral, and the derivative. The input to the PID controller is the error signal x_d which is connected with the three parallel input ports of the controller, as shown in Fig. 5.12. The output signals of the proportional, the integral, and the derivative controller elements are merged into a summing point. The output of the summing point is the weighted sum of the proportional, the integral, and the derivative controller outputs. The three outputs have the same positive sign, and the weighting factors of the summing inputs of the summing point are assumed to have a value of 1. In Fig. 5.12, the constant T_I represents the reset time of the integral element; and T_V represents the derivative action time of the differential element (Möller 2016).

From Fig. 5.12, the following equation can be derived:

$$y(t) = K_P \cdot x_\mathrm{d} + K_1 \int_{t_0}^{t_1} x_\mathrm{d}(\tau) d\tau + K_D \cdot \frac{dx_\mathrm{d}}{dt} + x_\mathrm{d}(0)$$

where x_d (0) is the initial value, K_P is the gain factor of the proportional term, and $\mathrm{T_I} = 1/\mathrm{T_N}$ is the integral controller gain factor with T_N as the reset time; and $\mathrm{T_V}$ is the derivative controller gain factor. After excluding K_P and with regard to the boundary condition $x_\mathrm{d}(0) = (0)$, it follows

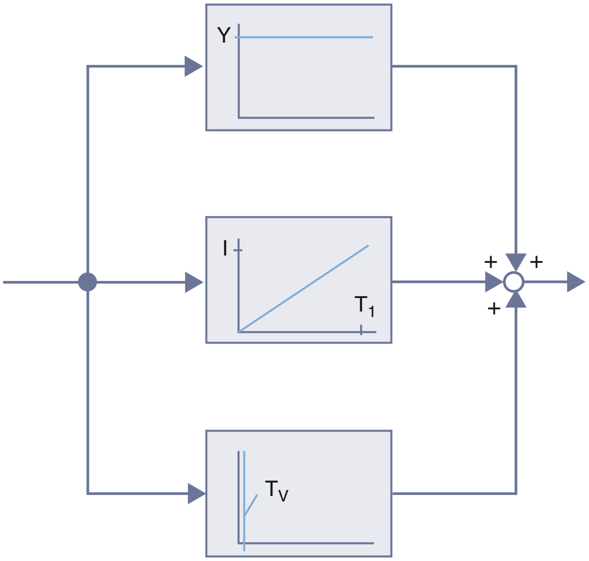


Fig. 5.12 Block diagram of the PID controller. For details see text

$$y(t) = K_P\left(x_\mathrm{d} + \frac{T_1}{K_P}\cdot\int_{t_0}^{t_1} x_\mathrm{d}(\tau)d\tau + \frac{K_D}{K_P}\cdot\frac{dx_\mathrm{d}}{dt}\right)$$

with

$$\frac{K_P}{T_I} = T_N$$

and

$$\frac{K_D}{K_P} = T_V$$

we receive

$$y(t) = K_P\left(x_\mathrm{d} + \frac{1}{T_N}\cdot\int_{t_0}^{t_1} x_\mathrm{d}(\tau)d\tau + T_V\cdot\frac{dx_\mathrm{d}}{dt}\right).$$

Using the Laplace transform, the above equation can be written as follows with the complex numbers denoting the frequency domain:

$$G(s) = K_P\left(1 + \frac{1}{s\cdot T_N} + s\cdot T_V\right).$$

For a number of calculations, it may be more appropriate to rewrite the above additive form into the following multiplicative form:

$$G(s) = K_P\cdot\frac{(1+s\cdot T_1)\cdot(1+s\cdot T_2)}{s\cdot T_N}.$$

Comparison of coefficients yields

$$T_1 = \frac{T_N}{2}\left(1+\sqrt{1-\frac{4T_V}{T_N}}\right)$$

$$T_2 = \frac{T_N}{2}\left(1-\sqrt{1-\frac{4T_V}{T_N}}\right)$$

where $T_N > 4\cdot T_V$. From $T_N > 5\cdot T_V$, the following relations can be found:

$$T_1 = T_N$$

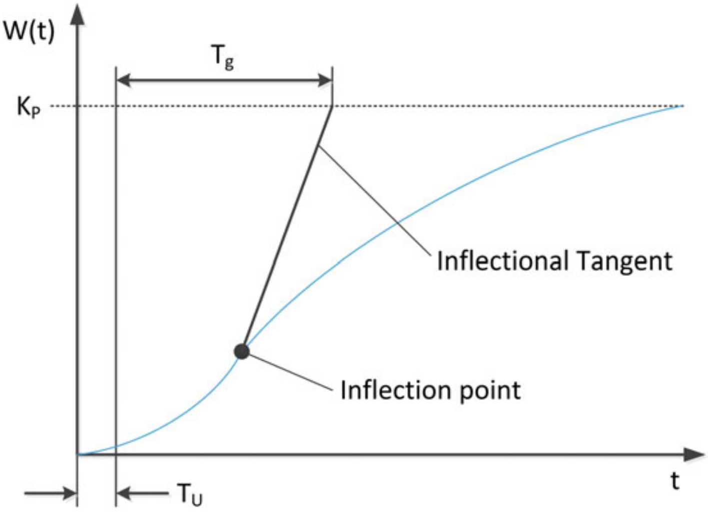


Fig. 5.13 Transient behavior of a step response (for details see text)

$$T_2 = T_{V.}$$

It can be seen from the above equations that the PID controller has two zero elements and a pole at the origin of the s-plane. The gain factors, K_P, T_N, and T_V, of the PID controller can be calculated using the tangent at the inflection point of the step response with the abscissa as the lower auxiliary variable T_U and the intersection of the tangent with the 5τ value of the step response as the top auxiliary variable T_g, as shown in Fig. 5.13 (Möller 2016).

From Fig. 5.13, the corresponding values for T_U and T_g, pictured on the abscissa time t, can be read. Let the PID controller overshoot the quotient of the auxiliary variable $O_{\max}$, for the maximum overshoot height at T_{95} describes the default values for the PID controller

$$K_P = \frac{T_{95}}{O_{max}} \cdot \frac{T_g}{T_U}.$$

Assuming that the PID controller is not allowed to overshoot results in the following equation with regard to the above introduced auxiliary variables:

$$K_P = \frac{T_{60}}{O_{60}} \cdot \frac{T_g}{T_U}$$
$$T_N = T_g$$
$$2 \cdot T_V = T_U.$$

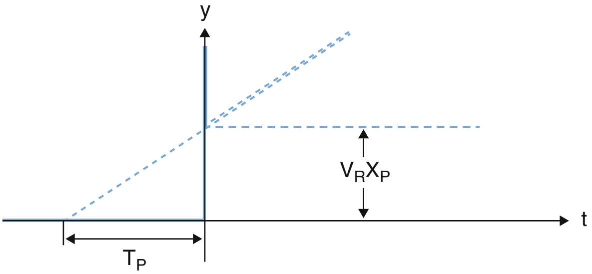


Fig. 5.14 Transfer function of the ideal PID controller (Möller 2016)

The ideal PID controller was introduced as a parallel connection of an ideal PID controller, which is represented by the addition of individual transfer functions as follows:

$$g(t) = K_P + \frac{K_P}{T_N} \cdot t + K_P \cdot T_v \cdot \delta(t).$$

The transfer function $g(t)$ of the ideal PID controller given above can be illustrated as shown in Fig. 5.14.

When designing a controller, simulation programs are very often used to optimize the controller design. This can be done based on the industry standard software package, MATLAB® Simulink (Chaturvedi 2010).

5.1.5 Cyber-Physical Vehicle Tracking

Analyzing and designing CPS for vehicle tracking require a priori knowledge on whether the system being designed can be assumed to be controllable, observable, and/or identifiable. Controllability, observability, and identifiability are important properties of CPS. With regard to the analysis of linear systems, it can be said that a linear system is state controllable when the system input u can be used to transfer the system from any initial state to any arbitrary state in finite time. Moreover, a linear system can be said to be observable if the initial state $\boldsymbol{x}(t_0)$ can be determined uniquely for a given output $\boldsymbol{y}(t)$ for $t_0 \leq t \leq t_1$ for any $t_1 > t_0$. If a mathematical model of a system can be written in the state notation, the method of controllability, observability, and identifiability analyses can be used for model predictions.

Vehicles are an important part of the overall transportation system, which includes not only a large number of human-made infrastructures, such as large bridges across lakes or rivers, long and big tunnels, urban elevated bridges, etc., but also a huge variety of vehicles, people, and goods in the complex transportation environment. Especially in urban traffic control systems, a large number of digital devices and information systems are available, as well as complex management and control systems. This allows developing road infrastructure CPS, vehicle road

Table 5.2 Function and constraints of cyber-physical transportation systems

	Physical traffic process	Information technology process	Functions
Road infrastructure CPS	Mechanics of changing the process of key transportation infrastructure, such as bridges, culverts, tunnels, subgrades, slopes, roadsides, etc.	Ubiquitous sensing in a wide range of reliable interconnected depth perception, forecasting, warning, and monitoring	Real-time monitoring of road facilities and transportation meteorological environment detection
Vehicle road coordinated CPS	Synergic relationship process of car-to-car and car-to-road which are running in the road and communication process	Wireless, high-speed, high reliability, secure communications; automatic driving	High-speed information exchange to guarantee safety of vehicles via efficient access
Traffic control CPS	Road traffic system process and traffic control process	Traffic control system model description, traffic system control, and traffic behavior control instruction optimization calculation	More secure and efficient dynamic road traffic control
Vehicle tracking CPS	Relationship between car-to-truck and truck-to-road running in the road, communication, and traffic control process	Wireless, high-speed, high reliability, secure communications of depth perception	High-speed information exchange to guarantee real-time monitoring of vehicles via efficient access

coordinated CPS, traffic control CPS, and cyber-physical vehicle tracking systems, respectively. The functions of these applications are shown in Table 5.2 (Jianjun et al. 2013).

5.1.5.1 Vehicle Tracking

To achieve efficient and safe road transportation is one of the motivations for conducting research on cyber-physical transportation systems, as it possesses information, and other features with regard to the essential needs of a cyber-physical vehicle tracking system, which is an important issue due to the growth in vehicle volume in recent years in both the public and private sectors. Public and private transportation is faced with the problem of transporting increasing volumes of passengers and freight. Within this process, freight must be identified several times. Currently, in most applications, bar code systems are used to identify the freight and the respective vehicle to which the freight belongs. These bar code systems, however, have some weaknesses, for example, they can repeatedly fail, resulting in the freight ending up in the wrong truck thereby wasting resources. Thus, the convergence of ubiquitous computing with embedded CPS, such as onboard units in trucks, is an important milestone enabling large-scale distributed cyber-physical computing systems which are strongly coupled with their physical environment. Hence, RFID chips, as a component of wireless communication, are of great interest in transportation and logistics in the global economy, i.e., in process optimization in freight transportation in the transportation and logistics domain.

With the emergence of the recently released Internet Protocol v6 and low-power wireless personal area network (6LoWPAN) (Mulligan 2007), the convergence between CPS and the IoT becomes a reality because it enables using the Internet as supportive infrastructure to sensor networks, similar to its integration with RFID systems. This also allows tracking and on-demand delivery, ensuring freight is transported to the right destination by constantly tracking the position of freight and trucks. Tracking in this sense means that RFID readers are used to monitor the movements of RFID-tagged vehicles. With regard to the term vehicle, any mobile item used to carry freight or passengers is referred to as a vehicle. Thus, various kinds of pallets, forklifts, and other put away and load units fall under this category, as well as various passenger cars and cargo trucks.

RFID tracking applications in transportation and logistics are, in general, implemented in order to gather up-to-date information on tagged freight and its movements, thereby facilitating effective in-time management. For this reason, stolen or lost freight should be detected, as well as freight delivered incorrectly or with significant delays. This problem should not be underestimated because it has a huge impact on time and money, i.e., development of a stand-alone system for tracking freight. Therefore, RFID might be a stepping stone to achieving success in this field.

Without demonstrating other technologies, it can be stated that RFID does not require the establishment of a line of sight. Furthermore, RFID tags are resistant to environmental impact, such as physical interaction with other items. Moreover, RFID supports multiple object recognition, so that several tags can be read simultaneously. However, while it is possible to extend the list of RFID advantages, there are still some potential drawbacks that have to be kept in mind when using this technology for vehicle tracking. In order to mitigate the risk of unsuccessful RFID implementation, comprehensive requirements analysis should be performed beforehand.

5.1.5.2 RFID-Based Vehicle Tracking

Vehicle tracking systems are commonly used by fleet operators for fleet management functions such as:

- Fleet dispatching
- Fleet routing
- Fleet tracking

These activities are needed to monitor, control, and plan transportation processes based on information from onboard units, which require an extended data security approach. Along with commercial fleet operators, urban transportation agencies use this technology for a number of purposes, including monitoring the schedule adherence of buses in service, triggering changes in bus destination sign displays at the end of the line (or other set location along a bus route), and triggering prerecorded announcements for passengers.

With regard to the aforementioned, vehicle tracking systems can also be understood as an integrated part of a layered approach to vehicle protection, recommended by the National Insurance Crime Bureau (NICB) to prevent motor vehicle theft. This approach requires at least four security layers based on the risk factors pertaining to a specific vehicle. Vehicle tracking systems are one such layer and are described by the NICB as very effective in helping police recover stolen vehicles.

In order to investigate the requirements for RFID-based vehicle tracking, several RFID vehicle tracking application use cases have been identified for further consideration. They are:

- Implementing RFID vehicle tracking in road systems
- Tracking tagged load units as a part of logistics and supply chain management

Figure 5.15 presents a simplified illustration of both use cases, showing a common RFID system structure and its interaction with other system components (Deriyenko 2012).

The first tracking application belongs to freight in logistics and supply chains. Here, freight items are usually tracked at several stages as they pass through the business workflow process. For better transparency, it is possible to perform tracking every time the freight approaches and leaves each stage.

There are several ways that RFID systems can be integrated into road systems. The first example is the implementation of RFID tracking of wagons by a Finnish railroad operator (Wessel 2011). Setting up readers along railroads allowed more precise information generation about a train’s location at any particular moment in time. Another example of using RFID tracking with road systems is automatic payment on toll roads, such as those in Germany, which makes it possible to overcome severe problems, such as traffic jams, at toll points and reduction of labor costs (Xiao et al. 2008). The system consists of onboard units based on RFID chips usually fixed on windshields or bumpers of moving vehicles and RFID readers located at the toll stations. To ensure the system works effectively, each chip (tag) should be associated with a corresponding payment account. In a

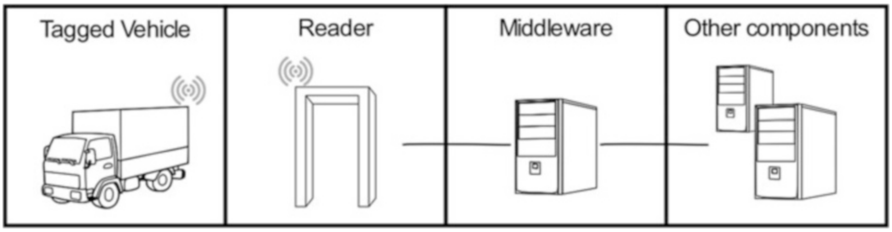


Fig. 5.15 RFID-based vehicle tracking system (Deriyenko 2012)

sunny day scenario, as a tagged vehicle enters the toll area and passes by the reader, its tag is requested to provide information for identification. Once the information is read by the reader, money is charged from the linked account.

Other examples illustrating the use of RFID in road systems are managing parking lots and tank gas stations (Pala and Inanc 2007; Mathis 2012). However, these approaches are very similar to the one used for toll collection.

5.1.5.3 Requirements Analysis

The requirements analysis for an RFID-based vehicle tracking system is essentially to identify, on one hand, the most relevant system constraints and, on the other hand, the essential knowledge required for conducting a system design that includes RFID readers, RFID tags, and RFID middleware. But the RFID-based vehicle tracking system should not only gather data, it also needs to preprocess data according to specific business operational rules. Against this background, the requirements analysis is based on analyzing available research projects and research papers published in the area of interest. Out of them, the following requirements have been identified (Deriyenko 2012):

- *Data cleanup:* Data gathered in its purest form is most likely not user-friendly and is not of great value to the user. For this reason, in most cases, preprocessing according to particular business needs is required. The middleware (see Fig. 5.15) should not only be part of an interconnection bus but should also perform such pivotal functions as cleaning up data, deleting duplicates, ordering, arranging data against selected granularity level, and carrying out other preprocessing operations, all aimed at preparing the data for further business usage, etc.
- *High throughput:* Implementation of RFID components is initially aimed at increasing system throughput ability; therefore, successful operation tracking a large volume of vehicles within a certain period of time is one of the most central requirements for vehicle tracking. Obviously, the importance of this requirement and other concrete indicators directly depends on particular business operational needs and constraints that have to be taken into account, particularly available financial resources.
- *Integration:* The main goal of the RFID-based vehicle tracking system is to provide the stakeholders in transportation and logistics with valuable, complete, and reliable information on time and in a convenient form. Creating a vehicle tracking system composed of RFID tags and readers results in generation of a certain amount of data, in some cases quite a significant amount. Gathering and stand-alone storage of this data do not make any sense; as it is only useful when it is available to the user. This results in an obvious requirement, that the RFID-based vehicle tracking system should be integrated with other enterprise information system components (with the help of middleware) in order to provide useable data.
- *Real-time operation:* In addition to handling a high volume of data quickly, the RFID-based vehicle tracking system should have feasible ways of providing the data to the user. In most cases, retrospective data gathered by tracking vehicles

has a certain value for business operations; but its importance cannot be compared to that of real-time operational data. Updating information received from readers within a short period of time is a vital requirement for vehicle tracking. However, the update rate may fluctuate according to the specifics of the business operation. Considering the use case on toll collection, there should obviously be no significant delays with processing vehicle data in order to perform payments. The same can be said for logistics and supply chain management activities. Users should be able to access the most up-to-date information about vehicle movements; otherwise, the whole system loses its advantage. Therefore, the whole RFID-based vehicle tracking system has to ensure a short response time. With regard to Fig. 5.15 and this requirement, however, other enterprise system components, meaning more than the one considered within this paper, have to be adapted to meet this need.

- *Reliability:* Reliability of the system depends on a number of influencing factors including radio-frequency interference, technical infrastructure, configuration and placement of readers and tags, etc. In general, problems that can arise while tracking can be roughly divided into two groups: false positives and false negatives. False positives owe their name to their origin. The system assumes items are present, while in reality they are absent or should not be taken into consideration, yielding a false positive recognition. This can happen for several reasons. On one hand, it is possible to be confronted with a situation where one item can be scanned two times, either by the same or by different readers. One of the solutions to that problem, mentioned in the literature, is to force tags to respond only when their first digits match the digits requested by the reader. However, this solution causes the whole system to become more overwhelmed. On the other hand, it is important to avoid reader signal collision if their reading ranges overlap. Another problem arises, if the system scans a tag that is supposed to be located beyond a reader's reading range. Therefore, tags and reader positions should be controlled properly with technical indicators of both devices, as well environmental specifics.

Nevertheless, some of the problems mentioned can be solved by a certain level of data preprocessing. But in general, the RFID-based vehicle tracking system should embed a feature that reduces the amount of false positives for real-time broadcasting by using effective anti collision solutions and requesting algorithms and other adequate approaches.

One of the most frequently mentioned problems that falls into the category of false negatives is the presence of metal or water, which affects tag readability and can be a problem for both false positives and false negatives. The reason is very simple; a tagged freight load may contain pallets carrying, for example, bottles of water. Also, mistracking of vehicles can cause numerous inconveniences and result in additional business operational costs.

There may be several reasonable solutions to overcoming these problems, e.g., using metal as an antenna or changing an antenna's impedance. In any case, regardless of the approach used, the RFID-based vehicle tracking system should be able to overcome obstacles, such as metal and water, which are preventing tags from being read.

Moreover, the RFID-based vehicle tracking system must be able to detect if some of its components are down. This means that it has to have appropriate user notification algorithms. As mentioned earlier, the reader can perform a request using the first digits of the tag identification number. Theoretically, such an approach can help to reveal the absence or failure of necessary tags. However, this solution is not applicable for all cases of RFID-based vehicle tracking, since all tag identifications should be stored in the system.

For example, an RFID-based system can help to detect if a load pallet is missing or its tag is not readable; but, for obvious reasons, this is unfeasible, for example, in the case of toll collection. However, in the latter situation, missing tag functionality is not necessary since the absence or breakdown of the tag will be identified anyway due to the inability of a car to pass through the barrier gate without it. Anyway, the requirement mentioned above can be optional and refers not only to tag monitoring but to readers and middleware as well.

5.2 Internet of Things

The Internet is a global system of interconnected computer networks that use the standard Transmission Control Protocol/Internet Protocol (TCP/IP) to serve billions of worldwide users daily. It is a network of private, public, academic, business, and government networks, from local to global in scope. Originating from the Advanced Research Projects Agency Network (ARPANET) around 1970, the Internet became available in the 1980s; by 1990 it had grown from the initial communication framework into the most popular network in use.

The Internet has gained further importance and is currently experiencing a massive growth driven by the Internet of Things, in which the real and the virtual worlds are converging. The IoT is described as a self-configuring wireless network of sensors whose purpose is to interconnect objects or things. The IoT appears to be one step further on the path to ubiquitous computing by embedding computing everywhere and programming it to act automatically, making it omnipresent. CPS are based on converging real (physical) and virtual (cyber) components connected to the Internet forming a dynamic global network infrastructure with self-configuring capabilities and based on a standard and interoperable communication protocol, IPv6. IPv6 is the latest version, routing traffic across the Internet. It was developed by the Internet Engineering Task Force to replace Internet Protocol, version 4 (IPv4), to overcome the long-anticipated problem of IPv4: address exhaustion. Internet Protocol, version 6 (IPv6) uses a 128-bit address which theoretically allows access to 2^{128} addresses for identification and location. Also, IPv6 provides other technical benefits in addition to a larger addressing space. In particular, it permits hierarchical address allocation methods that facilitate route aggregation across the Internet, thus limiting the expansion of routing tables. The use of multicast addressing is expanded and simplified and provides additional optimization for the delivery of services. Device mobility, security, and configuration have been considered in the design of the protocol. Internet Protocol, version 6, addresses are represented as eight groups of four hexadecimal digits with the groups being separated by colons.

A thing, object, or entity in the IoT is any possible item in the real world that joins the communication chain. Therefore, the initial main objective of the IoT was to combine communication capabilities characterized by data transmission.

The key object in the IoT is radio frequency identification (RFID) technology which enables the wireless connection of objects, things, or entities. An object, thing, or entity is any possible item in the real world that joins the communication chain. Therefore, the initial key objective of the IoT was to combine communication capabilities characterized by data transmission. Thus, the IoT can be thought of as the building of a global infrastructure for RFID or sensor radio technologies as a wireless layer on top of the Internet. Such a network of interconnected computers communicates with a wireless network of interconnected objects constantly tracking and accounting for millions of things, from parcels to razor blades to tires. These objects sometimes have their own IP addresses, are embedded in complex automotive systems, use sensors to obtain information from their environment, and use actuators to interact with it, e.g., air conditioning valves that react to the presence of people in a vehicle.

The growth in the forms of information and communication networks is evident by the widespread use of mobile devices. The number of connected mobile devices worldwide surpassed 2×10^9 in mid-2005 and was approximately 25×10^9 in 2015, as shown in Table 5.3.

From Table 5.3, it can be seen that the IoT represents the point in time when more devices are connected to each other than people are connected with/and/or/to devices. This has an impact on today's world and will change everything, including our daily lives, because staying connected has become an integral and intimate part of the 24/7 paradigm of everyday life for many millions of people.

Furthermore, the IoT has become an important concept in the global economy because wireless technology is making it possible to interact with the IoT from anywhere to everywhere at any time. This has opened the opportunity for new ubiquity-based products and services in the automotive domain with a high degree of innovation and a major impact on society and business.

Table 5.3 Connected devices in relation to world population in the third wave of computing (Möller 2016)

	Year				
	2003	2010	2015	2020	Increase
World population	6.3×10^9	6.8×10^9	7.2×10^9	7.6×10^9	+20.635%
Connected devices	500×10^6	12.5×10^9	25×10^9	50×10^9	$+10^2$
Connected devices per person	0.0793%	1.8382%	3.4722%	6.5789%	+82.962%

5.2.1 Internet of Things Enabling Technologies

The availability of the Internet and advances in software and telecommunication services with the ability to connect every object and/or thing, with any object and/or thing, at any time, and in any media, have accelerated the worldwide penetration of the IoT paradigm. In particular, the basic idea that every object and/or thing can also be part of a tiny computer and/or microchip that is connected to the Internet has outperformed any forecast. The enabling technologies of the IoT are:

- Miniaturization
- Nanotechnology
- RFIDs
- Sensors and actuators
- Smart entities

In addition, the increasing processing power available in the smallest of packages and/or devices in networked computing is the fundamental enabler for the IoT paradigm. RFID and sensors, among other technologies, have been increasingly deployed and allow the real-world environment to be connected into the IoT networked services. Entity-to-entity-oriented IoT applications are monitored in real time, depending on their actual status, while the IoT automatically reacts. This has finally resulted in smart objects and/or things which can act smarter than objects and/or things which have not been tagged with a unique visual or invisible identification code and/or equipped with sensors and/or actuators. These new smart objects will obviously raise many issues, such as (Chaouchi 2010):

- Addressing, identifying, and naming
- Choice of transport models
- Communication models of connected objects and/or things
- Connecting technology of objects and/or things
- Economic impact and telecommunication value chain evolution
- Interoperability between objects and/or things
- Possible interaction with existing paradigms, such as the Internet
- Security and privacy

Most of the Internet services were designed to satisfy person-to-person interaction. In contrast, IoT services rely on easy location and tracking of connected entities which means a new dimension has been added to the world of anytime, anyplace connectivity for anyone, resulting in the connectivity for anything. In summary, the relevant characteristics of the IoT are:

- *Connections:* Multiplying and creating entirely new dynamic networks of networks and the IoT. The IoT is based on solid technological advances and visions of network ubiquity that are zealously being realized.

- *Connectivity:* Generating and processing data traffic on the IoT. Connecting entities can be wireless or wired. The IoT also allows the connection of heterogeneous entities.
- *Embedding:* Short-range mobile transceivers in a wide array of additional gadgets and everyday items, such as smartphones, are enabling new communication forms between people and things and/or entities, such as people-to-vehicle, and between things and entities themselves, such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-X (V2X), and others.

As stated in a 2005 UN report:

> Today, in the 2000s, we are heading into a new era of ubiquity, where the users of the internet will be counted in billions and where humans may become the minority as generators and receivers of traffic. (Biddlecombe 2015)

The resulting roadmap of the IoT is shown in Fig. 5.16 (URL7 2017).

Typical views of the IoT are the following application domains in conjunction with cyber-physical systems:

- *Smart city:* Collective concept for the holistic development designs to make cities more efficient and technologically advanced, greener, and more socially inclusive. These concepts include technical, economic, and social innovations, the progressive digitalization that is taking place, and the revolutionized energy sector, such as smart grids, as the basis of urban life. However, mobility and transportation are essential for a smart city to function properly. Therefore,

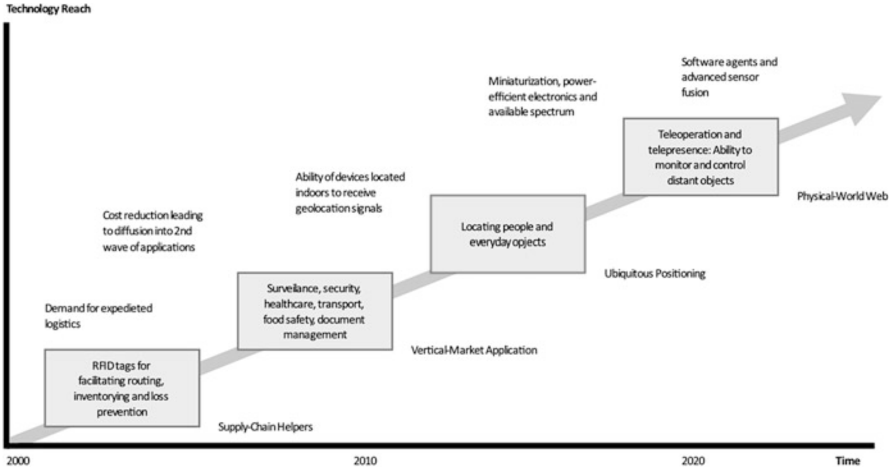


Fig. 5.16 Roadmap of the Internet of Things (Möller 2016) (Source: SRI Consulting Business Intelligence)

sharing concepts, traffic management systems, smart parking apps, and e-mobility belong to the essential features of a smart city to stay mobile, while keeping the city accessible and sustainable. Smart cities can be characterized with regard to their major attributes as follows:
  - Digital City
  - Green City
  - Knowledge City
- *Smart street lights:* Light-emitting diode (LED) technology designed for energy efficiency with intelligence and sensors whose data can be used for a range of purposes, primarily to control when and where light is on, tracking people within the space incorporating wireless networking, and the ability to support cameras and environmental sensors, such as gas leak detectors and seismic monitors, to make life in an urban area of a smart city safer. Examples include:
  - Adaptive lighting to conserve energy, among all streetlights on a network
  - Communications capabilities (audio and visual display)
  - Digital street signs
  - Emergency response centers
- *Smart mobility:* Ensures energy-efficient, comfortable, and cost-effective mobility that can be used intelligently by road users and can be interpreted as a slice of a smart city, crossing all of the mentioned before features and resulting in:
  - Reduced pollution
  - Reduced traffic congestion
  - Reduced travel costs
  - Improved safety
  - Improved travel speed
- *Smart traffic lights:* Vehicle traffic control systems that combines traditional traffic lights with an array of sensors and artificial intelligence to intelligently route vehicular and pedestrian traffic, taking into account the natural flow of traffic which results in a certain traffic rhythm. With the use of sensors, actuators, and communication technologies, the arrival time of vehicles at the road intersection traffic light can be calculated by monitoring their actual speeds. Based on this calculation, it is assumed that the vehicle will arrive at the traffic light when it has changed from its red phase to the green phase. For this purpose CPS traffic lights have to take into account the real-world traffic flow that results in a certain traffic rhythm (Möller et al. 2015).

5.2.2 RFID and WSN Technology

In today's IoT paradigm, many things and/or objects will be part of the network in one form or another. This is where RFID and WSN technologies will meet this new approach, as the information and communication systems used are invisibly embedded in the environment.

RFID technology provides operational efficiencies and improves handling transparency in the logistics of on-demand distribution. RFID systems incorporate microelectronic devices, called transponders, and reading units. Transponders are more commonly known as tags, and they are attached to the things and/or objects to be identified. Tags are available in a large variety of forms and functional characteristics and are classified as active and passive tags:

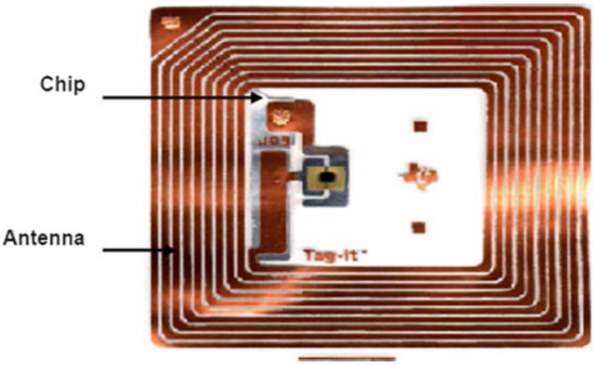
- *Passive tags:* Read/write range is shorter than most active tags; they do not possess an onboard source of power for signal broadcasting.
- *Active tags:* Read/write range is longer than most passive tags; they have their own power source for signal broadcasting.

Passive tags, such as the one shown in Fig. 5.17, are relatively inexpensive. They cost anywhere from a few cents to several dollars because they do not contain a power source. They draw power from a reader's radio signals which induce a current in the tag's antenna using either inductive coupling or electromagnetic capture. This power is used both for chip operation and broadcasting. These tags essentially reflect back the radio waves from the reader in order to broadcast, a phenomenon sometimes known as backscatter. However, their signal range is very low, usually less than 10 ft. Semi passive tags fall somewhere between the two; they use a battery for a chip's standby operation but draw energy from the reader during active broadcasting (Cisco 2008).

Low-cost tags, applicable to the grocery industry, cost from 20 to 35 cents; and the latest tag developments promise tags that will cost just around 5 cents (Kärkkäinen 2003). However, tags can also cost several dollars depending on many factors such as:

- Data capacity
- Form
- Operating frequency
- Range
- Performance requirements
- Presence or absence of a microchip
- Read/write memory

Fig. 5.17 Passive tag (Cisco 2008)



Passive RFID tags vary in how they broadcast to RFID readers and how they receive power from the RFID reader's inductive or electromagnetic field. This is commonly performed by two basic methods:

- *Load modulation and inductive coupling in the near field:* The RFID reader provides a short-range, alternating current, magnetic field that the passive RFID tag uses for both power and broadcasting. Through inductive (near-field) coupling, the magnetic field induces a voltage in the antenna coil of the RFID tag, which powers the tag. The tag broadcasts its information to the RFID reader. Each time the tag draws energy from the RFID reader's magnetic field, the RFID reader itself detects a corresponding voltage drop across its antenna leads. Tag can communicate binary information to the reader by switching a load resistor on and off to perform the load modulation. When the tag performs load modulation, the RFID reader detects this action as amplitude modulation of the signal voltage at the reader's antenna.
- *Backscatter modulation and electromagnetic coupling in the far field:* The RFID reader provides a medium-range electromagnetic field that the passive RFID tag uses for both power and broadcasting. Through electromagnetic (far field) coupling, the passive RFID tag draws energy from the electromagnetic field of the RFID reader. However, energy contained in the incoming electromagnetic field is partially reflected back to the RFID reader by the passive tag antenna. The precise characteristics of this reflection depend on the load connected to the antenna. The tag varies the size of the load that is placed in parallel with the antenna in order to apply amplitude modulation to the reflected electromagnetic waves, thereby enabling it to broadcast information payloads back to the RFID reader via backscatter modulation. Tags using backscatter modulation and electromagnetic coupling typically broadcast over a longer range than inductively coupled tags (Cisco 2008).

Active tags are typically used in real-time tracking of high-value assets in closed-loop systems, which usually justify the higher cost of the active tag. Active RFID tags are physically larger than passive RFID tags. They contain random access memory (RAM), which enables the active tag to store information from attached assets. This memory also makes active RFID preferable to passive RFID. Active RFID tag technology typically displays very high read rates and read reliability because of the higher transmitter output, optimized antenna, and reliable source of onboard power. The cost of active RFID tags varies significantly depending on the amount of memory, the battery life required, and whether the tag includes added-value features, such as onboard temperature sensors, motion detection, telemetry interfaces, and more. The durability of the tag housing also affects price, with the more durable or specialized housings required for specific tag applications available at higher costs. As with most electronic components of this nature, prices for active tags can be expected to decline as technological advances, production efficiencies, and product commoditization all exert a downward influence on market pricing (Cisco 2008).

Radio-frequency identification is now widely used for tracking things and/or objects and others. Hence, the RFID system architecture is marked by a sharp dichotomy of simple RFID tags and an infrastructure of wireless networked RFID readers. This architecture optimally supports the tracking of physical things and/or objects within well-defined confines but limits the sensing capabilities and deployment flexibility that more challenging application scenarios require.

Compared to passive tags, active tags are more expensive. Typically more than $20 each, they provide a longer read/write range of up to 100 feet or more. They offer greater functionality, and their battery life is up to 1 year (Zaheruddin and Mandaviwalla 2005).

Comparing RFID and the bar codes used today highlights the considerable strengths of RFID: RFID does not require line of sight between tags and a reader in order to be read, tags can be read through non-metallic materials, and approximately 60 tags can be read simultaneously (Kärkkäinen 2003).

An RFID system includes:

- Transponders (tags) that allow items to be identified
- Antennas and readers/writers that allow tags to be interrogated and to respond
- Software that controls the RFID equipment, manages the data, and interfaces with enterprise applications

Table 5.4 provides approximate values for the characteristics of high- and low-frequency tags. The exact values depend upon a combination of factors, such as tag type (active or passive), presence of radio noise or radio wave absorbing materials in the environment, the size and gain of the antenna, and the type of reader (Zaheruddin and Mandaviwalla 2005).

With advancements in microelectronic components and the related miniaturization of intelligent functions, wireless sensors can be implemented in decentralized locations where they are needed. Particularly important in this context is communication outside of the immediate network. It should be noted that communication often takes place through the user interface of the device itself, which calls for more advanced technologies. This has been achieved in recent years by the development of networked sensors, the WSNs. Intelligent sensor nodes are wirelessly linked to computer networks. Current and planned applications of WSNs range from early warning systems in production control to so-called smart dust.

Table 5.4 Characteristics of active and passive tags

<table>
<tr><th rowspan="2">Tag frequency</th><th rowspan="2" colspan="2">General tag type</th><th colspan="3">Approximate</th></tr>
<tr><th>Range</th><th>Transmission rates</th><th>Power consumption</th></tr>
<tr><td>Low</td><td colspan="2">Passive</td><td><1.0 m</td><td>1–2 kb/s</td><td>20 μW</td></tr>
<tr><td>High</td><td></td><td></td><td>1.5 m</td><td>10–20 kb/s</td><td>200 μW</td></tr>
<tr><td rowspan="2">Ultrahigh</td><td></td><td></td><td>10–30 m</td><td rowspan="2">40–120 kb/s</td><td rowspan="2">0.25–1.0 W</td></tr>
<tr><td></td><td>Active</td><td>20–100 m*</td></tr>
</table>

*With battery-powered tags

Smart dust belongs to one of the three forms of devices for a ubiquitous computing paradigm proposed by Marc Weiser (Weiser 1991) and can be considered as useful ubiquitous devices as introduced in Poslad (2009). Thus, smart dust is composed of systems of many tiny microelectromechanical systems (MEMS) (see Sect. 4.2.7), ranging from millimeters to micrometers to nanometers. Examples are sensors that detect physical or chemical quantities or are integrated into smart clothes (the integration of sensors, actuators, computers, power sources, etc. into the cloth, the whole being part of an interactive communication network). Smart dust is usually wirelessly operated on a computer network and distributed over a specific area to perform tasks, such as using RFID to sense a smart dust component introduced through the IoT paradigm. The size of an antenna for a tiny smart dust communication device ranges from a few millimeters to centimeters, and it may be vulnerable to electromagnetic disablement and destruction by microwave exposure.

5.3 Telematics, Infotainment, and the Evolution of the Connected Car

Telematics refers to the use of wireless components and technologies to transmit data in real time within a network. Telematic components are typically used in vehicles to collect and transmit data on vehicle use, maintenance requirements, or vehicle servicing. Telematics can also serve as a platform for the usage-based insurance (UBI) premiums business, also known as pay as you drive (PAYD) and pay how you drive (PHYD) programs, as well as fleet insurance and other telematics features. Infotainment is a made-up word combining the terms “information” and “entertainment,” and refers to a type of media which provides a combination of information and entertainment. In this regard, the term also refers to hardware/software products and systems which are built into, or added to, vehicles in order to enhance driver and/or passenger experience.

The automotive industry is transforming. Automakers are focussing on the innovative area of connected cars and autonomous vehicles, which requires new technological solutions for designing vehicles around user needs and not technology only, as well as the development of new business models. Therefore, the challenge in designing connected cars is to take all of the new technology being developed for fully autonomous vehicles, advanced driving assistance systems (ADAS), and predictive intelligence and tap into an entirely new paradigm with regard to IoT, autonomous driving, connected vehicles (V2X), and predictive intelligence. Ultimately, all this has to be embedded in new business models for automakers, service providers and Tier 1 suppliers.

5.3.1 Telematics

Telecommunications and informatics (telematics) applied in wireless technologies and computational systems are the basis for today's vehicular advanced telematic concepts such as:

- *Advanced driving assistance systems (ADAS):* Automotive electronic components developed to support the driver in the driving process and to enhance vehicle systems with regard to safety and better driving (see Sect. 4.9 and Chap. 11).
- *Hands-free cell phone interfaces (HFCPI):* Allow drivers to initiate hands-free cell phone calls, text/browsing during hands-free calls, and end hands-free calls with a hands-free cell phone. The hands-free interface also requires that drivers enable a Bluetooth® connection, pair their cell phone, and manually dial if their voice commands are not recognized (Fitch et al. 2013).
- *Emergency warning system for vehicles (EWSV):* Telematic concepts developed particularly for international harmonization and standardization of vehicle-to-vehicle (V2V), roadside-to-vehicle (R2V), and vehicle-to-roadside (V2R) real-time dedicated short-range communication systems. Instantaneous direction travel cognizance of a vehicle may be transmitted in real-time to surrounding vehicles equipped with EWSV and traveling in the local area to receive warning signals of danger.
- *Satellite navigation:* Telematic concept using a Global Positioning System (GPS) and electronic mapping tool to enable the driver to locate a position, plan a route, and navigate a trip.
- *Wireless vehicle safety communications (WVSC):* Telematics concept in vehicle safety and road safety. It is an electronic subsystem in a vehicle or in another vehicle for the purpose of exchanging safety information, such as road hazards and the locations and speeds of vehicles, over near-field communication short-range radio links which are wireless communication channels specifically designed for automotive use. This may involve temporary ad hoc WLANs. The WVSC wireless local area networks (WLANs) are based on the IEEE 802.11p standard and are marketed under the Wi-Fi® registered trademark. Wi-Fi is the name of a non-profit international association which certifies interoperability of wireless LAN products based on the IEEE 802.11 standard.

V2V, R2V/V2R, vehicle-to-home (V2H), and vehicle-to-enterprise (V2E) are new communication features of the vehicle information technology (IT) between vehicles and other objects. In general, this communication is also called V2X communication, where X can stand for vehicle, infrastructure, or other things.

- *V2V:* Direct information exchange between moving vehicles. V2V communication is the early warning system of vehicle drivers and passengers to

avoid accidents and to prevent critical driving maneuvers. Another goal is the optimization of traffic flow through fast and early information exchange about traffic situations and unfavorable weather conditions, such as severe rain with a hydroplaning hazard or icy roads.
- *R2V/V2R:* Vehicles communicate with infrastructure devices and vice versa. Traffic control systems, smart traffic light systems, finding free parking spots, and automatic parking belong to R2V/V2R. In addition to the aforementioned cases, information on congestion and accidents can be communicated, along with early warnings when emergency vehicles from police, fire department, and medical rescue are approaching to immediately open a corridor for emergency vehicle access.
- *V2H:* Communication between a vehicle and home appliances. For example, using V2H, the vehicle driver or passenger can ask whether the coffee machine is switched off at home, the bathroom window is closed, the entrance door is locked, or other possible applications.
- *V2E:* Represents communication between vehicles and infrastructure that are operated privately and commercially. This includes, for example, the communication of a vehicle with a parking garage, where a parking garage with a free car park is located. The vehicle is then navigated to it (Johanning and Mildner 2015).

In this regard, 802.11p, also referred to as wireless access for the vehicle environment (WAVE), is the primary standard that addresses and enhances telematic concepts for applications in intelligent transportation systems (ITS). Intelligent transportation systems apply information and communication technologies in the field of road transport, including infrastructure, vehicles, and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. In this regard, the term telematics refers to an interdisciplinary field of applications that encompasses:

- Computer science applications, such as:
  - Internet usability
  - Multimedia usability
- Engineering applications based on:
  - Instrumentation technology
  - Sensor technology (see Sect. 4.2.7)
  - Wireless communication networks
- Road safety
- Road transportation
- Telecommunications
- Vehicular technologies

The application of telematics concepts can involve any of the following (URL8 2017):

- *Global Navigation Satellite System (GNSS) technology:* Integrated with computers and mobile communications technology in automotive navigation systems, which mostly use a satellite navigation device for position data that is then correlated to a position on a road
- *Integrated use of telecommunication and informatics:* Applied in vehicles and for control of vehicles on the move
- *Technology features:* Receiving, sending, and storing information through telecommunications devices in conjunction with exerting control of remote objects
- *Use of such systems:* With regard to road vehicles, also called vehicle telematics

Vehicle telematics can help to improve efficiency in the transportation and logistics business. The domain-specific applications include:

- *Container tracking:* Freight containers can be tracked by GPS using, e.g., a battery-powered GPS device communicating its position via mobile phone or satellite communications. Benefits of this approach include increased security and the possibility of rescheduling the container movements based on accurate information of its location.
- *Fleet management:* Includes the activities required to control, monitor, and plan transportation processes based on vehicles such as buses, cars, trucks, aircraft, trains, and vessels. Fleet management includes a range of management functions based on data regarding the current state of the transportation systems, such as:
  - Dynamic vehicle scheduling with regard to traffic conditions to divert them to alternative routes and away from congested routes
  - Vehicle driver's working hours
  - Vehicle fuel management
  - Vehicle health and safety management
  - Vehicle maintenance based on odometer information
  - Vehicle telematics (tracking and diagnostics)

Regarding the transportation of hazardous materials, information concerning the type and state of the loaded shipments can be of significant help in taking appropriate measures in the event of an accident.

Fleet management allows motor carrier companies that rely on transportation and logistics in their business to remove or minimize the risks associated with vehicle investment by improving efficiency and productivity, reducing their overall transportation costs, and providing 100% compliance with government legislation and duty of care obligations. Duty of care requires an individual to adhere to a standard of reasonable care by taking action when harm to others is foreseeable.

The most challenging fleet management task is vehicle scheduling, which includes determining which vehicle should approach which cradle, which station of delivery, or which maintenance service station at what time. The generation of schedules has a considerable impact on the motor carrier's profit. Hence, schedules have to be generated such that the difference between the revenue gained and the cost of fleet vehicle movement is minimized (Goel 2008).

- *GPS tracking:* Usually accurate to around 10–20 m, the European Space Agency (ESA) has developed the European Geostationary Navigation Overlay Service (EGNOS) that supplements the GPS, the Global Navigation Satellite System (GLONASS), and the Galileo system by reporting on the reliability and accuracy of positioning data. EGNOS technology is accurate to 1.5 m (4 feet).
- *Vehicle tracking:* Monitoring the location, movements, status, and behavior of a vehicle or fleet of vehicles. This is achieved through a combination of a GPS/GNSS receiver and an electronic device usually comprised of a GPS GSM GPRS modem or short message service (SMS) sender installed in each vehicle, communicating with the user dispatching emergency or coordinating unit and PC- or web-based software. The General Packet Radio Service (GPRS) is a packet-oriented mobile data service available to users of the 2G cellular communication systems, Global System for Mobile Communications (GSM), as well as in the 3G systems. In the 2G systems, GPRS provides data rates from 56 up to 114 kbit/s. The data is turned into information by management reporting tools in conjunction with a visual display on computerized mapping software. Vehicle tracking may also apply odometry which uses data from motion sensors to estimate changes in position over time or dead reckoning which is the process of calculating a current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course, as an alternative or complementary means of navigation.
- *Trailer tracking:* Tracking movements and the position of a vehicle's trailer unit through the use of a location unit fitted to the trailer and a method of returning the position data via a mobile communication network or geostationary satellite communications, for use through either PC- or web-based software. Trailer tracking systems require four essential components to run:
  - Backend server and database
  - Communication network
  - Tracking device
  - User interface software

Cold storage freight trailers that deliver fresh or frozen foods are increasingly incorporating telematics to gather time series data, a series of data points listed in time order, on the temperature inside the cargo container, both to trigger alarms and record an audit trail for business purposes. An increasingly sophisticated array of sensors, many incorporating RFID technology (see Sect. 5.2.2), are being used to ensure the cold chain.

The Association of Equipment Management Professionals (AEMP) developed the industry's first telematics standard. In 2008, AEMP brought together the major construction equipment manufacturers and telematics providers in the heavy equipment industry to discuss the development of the industry's first telematics standard. Following agreements with industry to support such a standard, the AEMP formed a standards development subcommittee to develop it. The group developed the industry's first standard for the delivery of telematics data (URL8 2017). The AEMP's telematics data standard was developed to allow end users to integrate key telematics data into their fleet management reporting systems. As such, the standard was primarily intended to facilitate importation of these data elements into enterprise software systems, such as those used by many medium to large construction contractors. Prior to the standard, end users had few options for integrating this data into their reporting systems in a mixed-fleet environment consisting of multiple brands of machines and a mix of telematics-equipped machines and legacy machines. One option available to machine owners was to visit multiple websites to manually retrieve data from each manufacturer's telematics interface and then manually enter it into their fleet management program's database. This option was cumbersome and labor intensive.

A second option was for the end user to develop an application programming interface (API), or program, to integrate the data from each telematics provider into his or her database. This option was quite costly, as each telematics provider had a different procedure for accessing and retrieving the data; the data format varied from provider to provider (URL8 2017).

A third option for mixed-fleet integration was to replace the various factory-installed telematics devices with devices from a third-party telematics provider. Although this solved the problem of having multiple data providers requiring unique integration methods, this was by far the most expensive option. In addition to the expense, many of the third-party devices available for construction equipment are unable to access data directly from the machine's electronic control modules (ECMs), or computers, and as such are more limited than the device installed by the OEMs in terms of the data they are able to provide. In some cases, these devices are limited to location and engine run time, although they are increasingly able to accommodate a number of add-on sensors to provide additional data (URL8 2017).

The AEMP Telematics Standard provides a fourth option. By concentrating on the key data elements that drive the majority of fleet management reports, making those data elements available in a standardized XML format and standardizing the means by which the document is retrieved, the standard allows the end user to use one API—the ability to integrate third-party software applications—to retrieve data from any participating telematics provider. Because one API can retrieve data from any participating telematics provider, as opposed to the unique API for each provider that was required previously, integration development costs are greatly reduced.

In addition to the new data fields, the AEM/AEMP Telematics API Standard also changes how the data is accessed in an effort to make it easier to use and integrate with other systems and processes. It includes standardized communication protocols for the ability to transfer telematics information in mixed equipment fleets to end user business enterprise systems, enabling the end user to employ their own business software to collect and then analyze asset data from mixed equipment fleets without the need to work across multiple telematics provider applications (URL8 2017).

The AEM/AEMP Telematics Standard has been approved by the International Organization for Standardization (ISO) and issued as ISO/TS 15143-3:2016, Earth-Moving Machinery and Mobile Road Construction Machinery—Worksite Data Exchange—Part 3: Telematics Data.

5.3.1.1 Carsharing

Telematics technology has enabled new services like carsharing which is a model of vehicle rental for:

- Booking decisions of customers based on spontaneous demands
- Customer mobility support
- Multiperiod usage
- Predetermined customer arrivals at a carsharing station
- Short period of time usage
- Stochastic customer arrivals
- Uncertain operating usage

Carsharing is attractive to customers who occasionally use a vehicle, as well as others who would like occasional access to a vehicle of a different type than they use day to day. Carsharing follows the trend of today's sharing economy (Meyer and Shaheen 2017). It allows customers to share resources, such as equipment, services, and skills, with one another, often at significantly lower cost than traditional rentals. The renting organizations are using a commercial business model. They could also be organized as a company, a public agency, a cooperative agency, or an ad hoc grouping, such as in ridesharing. With regard to carsharing, telematics-enabled computers allow new business models to track customer usage and bill customers on a PAYD basis. Furthermore, some of the carsharing systems show customers where to find an idle vehicle in a station-based vehicle fleet or in free-floating carsharing. Others use telematics features to monitor and report on vehicle use within predefined geofence areas in order to demonstrate the reach of a transit media's vehicle club fleet.

The carsharing model for combustion vehicles has some different aspects with regard to an e-car carsharing model. A major concern in the e-car carsharing model is driving distance due to the limited battery capacity of today's e-cars and the relatively long battery charging time at the respective loading stations. With the implementation of the necessary infrastructure in the near future, e-carsharing will also become a successful business model. In the meantime, a lot of research work needs to be done to determine the ideal operating strategies.

5.3.1.2 Vehicle Insurance

The basic idea of telematics vehicle insurance is that a driver's behavior is directly monitored while the person drives, and this information is transmitted to the vehicle insurance company that is providing financial protection against physical damage and/or bodily injury resulting from traffic collisions and against the liability that could arise. The insurance company then assesses the risk of that driver having an accident and charges UBI premiums accordingly, also known as PAYD and PHYD. The costs depend on the type of vehicle used, measured against time, distance, behavior, and place. Hence, a driver, who drives less responsibly, will be charged a higher premium than a driver who drives smoothly and with less calculated risk of claim propensity. Other benefits can be delivered to end users with telematics, as customer engagement can be enhanced with direct customer interaction. Using the smartphone as the in-vehicle device for tracking and monitoring is of great interest for insurance telematics and automotive electronics applications.

5.3.1.3 Smart Ticketing

Smart ticketing is characterized by the usage-dependent billing modality which supports the smart mobility approach. This ensures the release and use of the means of transportation and guarantees its availability. The risk involved with the cashless transactions is mitigated by use of an identification device. Therefore, a process-oriented procedure covering the entire travel cycle can be achieved. This is independent of the traveler’s route selection and chosen means of transport, but it depends on which provider is offering the transport route, unless the traveler has made special requests.

In order to implement a smart ticketing system, intelligent usage-based billing is required. It can be composed of two elements:

- User identification
- Intermodal-oriented order acceptance and payment system

In addition, the smart ticketing system requires a minimum data record for the unambiguous identification of a previously unknown customer. This enables the new customer to book and settle user-related transport orders. In the case of a well-known customer, preferences regarding the means of transport and frequent routes and services are stored in the customer’s profile. These preferences can be, for example, the driver class, window or gangway, rest zone, large compartment, preferred space, and other wishes.

Smart ticketing can also be used to implement process- and personal-related pricing in a simple manner, for example, through the following, along with many more offers (Belay 2016):

- Bonus programs
- Discounts
- Special season ticket prices
- Subscription prices
- User-related offers

5.3.1.4 Machine-to-Machine Telematics

Machine-to-machine (M2M) data modules are sophisticated and come with an array of features and capabilities, such as:

- Embedded Java
- Embedded M2M optimized smart cards, known as machine identification modules (MIMs) or M2M identification modules
- A flexible land grid array surface mounting
- GNSS technology

to step up the IoT. Global navigation satellite system, short-range, 2G, 3G, and even 4G communication modules are the technologies that facilitate M2M communication. There are several telematics devices that are part of the transportation segment:

- Electronic toll systems
- Infotainment systems
- Navigation
- Stolen vehicle recovery
- Vehicle diagnostics

These components support receiving the parking, toll, and vehicle information with real-time updates. M2M is also gaining acceptance in various subsidiary industries, such as automobile leasing, fleet management, and related sectors. The rising demand for embedded telematics in vehicles is expected to drive down the prices of devices and make it affordable for companies to incorporate them. However, the lack of awareness and cost sensitivity could pose a challenge in this sector. Globally, automakers are working on embedding M2M technologies in their vehicles. Deployment of M2M telematics applications in the automotive industry is assumed to help decrease the number of road accidents and damage. Deployment of similar products will lead to the automotive sector supporting the digital transformation in vehicles.

Furthermore, today's vehicles have integrated computer systems and other automotive electronic gadgets which support the driver. Machine-to-machine telematics provide vehicles with fully loaded sensor technology, with all of the essential information about engine performance, temperature, fuel, and so forth. It is expected that all new cars will be Internet-enabled by 2025 through IoT/M2M solutions. Increasing demand for connected devices, rising awareness, and penetration of smart devices are some of the factors driving the growth for IoT and M2M solutions in the market (Gulati 2015a, b).

The telematics market segments with regard to the respective services are summarized in Fig. 5.18.

5.3.2 Infotainment

Integrated infotainment systems in vehicles, so-called in-vehicle infotainment (IVI), deliver entertainment and information content to vehicle users. The content delivered via infotainment is designed to be informative yet entertaining enough to attract and maintain the consumer's interest. In this regard, infotainment refers to a variety of content served through traditional media, such as the Internet, radio, television, and others.

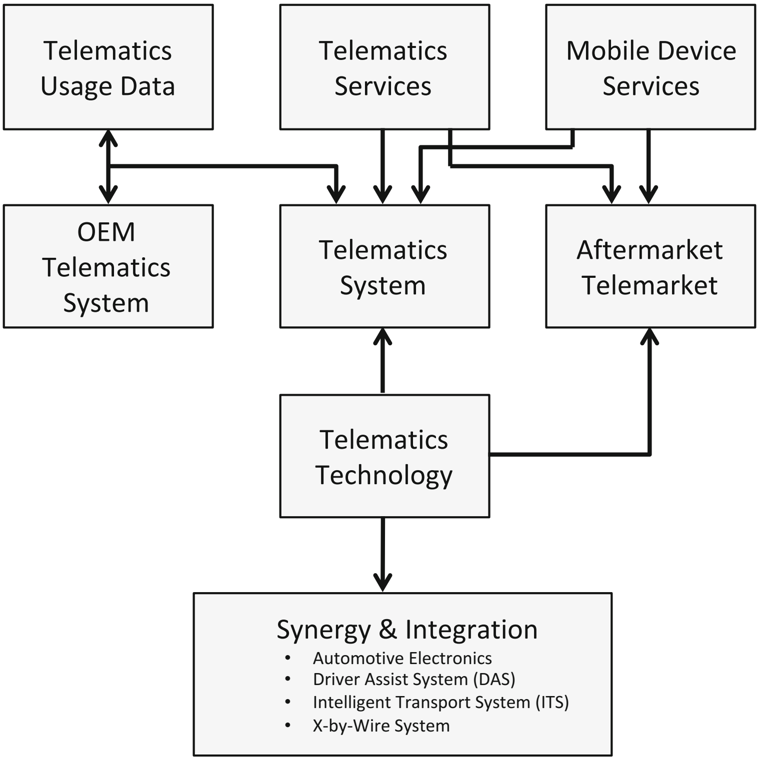


Fig. 5.18 Telematics market segments, modified (Juliussen 2003)

IVI systems frequently utilize Bluetooth technology and/or smartphones. Bluetooth is a wireless short-range radio technology simplifying communications among Internet-enabled devices and between devices and the Internet. It also aims to simplify data synchronization between Internet devices and other computers. A master Bluetooth device can communicate with a maximum of seven devices in a piconet, an ad hoc computer network using Bluetooth technology. The devices can switch roles, by agreement, and the slave can become the master. The Bluetooth core specification provides for the connection of two or more piconets to form a scatternet, a type of ad hoc computer network consisting of two or more piconets, as shown in Fig. 5.19, in which certain devices simultaneously play the master role in one piconet and the slave role in another. The master chooses which slave device to address; typically, it switches rapidly from one device to another in a round robin fashion. Since it is the master that chooses which slave to address, whereas a slave is (in theory) supposed to listen in each receiving slot, being a master is a lighter burden than being a slave.

While each IVI system is different, typical tasks that can be performed with an IVI system include managing and playing audio content; utilizing navigation for driving; delivering rear-seat entertainment, such as movies, games, social networking, etc.; listening to incoming and sending outgoing SMS text messages; making

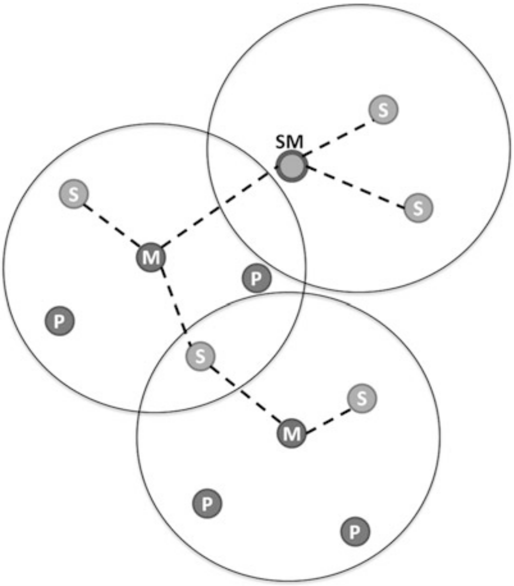


Fig. 5.19 Scatternet with master (M) indicated as dark gray dots, slave (S) indicated as light gray dots, and piconet (P) indicated as gray dots (URL9 2017)

phone calls; and accessing Internet-enabled or smartphone-enabled content, such as traffic conditions, sports scores, and weather forecasts.

With regard to social networking, several social media websites and embedded Web 2.0 Internet-enabled applications allow the creating, exchanging, and sharing of user-generated content, such as text posts or comments, digital pictures, or video posts, in virtual communities and networks.

In addition, many vehicles now have a constant connection with the cloud of the respective automaker where vehicle data can be stored or social media services can be downloaded to the vehicle's onboard unit (see Sect. 5.4.2). In addition to Google and Facebook®, this includes news and weather services. In this regard, Google Maps™, which provides real-time traffic data, can be directly integrated into the onboard unit of the vehicle. This corresponds to the further development of the traffic message channel (TMC) feature with more up-to-date information on the radio, such as congestion information.

5.3.3 Evolution of the Connected Car

Connected car technology first emerged in the mid-1990s, with a focus on technology-driven telematics concepts. Today, the connected car technology has the potential to radically change the way people travel because vehicles are already moving computer systems that run on data as much as they depend on fuel. It promises to greatly:

- Reduce road accidents
- Reduce greenhouse gas emissions
- Speed up commuting and freight traffic

The impact on economy and lifestyle is looking increasingly impressive, and there is strong support and enthusiasm emanating from government, automakers, and their OEMs and Tier 1 suppliers. Thus, automakers all over the world are currently developing, presenting, producing, and marketing new vehicle features that enable the exchange of information with the Internet through specific interfaces, bringing the Internet into the automotive world. The joint connection of vehicles and the Internet opens up new possibilities for the entire automotive industry, providers of Internet services, and their customers who use these features, along with the challenges, opportunities, and risks this development entails. In Siebenpfeiffer (2014) a detailed overview on connected cars is given which covers the aspects safety, Car IT, and concepts.

Some automakers have broadened their overall mission and have gone beyond the production of vehicles to become real mobility providers through connected cars. This change in mission clearly has implications for the strategic motivation for in-vehicle services and the automaker's overall business model. The digital transformation paradigm has elevated the challenges, opportunities, and risks of this development because vehicles computing capabilities make endpoint security a moving target. Endpoint security for mobile computers and other vehicles devices is identified as a point of risk. Modern vehicles have as many as 20–200 moving end points that are connected to each other and to the networks of any businesses providing services to those vehicles. This enables the connected car to exchange information between itself and its environment via the Internet, whereby the vehicle's connection to the Internet is provided either by a transmitter/receiver unit built into the vehicle itself or through third-party systems, such as smartphones and/or tablets. This transforms the vehicle into a hub of communications enabling in-vehicle use of data and services through appropriate operating and display concepts. Features users expect in vehicle-connected services are, as a minimum:

- Driver safety
- Navigation
- Security

In addition, applications that enhance connectivity may be desired but not required. Furthermore, cloud applications (see Sect. 5.4.2) and a Hypertext Markup Language 5 (HTML5) engine to render content in the vehicle are seen as appropriate services. HTML5 is the fifth edition of the Hypertext Markup Language, a computer language for marking and linking text and other contents of electronic documents, mainly on the Internet.

The demand for in-vehicle services is primarily characterized by three factors:

- Individualization
- Relation to mobility
- Vehicle brand identity

According to Bechmann et al. (2015), 95% of the respondents consider the growing demand for mobility-related information as a major factor driving connected car development. Services such as enhanced navigation or traffic information are seen as highly relevant using these functions, with the quality and timeliness of the content being a major success factor. There is above-average willingness to pay for these services. This also reflects the high potential for new telematics functions in the business-to-business (B2B) sector. This trend represents an entirely new market for mobility services, services that bring people from one place to another and support them during and after a trip. In addition to navigation and traffic information, systems offer a variety of other features that can be considered, such as:

- *Driver Wellnes Monitoring wizard:* Fatigue sensors and other features
- *Entertainment features:* Video streaming, Wi-Fi hotspots, and other features
- *Mobility management:* Current high-volume traffic information, gas consumption optimization, and other features
- *Safety functions:* Danger warnings, emergency functions, and other features
- *Vehicle management:* Remote control, maintenance information, and other features

With each step of automation up to fully autonomous driving, these vehicle business models will become even more important. New mobility concepts will include the joint use of vehicles to provide flexible mobility.

However, vehicle individualization is also an important factor for younger drivers in particular. Young customers who are enthusiastic about adopting new technology will want vehicles that function as an extension of their virtual environment, sporting features like individual user profiles; personalized services; and social media support.

Therefore, as reported in Bechmann et al. (2015), automakers are pushing services and offer into the market that fit their brand. Automotive OEMs are pursuing vehicle connectivity for the state-of-the-art image it conveys, with the ultimate goal of achieving strategic differentiation between themselves and the competition and earning customer loyalty. The services offered range, as previously mentioned, from safety enhancements through information on the vehicles' surroundings, to convenience services, and even to improved connection to individualized, customer-specific service points.

One possible convenience service is infotainment, a feature that their respondents view as being very important to customers. Freedom to use the Internet seems to be less important, with most respondents considering it to be a basic function. In both cases, willingness to pay is no higher than with smartphones or the levels usually seen for media balancing value and cost of services. However, consumer information becomes interesting when services relate to a specific location or to mobility.

The demand for vehicle connectivity is high, and technology will initially be used by OEMs and Tier 1 suppliers for strategic positioning in the market. Profitable business models are expected, spurred by new applications offered by various providers (see Sect. 2.3). The expected value creation potential is enormous. The overall market for connected cars in 2015 was about € 32 billion. By 2020, considerable growth to about € 115 billion is expected. Here alone, the market volume for the functional areas of safety and autonomous driving is growing to an estimated € 83 billion, which occupies two thirds of the market (see Sect. 2.4.). According to a market potential of € 32 billion, as reported in "Connected car opportunities and risks for future provider" in the automotive market Bundesverband Digitale Wirtschaft (BVDW) position paper (URL10 2017), desirable functions or experience areas include:

- Entertainment
- Home integration (see Sect. 5.3.1)
- Mobility
- Well-being

However, connectivity decisions are an important factor in determining the value proposition and the supporting business model for connected car services. Connectivity service trends for in-vehicle services include:

- *Embedded solutions:* Connectivity and applications are built directly into the vehicle, where today they are platform dependent.
- *Remote solutions:* Applications reside in a smartphone.
  - Remote skin resides in the vehicle which controls smartphone applications. Connectivity is achieved by universal serial bus (USB) or Bluetooth.
  - Remote terminal client (such as Virtual Network Computing (VNC)) in the vehicle replicates the smartphone HMI. Connectivity is achieved by USB or Bluetooth.
- *Tethered solutions:* Applications reside only in the vehicles. Smartphones provide connections to the cloud. Connectivity is achieved through USB or Bluetooth.

The first development stage to the connected car will encompass technological integration and infrastructure development. Based on considerable self-driven activity, various market players will emerge that will introduce new in-vehicle applications for various groups of users, such as:

- Platform providers
- Software developers
- Telecommunications carriers

Automotive OEMs will have to decide whether to open their systems to these applications or to continue to favor their own proprietary applications. In line with this trend, the connected car will evolve in the market over several stages.

Luxury and high-end, trendy city vehicles, especially those associated with alternative drive concepts, such as e-vehicles, will be at the forefront of technology and innovation. Vehicle connectivity will become the standard in high-end vehicles with about 80% of vehicles in this class having these features soon. These vehicles will be equipped with their own transmitter/receiver units. At the same time, city vehicles, about 33% of which will feature connectivity, will appeal particularly to young, urban buyers. Connectivity in this segment will be provided by users' own smartphones. The challenge for OEMs in terms of this target group is to provide attractive services at the speed and quality these users are accustomed to receiving from the Internet community.

The segment of customers who are young, technology minded, but less willing to pay will demand low-cost, flexible solutions. The market potential for aftermarket in-vehicle connectivity solutions is certainly interesting, at 20% of existing vehicles. Because of the limited number of interfaces for retrieving data from the available vehicles, the scope of functions provided in these aftermarket solutions will probably be limited to providing services that largely do without data from the vehicle itself.

Since development of additional applications takes place outside of the automotive life cycle and is driven by individual business models, the aftermarket, with its focus on applications, will gain tremendous momentum in the coming years. Thus, automakers will be under pressure to ensure customer loyalty in the aftermarket segment so that they do not lose customers to third-party providers because aftermarket features are generally installed directly at OEM dealerships or at locations operated by automotive accessory specialists (Bechmann et al. 2015).

From the above it can be seen that the technologies involved in realizing the connected car currently exist in the automotive, software, and telecommunications industries and their OEM and Tier 1 suppliers. However, a major concern with regard to the development of value creation networks is to close competency gaps among individual partners with regard to the development of a shared understanding of the entire value chain. This has a huge impact on the risk of accidents and damage claims related to connected cars, especially if claims are the result of cyberattacks (see Chap. 6), which makes ensuring vehicle security an important issue.

Another major concern, especially for the automotive OEMs, are the long vehicle product life cycles, which are diametrically opposed to the short life cycle in the consumer goods and telecommunications industries. This calls for flexible architectures in connection with the far-reaching standardization of interfaces for easy, smooth data integration as well as a special focus on the use of middleware. The challenge is, therefore, to ensure that the appropriate technologies for different vehicle segments are used throughout the vehicles' life cycles. Recommended actions given in (Bechmann et al. 2015) are:

- *All service providers:*
  - Decouple the process from the innovation, product creation, and update cycles of all value creation partners
  - Define safety and security standards
  - Define standards and interfaces
  - Define strategic portfolios of services, with high-quality mobility services as the starting point
  - Develop and establish cooperation strategies and collaborative models for potential partners
  - Outline flexible architectures
- *Automakers:*
  - Achieve branding through unique selling propositions (USPs) in the range of options offered for connected cars
  - Ensure customer loyalty in the aftermarket segment
  - Ensure elevated innovation
  - Map out product value and platform strategy for different target groups
  - Scale system between specific services related to exclusive brands and generally open services
- *Service and platform providers:*
  - Develop core competencies for intelligent data networking
  - Develop strategic portfolios of services with the potential to generate revenue
  - Review possible sources of revenue with downstream service providers, such as aftermarket service providers, infrastructure operators, OEMs, and others
- *Telecom infrastructure providers:*
  - Build infrastructure to capture real-time data from vehicles, applications, and infrastructure elements
  - Develop broad-coverage, high-performance infrastructures
- *Suppliers:*
  - Develop innovations for the automaker
  - Supply aftermarket solutions

5.3.3.1 Technology Maturity Levels and Driving Factors

Automotive manufacturers are in control of all services based on the connected vehicles marketed under their brands. Content and applications are hosted on servers operated by the automotive OEMs with access provided only via manufacturer-specific portals. All services not directly developed by the manufacturers and their partners undergo a certification and review process within the OEMs' organizations. The automotive manufacturers' main concern, system security (see Chap. 6), thus remains under their control. Automotive OEMs, however, can hardly keep up with the rapid pace of development on the Internet, short update cycles, and the many different user profiles and applications in use.

Since 2015, a large number of applications have been available to drivers on platforms operated by service providers. They represent an intelligent way to combine different pieces of information from the Internet, thereby generating high value-add for users' cars. These applications are based on:

- *Automotive cloud service system (ACSS):* ACSS is a service-oriented architecture (SOA) for the next generation of automotive software platform. It is a computing model for providing and sourcing IT services that are highly configurable, adaptable, and scalable over the Internet with an ongoing operating expenditure compared with traditional IT models. ACSS can facilitate new and expanded channels, as well as improve access to client data, allowing for better tailored products and services. However, automakers pioneering the design of new cloud features for cars will likely continue to address any concerns associated with data security or troublesome downtime events in an effort to make the cloud fit the needs of tomorrow's drivers.
- *High bandwidth:* At the VDI Wissensforum on automotive electronics in Baden-Baden (Germany) in 2011, several players announced their commitment to Ethernet as the future standard for in-car data, high-bandwidth communications. The Ethernet physical layer for automotive environments is the key element for a breakthrough of Ethernet in this domain. It enables OEMs and suppliers to implement Ethernet-based data bus systems without EMC problems and at very low cost, even in safety-critical automotive environments.
- *HTML5:* Is the fifth version of HTML, a computer language for marking and linking texts and other content of electronic documents, mainly on the Internet. HTML makes it possible for connected cars to be individualized with all of the component features required by the user.

The cloud, which provides data and makes it available on various devices, brings the data into vehicles easily and smoothly. Responsibility and ensuring system security within the vehicle are, however, open issues, as described in detail in Chap. 6.

The technologies involved in realizing the connected car currently exist primarily in the automotive, software, and telecommunications sectors. The biggest area where action is needed lies in the development of value creation networks and closing of competency gaps among individual players, along with development of a shared understanding of the entire value chain. The risk of accidents and related damage claims makes ensuring system security especially important.

As mentioned earlier, a major challenge, especially for automotive OEMs, are the long product development, which are diametrically opposed to the short life cycles found in the consumer goods and telecommunications industries. This means there is great need to realize flexible architectures in connection with far-reaching standardization of interfaces for easy, smooth data integration and maintenance. These factors enable efficient use of technologies in different types of vehicles over the vehicle's entire lifecycle.

For the new in-vehicle services which are meant to be used by the driver while driving, the focus is on maximum ease and convenience in using the input and output devices. Through widespread use of smartphones, tablets, and aftermarket navigation system solutions, touch screens have become established as the preferred interface. Like voice command functions, touch screens are highly user-friendly and promise low driver distraction rates.

Besides these telematics maturity levels and driving forces in telematics concepts, the European Union (EU) has mandated the implementation of the European in-vehicle interoperable and harmonized emergency call (eCall) service initiative based on 112, the common European emergency number. Every new vehicle launched in the market must be equipped with technology enabling automatic emergency calls in the event of an accident beginning April 2018. This mandate will necessitate technology solutions, such as in the vehicle cockpit-embedded subscriber identity modules (SIMs) versus smartphones, to ensure a consistent and reliable connection between the vehicles and very fast wireless communication networks higher than 375 Mbit/s. Similar discussions are underway in the US for mandates on backup cameras and other safety-oriented features. Thus, automatic emergency calling functions are a major factor driving the connectivity of vehicles. Whether the performance of eCall systems will be sufficient for other services, e.g., to get clarity about the cause of an accident, whether the data recorded on the SIM card are reported to the police or the insurance company remains an open question, however. Furthermore, hazard warning functions and vehicle diagnosis by the OEMs are also seen as potential driving factors. Direct access to the vehicle by the OEM for service and warranty purposes is particularly important, especially in the alternative drive technologies segment. On the content side, the steadily rising volume of traffic means that mobility-related information, such as high-definition traffic real-time information (HDTRI) and floating car data telematics technology, is important too.

Development of traffic safety standards will tighten within the scope of the connected car. With regard to how binding new standards will be, expert's opinions are split, with some believing the issue will be regulated by law and a larger group considering it more likely that these features will be self-regulated (Bechmann et al. 2015).

5.3.3.2 Business Models in Connected Cars

Developing and establishing sustainable, attractive business models are based on the assumption that the vehicle user might be willing to pay for services and applications. Therefore, digital solutions play a key role with consumers. As these new offerings are introduced to the marketplace, the development of new service models and the associated internal operational transformation will be just as important as technology investment to the success and profitability of these solutions. In this regard, connected cars are a leading area of investment for automakers. To varying degrees, connected cars offer services such as:

- Emergency
- Multimedia
- Navigation
- Security
- Diagnostics

All of these become more comprehensive and expand to include components or systems used at the user's home and/or in the user's office. Hence, automotive OEMs must consider how to transform their business to offer customers a connected transportation experience. Therefore, the major goal of connected cars is to offer exciting new digital capabilities for customers, which will change the way they will use and interact with their vehicles. Moreover, connected services, as part of connected cars, also open a myriad of opportunities to revisit revenue innovation and to enhance, extend, and redefine interaction with customers by:

- Enhancing the customer experience and increasing differentiation by offering right pricing and package combinations of connected services
- Extending the type of connected services and capabilities to generate new revenue streams beyond the traditional vehicle-to-driver relationship by enabling movement of people between vehicles and modes
- Redefining value to customers by integrating new digital characteristics, such as supporting how people should move around in increasingly crowded spaces (Gyimesi and Berman 2011)

Hence, the necessary technological investments in vehicle connectivity require that automakers must collaborate with new partners, suppliers, and customers, as well as throughout the enterprise itself in an ever more complex network. In addition, many of these partners are outside of the traditional automotive industry and include telecommunications, software, and content providers, as well as other electronics manufacturers with traditionally faster innovation cycles. Managing such complex alliances with companies that only do a small portion of their business within the automotive industry can be challenging. As services are added from various partners, automakers must efficiently and consistently engage and disengage with the new partners, as well as build an alliance. Original equipment manufacturers need to reconcile the dual—and very different—timelines of automobile development and ICT development. The ability to innovate and deploy connectivity solutions to the installed base in a shorter timeframe will be a critical operational capability and success factor for automakers.

Just like a variety of other businesses, automotive companies are determining how to stake their claim in the emerging mobility services business models. As congestion, population growth, and pollution push customers to consider the limitations of vehicles, greater urban transportation data, smartphones, and ubiquitous telecommunications present opportunities for new, exciting digital offerings. Some of them are described more in detail in Meyer and Shaheen (2017), for the sharing economy and multimodel mobility as well as for innovative transportation technologies. Since most customers don't want to give up access to vehicles, automakers are challenged to bundle the right mix of cars and other transportation modes into compelling, integrated new offerings.

Digital solutions are needed both in the vehicle and outside of it (Gyimesi and Berman 2011). Therefore, some automakers are broadening their overall mission to go beyond the production of vehicles to become mobility providers. This change clearly has implications for the strategic motivation for in-vehicle services and the overall automakers' business model. For example, Peugeot's original strategic position was that telematics are an integral part of its core offering, so it provided these services for free for the lifetime of the vehicle. Volvo, on the other hand, views connected car services as a way to enhance and strengthen its core offering and believes that consumers should pay an upfront cost for connected car services for the first owner. These strategic decisions have influenced the types of services offered, the connectivity means employed, and the business models deployed.

Apple redefined itself when it moved from offering a simple portable media player in 2001 to providing a seamless music experience in 2003, bringing together the device with the online digital music store. This value proposition further evolved when Apple launched the iPhone® in 2007, followed by the App Store. Considering "what if" questions to contemplate the "impossible" can foster innovation on the strategic definition of the mission and the associated business models used. These strategic principles shape the creation of the value proposition, the appropriate business model, and the value chain to deliver the services and can vary across the same brand, by region or by model (GSMA 2012).

5.4 Platforms and Architectures

The connected vehicle is an advanced technology representing a traffic environment in which, potentially, every vehicle is networked with any other vehicle connected by modular, scalable, open, and secure connection platforms. This kind of platform can be cloud-based operating different telematics services. Thus, interoperability and scalability of platforms are essential for the connected vehicles paradigm and infrastructure, especially for independent data exchange by automakers, OEMs, and Tier 1 suppliers. Moreover, these platforms also process and enrich big data, turning it into valuable knowledge, an important issue with regard to V2X, combining data from vehicles, devices, and systems to enable innovative solutions that provide drivers with greater safety, service, and convenience.

Hence, the multiple processing systems used in connected vehicles serve as major drivers for the development of advanced mobility services as well as new business models. So, connected car platforms range from server-based, open, modular, secure, and highly scalable infrastructures to open, modular, secure, and highly scalable cloud-based infrastructures on which telematics services can be based and operated. This permits fast service development and easy integration of various devices and business applications and seamless integration into existing IT systems as well. Moreover, advanced features and technologies of embedded IVI, which requires multicore architectures for in-car digital entertainment, are part of modular, scalable, open, and secure platforms. The target functions for today's IVI vary from terrestrial reception, digital reception, and compressed audio, up to hands-free voice, calling voice, and USB media playback, possibly in different user modes, such as single versus dual media sound. In the near future, new functions, such as near-field communication, wireless streaming, and more, will become important. The main challenge is that the platform must be open for future functions, which are unknown at design time.

Another challenge is to reduce the design effort by maximizing reuse of hardware and software, especially from related domains such as traditional consumer electronics (Moonen et al. 2005), which require the differences between consumer electronics and the automotive industry to overlap, taking into account the possible set of simultaneously activated functions. These functions have timing constraints, such as hard real-time (HRT), soft real-time (SRT), and best effort (BE). In the case of HRT, missing any deadline is not permitted. In the case of SRT, some deadlines may be missed, but the miss ratio should be low. BE functions, like access services, do not have deadlines. Hence, connected vehicle platforms and architectures need to be flexible and upgradable as well as operate in real time. They mainly consist of the following interlinked components and services:

- B2B interfaces to external devices
- Central platform services
- Device gateway
- Worldwide operation
- 24/7 service management

These can be realized by a modular SOA offering the following features:

- *Global:* Hosting and operation based at certified data centers for security reasons
- *Highly available:* Multi redundancy and high reliability of the connected car platform for stable and secure operation
- *Scalable:* Horizontal and vertical scalability with regard to the connected car platform's cluster capability
- *Secure:* Tier 1 connected car architecture

5.4.1 Connected Car Architecture and Challenges

Today's automotive architecture is comprised of diagnostics, infotainment, and telematics as a result of advanced communication technologies, such as Long-Term Evolution (LTE), the 3.9G wireless standard of the fourth generation. An extension is called LTE-Advanced or 4G, which is backward compatible with LTE. With LTE 4.5, more than 375 Mbit/s allow significantly higher download speeds than older standards, depending on the reception situation. The next step will be the 5G communication network standard.

With regard to LTE communication technology standards, the future of driving through V2V and V2I (also known as V2R) and collectively referred to as V2X will allow a seamless exchange of information between them as the key to unlocking mobility.

Vehicle-to-vehicle is a mesh network in which each vehicle is a node with the ability to transmit, receive, and retransmit messages to other nodes. The resulting network is based on three sets of standards:

- *IEEE 1609:* Family of standards for WAVE, it defines the architecture and procedures of the network.
- *SAE J2735 and SAE J2945:* Define the information carried in the message packets. This data includes information from sensors on the car, such as the location, direction of travel, speed, and braking.
- *IEEE 802.11p:* Defines physical standards for automotive-related dedicated short range communication (DSRC).

Vehicle-to-infrastructure allows the vehicle to communicate with traffic lights, traffic management systems, and other stationary infrastructure components, which would also become nodes in the mesh network. This allows vehicles to receive information relating to the timing of traffic lights and roadside units (RSUs) or warn the driver of a potential hazard in a blind spot at an intersection. Vehicle-to-infrastructure will, in the future, also allow parking in free parking spaces and identify and announce free parking spots.

Therefore, V2V and V2I communications are considered to be key technology architectures for safe and intelligent mobility in the future, allowing the testing of V2X applications in real metropolitan field trials. These applications include vehicles, RSUs, and infrastructure facilities for traffic and test management. Also, several third parties are involved to provide access to additional services. As a result, such a system requires a commonly accepted architecture of the individual components and a seamless communication network for reliable and efficient information interchange. With regard to V2X, advanced use cases such as the following are feasible:

- Connected infotainment
- Real-time diagnostics
- Real-time tracking

In this regard, the software architecture of modern connected vehicles is comprised of three main components:

- *Connected car gateway (CCG):* Entry point for a vehicle to communicate with the external environment. CCG encompasses advanced features, such as 4G connectivity, hotspot, cloud connectivity, V2V communication, ability to control the car remotely, firmware updates over the air (OTA), remote diagnostics, predictive maintenance, eCall, and crash notification, which makes it a very complex architecture.

- *Cloud-based servers (CBS):* A term applied to large, hosted, secure data centers, usually geographically distributed. They offer various computational services on a utility basis as a new way to host applications, as well as perform real-time analytics on data from the vehicle to generate real-time insights.
- *Applications on smartphones:* Provide an intuitive user interface that allows users to interact with the vehicle over wireless networks performing a variety of operations, ranging from getting vehicle status to controlling some of the aspects of the car, such as switching on the heating, ventilation, and air control (HVAC) or locating a car in the parking lot.

With regard to connectivity, the CCG is comprised of long-range connectivity modems, such as LTE; short-range connectivity modems, such as Wi-Fi; and positional tracking systems, such as GPS. Advanced connectivity features are required for transmission and reception of data in real time to/from the Internet. At the lower end, 2G/2.5G modems provide data rates of less than 100 kbps going to LTE, which provides data rates at a few Mbps. Modem integration can be done using either dedicated modules from vendors such as Telit or Sierra Wireless or built-in modems that come as part of a system on a chip (SoC) delivered by vendors such as Qualcomm.

eCall services provide emergency alerts to public safety access points (PSAP) so that help can be provided to victims in the shortest span of time. In most cases, it involves communicating information about the accident, including location, number of occupants, speed, direction, etc. Thus, vehicle emergency data sets (VEDS) can help the recipient of the information to assess the severity of the incident and provide the necessary help. The EU has passed a regulation that requires all passenger cars to be equipped with eCall systems by April of 2018. The eCall system automatically dials Europe’s emergency number 112 in the event of a serious accident.

Global standards for eCall are emerging with 3GPP standardizing eCall requirements as part of 3GPP TS 26.267, TS 26.268. The transmission of VEDS is followed by an automatic call to the call center so that voice communication can be established with the occupants of the car.

In the US, the vision for Net GEN 9-1-1 is to enable a PSAP to automatically receive and process the VEDS. The US has not yet adopted a standard protocol for eCall, although some of the telematics service providers, such as GM’s OnStar®, Ford’s SYNC® 911 Assist®, Lexus Link®, etc., provide similar services and each one of them uses their own proprietary method for transmitting data to the call center.

The CCG application framework allows implementation of a software development kit (SDK) that permits third parties to develop applications that can be downloaded into the device. This will enable development of an ecosystem to provide a variety of services using the data that is available from a CCG box, such as usage-based insurance, preventive diagnostics, and location-based services. The framework abstracts all hardware-specific intricacies from the app developer. The framework exposes APIs in Java/HTLM5/JS for ease of programming (URL11 2017).

With more and more vehicles connecting to networks today, the possibility of an intruder obtaining access to internal vehicle networks and performing malicious activities are real threats (see Chap. 6). The infamous Jeep® hack occurred when someone was able to physically compromise a car as it was engineered using "old school" technology. Any failure at one single point would result in a breakdown of the cryptographic chain of trust. The connected vehicle units that are connected to the Internet need to implement multiple layers of security so that a break in one layer does not compromise the entire system. Software security issues have to be addressed at various levels right from the time the firmware is flashed in a factory, and all the way to ensuring the integrity of downloaded applications and workshops where the firmware will be flashed.

5.4.2 Connected Car Reference Platform

Qualcomm Technologies announced the Qualcomm® Connected Car Reference Platform (CCRP), accelerating the adoption of advanced and complex connectivity into the next generation of connected cars. They are keeping pace with an ever-increasing set of automotive use cases facilitated by the latest advances in 4G LTE, Wi-Fi, Bluetooth, and V2X communications. The platform is also designed to meet challenges such as wireless coexistence, future-proofing, and support for a large number of in-car hardware architectures.

The CCRP is built upon Qualcomm Technologies' automotive product and technology portfolio, including Qualcomm Snapdragon™ X12 and X5 LTE modems, quad-constellation Global Navigation Satellite System and 2D/3D dead reckoning (DR) location solutions, Qualcomm® VIVE™ Wi-Fi technology, dedicated short-range communications (DSRC) for V2X, Bluetooth, Bluetooth Low Energy, and broadcast capabilities, such as analog and digital tuner support using software-defined radio via Qualcomm® tuneX™ chips. In addition, the platform features in-vehicle networking technologies, such as OPEN Alliance BroadR-Reach (OABR) gigabit Ethernet with Automotive Audio Bus ($A^2B^®$) and controller area network (CAN) interfaces.

Advanced features included in the CCRP design are:

- *Future-proofing:* Allowing the vehicle's connectivity hardware and software to be upgraded through its life cycle, providing automakers with a migration path from DSRC to hybrid/cellular V2X and from 4G LTE to 5G
- *OEM and third-party applications support:* Providing a secure framework for the development and execution of custom applications
- *Scalability:* Using a common framework that scales from a basic telematics control unit (TCU) up to a highly integrated wireless gateway connecting multiple

ECUs within the car supporting critical functions, such as over-the-air software upgrades and data collection and analytics
- *Wireless coexistence:* Managing concurrent operation of multiple wireless technologies using the same spectrum frequencies, such as Wi-Fi and Bluetooth

The CCRP allows automakers and their suppliers to explore, prototype, and commercialize connectivity designs using modules and solutions offered based on Qualcomm Technologies' roadmap.

5.4.3 Connected Car in the Cloud

Cloud computing is in use by multiple industries, and the automotive one is no exception with regard to connected cars. Cloud computing, in general, includes technologies and business models to dynamically provide IT resources and to bill for their use according to payment models. Instead of businesses operating IT resources in their own enterprise data centers, they are using cloud computing which is available in the form of a service-based business model. This model is available through the Internet or an Intranet whereby the business model represents how a company can generate value for its customers and ensure a return for the company. Thus, enterprises can reduce their long-term IT capital expenditures by deploying cloud computing as their IT resource. As IT resources of various types are flexibly deployed in a service-based way, they are referred to as everything as a service (EaaS) and are divided into four classes of cloud services:

- *Business Process as a Service (BPaaS):* Allows customers to outsource all of their business processes to a cloud provider and implement them through business process technologies. Therefore, the provider offers all of the IT resources, and not the IT-based services a customer needs to support his business processes. Hence, BPaaS abstracts more from IT resources and focuses on the customer's business processes.
- *Infrastructure as a Service (IaaS):* Provided when physical or virtual servers are offered. The cloud manages the servers and ensures their connectivity.
- *Platform as a Service (PaaS):* Superior-grade functionalities are available, enabling the operation of customer-specific applications which may include, for example, entire databases, process engines, web services, and other features. In general, application functionalities which are not directly used by people but are integrated into other applications belong to this service class.
- *Software as a Service (SaaS):* Includes offering complete customizable software applications. Users access these applications through a network, sharing hardware, and platform IT resources but without noticing or interacting with each other. Many business sectors, for example, customer relationship management (CRM) or enterprise resource planning (ERP), can be supported by cloud services.

To make these cloud-based services available to automotive consumers, new vehicles will increasingly rely on innovative cloud-based technologies for requisite tasks, such as vehicle connectivity to the off-board world and Internet, two-way data, information transfer between the vehicle and the cloud, and reliable access to highly scalable data storage, processing, and analytics capabilities.

For connected cars, and thus smart mobility, cloud-based systems are ideally suited as reference architectures. In this case, the lowest level of the architecture is characterized by different sources of information, from smart devices or weather forecast stations, delivered to the cloud and processed into important information available from the cloud. This information can be delivered to user devices and used, for example, by an app or the browser of a user's smartphone. In this regard, the cloud platform provides cloud application containers and services for the development and operation of applications. This layer is the PaaS. Compared to the IaaS, the PaaS defines which platform runs on a server. Once the application is developed and tested, it has to be adapted to the different services. To do this, PaaS must provide services for the deployment of the various components.

Today, connected car and integrated cloud technology are already state of the art. Ford, for example, has announced an expansion of connected vehicle services capability with the creation of the Ford Service Delivery Network powered by the Microsoft® cloud platform which was launched in 2008 as Windows® Azure and rebranded in 2014 as Microsoft Azure, which is the major cloud platform that is consistently used for both IaaS and PaaS.

The advantage of cloud services is the scalability and accessibility to new applications, resources, and services. Microsoft categorizes Azure services into 11 main product types (URL12 2017):

- *Analytics:* Provides distributed analytics and storage, as well as real-time analytics, big data analytics, Data Lake machine learning, and data warehousing.
- *Computing:* Provides virtual machines, containers, batch processing, and remote application access.
- *Data storage:* Category includes database as service, as SQL and non-SQL (NoSQL), as well as unstructured and cached cloud storage.
- *Development:* Services help application developers share code, test applications, and track potential issues. Azure supports a range of application programming languages, including JavaScript, Python, .NET, and Node.js.
- *Hybrid integration:* Services for server backup, site recovery, and connecting private and public clouds.
- *Identity and access management (IAM):* Ensures only authorized users can employ Azure services and helps protect encryption keys and other confidential information.
- *Internet of Things:* Services help users capture, monitor, and analyze IoT (see Sect. 5.2) data from sensors and other devices.
- *Management and security:* Helps cloud administrators manage their Azure deployment, schedule and run jobs, and create automation. This product group also includes capabilities for identifying and responding to cloud security threats.

- *Media and content delivery network:* Includes on-demand streaming, encoding, and media playback and indexing.
- *Networking:* Includes virtual networks, dedicated connections, and gateways, as well as services for traffic management, load balancing, and domain name system (DNS) hosting.
- *Web and mobile:* Supports the development and deployment of web and mobile applications and also offers features for API management, notification, and reporting.

The full list of Azure services is constantly subject to change.

Most cloud-based services are available courtesy of a vehicle's connection to a smartphone, such as Apple's iPhone or the Motorola Droid. That is because those devices provide the wireless data connections required for getting information from the remote servers where it originates into a vehicle. The idea is to connect the smartphone with the user interface of the vehicle making the interaction safer. With that data stream, today's leading telematics systems from automakers and their OEM and Tier 1 suppliers provide a number of different functions to vehicle passengers.

Connected car cloud platforms are not only offered from technology giants like Microsoft. Airbiquity, for example, has a connected car cloud platform, an open platform architecture, that integrates the entire spectrum of vehicle systems, connectivity devices, communication networks, content providers, and backoffice IT systems for traditional and emerging use cases. The platform is called Choreo; it enables automotive OEMs to deploy, manage, and dynamically update innovative connected car software globally for their customers. It provides service delivery for eight automotive brands and powers over six million vehicles around the world. Choreo also enables driver safety and convenience features such as remote vehicle monitoring, geofencing, and automatic crash notifications.

As more automakers launch new cloud-based applications, resources, and services, it will become increasingly clear that cloud technology is the best way to power connected car software today and in the future (URL13 2017). That is because:

- Automakers must fully embrace the cloud technology if they want to achieve faster software deployments to deliver competitively differentiated features and services to existing and prospective customers. Cloud technology is uniquely suited to efficiently configure, scale, manage, and to update connected car software features and services dynamically. For example, Nissan saw this potential and seized the opportunity by using cloud technology to deploy their NissanConnect^{SM} with a mobile apps infotainment program across more than 50 countries and over 20 vehicle models in just 16 months. This kind of software deployment speed was unheard of prior to the introduction of cloud-based technology and service delivery capability.

Automakers are not the only ones that directly benefit from the connected car cloud technology because consumers will have many opportunities to derive value as well. Connected cars have the ability to provide a steady stream of valuable information about the vehicle and driver that can be used to enhance the consumer's driving experience post-purchase. By learning more about their vehicles and individual consumer driving habits and preferences, automakers can create highly personalized and relevant driving-centric services and promotions with current and new third-party partners, such as automotive dealers, online service providers, and brick and mortar retailers for oil changes, collision repair, parking, food, beverages, and other convenience items (URL13 2017).

With the emergence of connected infotainment systems, such as connected navigation, social media, music streaming, and in-car Wi-Fi, and accompanying automotive application frameworks, more advanced vehicle connectivity platforms and cloud capabilities are required. This is resulting in advanced cloud-based connected car platforms with capabilities that far exceed those of legacy telematics platforms and also require broadband cellular connectivity, initially 3G but now increasingly 4G, and with 5G-based services. Additionally, OTA is quickly becoming a key vehicle life cycle management tool as well as an enabler of analytics and big data approaches. Finally, with connected vehicles increasingly communicating, interacting, and engaging with other connected industries, such as energy, transportation, and smart home, the cloud is quickly becoming the key technology for enabling cars to connect with the wider Internet of Everything (IoE), as reported in the *2015 ABI Technology Analysis Report AN-1999* (URL14 2017). The report also discusses typical connected car cloud applications, benefits, limitations, constraints, solutions, main players, and forecasts per application and service category.

Due to the emergence of more advanced vehicle connectivity platforms and cloud capabilities, the automotive industry has to pay more attention to transformative technologies like ADAS, V2X, 5G connectivity, AI, augmented reality (AR), driverless vehicles, electrification, and IoT that will enable the mobility as a service (MaaS) paradigm and allow for new business models, such as carsharing and ridesharing. This allows new business models, such as the carsharing and ridesharing. Third-party platforms, such as Apple CarPlay® and Android Auto, increasingly dominate the industry.

The next innovative step will be car-to-cloud vehicle sensor data crowdsourcing for traffic management, automated parking, weather, and high-definition (HD) map services and cloud-to-car OTA updates for life cycle and cyber security (see Chap. 6) management. Thus, commercial connected car technology will evolve from aftermarket fleet telematics to embedded connectivity, active safety, ADAS, platooning, and autonomous vehicles.

5.5 Autonomous Vehicles

Meanwhile, innovative companies are working hard and fast to create the technology that will enable 100% self-driving vehicles, also called autonomous vehicles or driverless driving. From a more general perspective, autonomous driving can be seen as the most advanced technological development in smart mobility.

Autonomous driving means the independent and purposeful driving of a vehicle without the intervention of a human. Technical, legal, and social aspects have to be taken in account carefully. On the way to fully autonomous driving, several steps are required, which range from accompanying vehicle functions, partially automated, highly automated, and fully automated vehicle functions, which are actively carried out by the vehicle, as published in the National Highway Traffic Safety Administration (NHTSA) guidelines for the testing and deployment of autonomous vehicles (NHTSA 2016). These levels are as follows:

- *Level 0:* The human driver does everything.
- *Level 1:* An automated system on the vehicle can sometimes assist the human driver with certain aspects of the driving task.
- *Level 2:* An automated system can actually handle some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving tasks.
- *Level 3:* An automated system can actually, in some cases, both perform parts of the driving task and monitor the driving environment, but the human driver must be ready to take back control when the automated system requests to do so.
- *Level 4:* An automated system can drive and monitor the traffic independently while the human does not need to take back control. However, the automated system can operate only in certain environments and under certain conditions.
- *Level 5:* An automated system on the vehicle can perform all driving tasks that a human driver can perform and under all conditions.

As can be seen from the NHTSA classification, a distinction is drawn between Levels 0–2 and 3–5 based on whether the human operator or the automated system is primarily responsible for monitoring the driving environment. Therefore, an automated vehicle which is built up on a combination of hardware and software, both remote and onboard, can be characterized as an object that performs a driving function, with or without a human actively monitoring the driving environment. Thus, in the case of partial automation, Level 2, the driver must continue to monitor the vehicle. In the highly automated vehicle, Levels 3 and 4, the vehicle is controlled for a certain period of time and under certain conditions. In fully automated operation, Level 5, the vehicle has permanent control and drives the autonomously.

The first steps toward autonomous vehicles can be seen in existing vehicle safety and convenience features, such as:

- *Automatic braking:* The purpose of automatic braking is to aid in stopping vehicles more quickly with the potential for preventing a high number of fatal vehicle accidents each year.
- *Lane departure warning (LDW):* See Sects. 4.2.4 and 4.9.1, as well as Chap. 11.
- *Self-parking:* See Sect. 4.9.1 and Chap. 10.

As these features continue to evolve toward true autonomy, it is assumed that there will be no need for a steering wheel and pedals because of the intelligent algorithms embedded into autonomous vehicles which take over control of the vehicle. An autonomous vehicle will have a fully integrated sensor system capable of detecting its surroundings within a 360°angle of view. This fully integrated sensor system will have up to 12 vehicle-integrated sensors including:

- Cameras (see Sect. 4.9.2.4)
- Laser sensors (see Sect. 4.9.2.3)
- LiDAR sensors (see Sect. 4.9.2.2)
- Radar sensors (see Sect. 4.9.2.1)
- Ultrasound sensors (see Sect. 4.2.6)
- Vision sensors (see Sect. 4.9.2.5)

The sensor information detected is transmitted via data buses to the central control units, which emit commands to activate the following driving systems depending on the data position commands:

- Acceleration
- Braking
- Steering

A fully automated (autonomous) vehicle will thus be realized by integrating various kinds of technologies, including the following core technologies (Johanning and Mildner 2015):

- Active and passive safety
- Active driving systems:
  - Brakes
  - Drive system
  - Steering
- Car in the cloud:
  - Big data
  - Breakdown service
  - Vehicle maintenance/repair
  - Vehicle supervision
- Communication with mobile devices
- Data security
- Intelligent algorithms
  - Action and response logic:
    Fueling
    Navigation
    Vehicle maneuver

  - Recognition of special situations:
    Accident
    Congestion
    Construction area
    Detour
  - Detection of traffic signs
- Navigation
- Sensors
  - Inside the vehicle:
    Camera
    LiDAR
    Radar
    Sonar
  - Outside the vehicle
- V2 remote site:
  Vehicle-to-enterprise (V2E)
  Vehicle-to-home (V2H)
- Vehicle-to-vehicle (V2V) communication
- Vehicle-to-infrastructure (V2I) communication
  - Near:
    Locating equipment
    Municipal public service and rescue services
    Traffic light system
    Traffic management system
  - Far:
    Commercial traffic services
    Traffic situation

Besides the aforementioned core technologies for autonomous driving, governments will need to be increasingly involved to set the legal requirements and framework conditions as guidelines for technology adoption and integration into existing and new smart public infrastructure, such as:

- *Smart roads:* Despite the many technological advances made to vehicles and mobile devices, little change can be seen to roads which would help to improve the driving of vehicles, particularly when it comes to road safety. Therefore, the technologies required to turn a road into a smart road can be summarized as follows:
  - *Induction priority lanes:* E-vehicle drivers can charge their car batteries on the go.
  - *Interactive lighting:* Motion sensors will light only a particular section of a road where a vehicle is approaching.
  - *Reflective dots:* Advanced through incorporation of LED lighting, sensors, microprocessors, and wireless communication capabilities, powered by built-in

  photovoltaic cells or piezoelectric panels to generate electricity when a passing vehicle drives over the marker.
  - *Road safety units:* Focus solely on conducting strategic traffic enforcement to reduce serious injuries and fatal collisions on roads.
- *Smart traffic signals:* Take into account traffic flow which results from a certain traffic rhythm. This will have a dramatic impact on the quality of urban living. It uses sensors, actuators, and communication technologies to calculate the arrival time of vehicles at road intersections with traffic lights by monitoring vehicles' actual speed. Based on this calculation, it is assumed that the vehicle will arrive at the traffic light when it has changed from its red phase to the green phase (Möller et al. 2015).
- *Smart transit systems:* Allows access to real-time departure information from bus or metro stop locations throughout a city. By using online trip planning apps, the user can download complete schedule information for the day as well as other essential features.

In the not-too-distant future, automakers will increasingly be under pressure—and in some cases required—to comply with and participate in government-sponsored policies and infrastructure initiatives. This is good and needs to happen; but it will take an exponentially larger amount of money, technology, and time to enable the evolution from the connected car as we know it today to the autonomous vehicle of the future (Airbiquity 2016).

In this regard, connected trucks can lead the transition to digitized vehicles. One of these digitization efforts is an open software platform and a real-time network of all involved stakeholders in the supply chain, from express agents, loaders, dispatchers, and drivers to the recipients. Based on the data collected, all users can benefit, e.g., express agents, from potentially lower transport costs, e.g., by reducing the number of empty trips, usage of data of the tour, truck position, driving times, and more. However, this implies fully networked trucks which also are the basis for the introduction of platooning, where networked trucks closely follow each other with a very short distance between vehicles (10–12 m, 32–39 feet) which also means less space taken up on the road.

The technology used is based on the automotive standard for wireless connections. The vehicles can communicate within a radius of 200 m of one another, which is enough for truck platooning with no need for elaborate infrastructure. In addition to the technical development, the necessary legal framework needs to be adjusted. Currently, the legal minimum distance of trucks on the highway is 50 m (164 feet). Truck platooning can improve traffic safety. Moreover, platooning is also a cost saver as the trucks drive close together at a constant speed.

The next big step in technology is the driverless, autonomous driving truck, or the autonomous driving vehicle in which an "autopilot" controls the vehicle. But real-world traffic is complex. The automotive industry is experimenting with autonomous prototypes on the road, apparently without major problems so far. However, city traffic is much more difficult. Semiautomatic functions are now available everywhere.

There are also critical voices concerned about autonomous driving in general. Engineers and automakers agree that the transition to autonomous driving is the real problem today. This has to do with the time frame in which both autonomous vehicles and those controlled by drivers are on the road together. This transition is referred to as mixed traffic in which some vehicles can communicate with one another and some vehicles cannot. This means that the transition from nonautonomous to autonomous driving will be characterized by mixed traffic over a significant length of time. Essentially, the following crucial ethical questions have to be answered:

- Can an automaker's software engineers make life and death decisions?
- Are the automaker and its software engineers allowed to develop, implement, and execute intelligent algorithms which may have to decide whether, e.g., a car will run over a playing child or run over another human being standing right next to the child?

These are difficult ethical questions—whether or not a vehicle's computer with its intelligent algorithms should be allowed to make life or death decisions based on the technology embedded by the automaker and its programmers. In the end, the individual driver has always had to make such difficult decisions and bear the responsibility for them. The issue is how the driver can trust that the embedded software is not fraudulent and thereby hazardous. The Volkswagen diesel emissions scandal is an example of how legal requirements can be circumvented by using software algorithms to outwit legal guidelines, cheating both the buyers of the vehicles and the registration office. Who will guarantee that such a fraud will not be perpetrated in autonomous vehicles?

Despite the current debates on autonomous driving, the unanimous opinion is certainly that the driver, and in the case of autonomous driving the current user, is always the final decision maker and, therefore, responsible for the vehicle. There are some legal challenges to autonomous driving, however, as reported in the 52nd Santa Clara Law Review 1145 (Beiker 2012). The traditional approach to traffic litigation assumes the cause of an accident to be a human or technical failure, environmental conditions, or some combination thereof. Considerations become more complex in the case of an autonomous vehicle. As the vehicle navigates itself through traffic, it makes mission-critical decisions, which, in a narrow range of circumstances, can and will contribute to accidents. Such an event cannot necessarily be classified as a technical failure, however, in the same way as, for instance, a damaged tire. This presents an arguably novel situation wherein artificial intelligence acts on behalf of a human with life or death consequences. It is unclear how the courts, regulators, and public will react to accidents involving robotic cars. Overreaction is a clear danger, even if it could be shown that a transition to autonomous vehicles leads to far fewer traffic-related deaths overall. Mitigating these issues will require, at a minimum, research and education. Examples of how to prepare the courts and the public for autonomous vehicles may include:

- Extensive beta testing with limited autonomy
- Mandatory data recorders for autonomous vehicles
- Mock trials and focus groups
- Pilot fleet communities with statistical comparisons
- Special insurance policies for autonomous vehicles

5.6 GENIVI Alliance

A nonprofit industry alliance, GENIVI, is committed to adopting an IVI open source development platform, setting requirements and implementation standards, and providing certification programs. GENIVI seeks to provide entertainment and information features and functionality so that infotainment applications will be universally available.

The GENIVI Alliance was announced in 2009 at the CeBIT fair in Hannover, Germany, with eight founding members from different industries:

- *Automakers:* BMW, PSA Peugeot Citroen, General Motors
- *Tier 1 suppliers:* Delphi, Magneti-Marelli, Visteon
- *Operating system vendor:* Wind River
- *Silicon vendor:* Intel

The goal of the GENIVI Alliance was to define a common software platform, based on Linux® and open source software that implemented the non-differentiating functionality required for IVI systems.

Within the automotive industry, IVI delivery and maintenance are a challenge for many automakers. IVI features and applications commonly include:

- Connectivity and external communications
- Connectivity to mobile devices and the Internet
- Entertainment, radio, and media player
- Navigation- and location-based services

Some of these functions are unique to automotive applications, but most are strongly influenced by the nonautomotive consumer sector. Hence, adopting an open source software development model and enabling the transfer of innovation between related industries were a logical consequence. Therefore, the innovative infotainment systems, along with the development of the latest feature-rich smartphones that are able to seamlessly interact with the IVI system, are playing an increasingly large part in today’s vehicle purchasing decisions.

Consequently, the GENIVI Alliance concentrates on developing and delivering the precompetitive components of the IVI stack, such as:

- Linux-based core services
- Middleware
- Open application layer interfaces

Historically, with regard to the automotive industry, automakers competed across the whole IVI stack. However, much of it is non-differentiating from a customer point of view. Therefore, the logic behind the GENIVI Alliance was to identify which areas of the IVI stack are non-differentiating and to come up with a level of standardization enabling OEMs to continue to compete in their nonautomotive businesses on a higher level in the solution stack.

During IVI product development, the OEMs or Tier 1 suppliers build the remainder of the solution on top of that non-differentiating middleware driven by GENIVI. This approach enables developers, who traditionally found it difficult to work within the closed automotive industry, to gain access and work together. Meanwhile GENIVI has over 180 automotive industry companies promoting deployment of open source software in the automotive electronics business, specifically in the infotainment business.

The GENEVI Alliance members produce and maintain code in open source development projects and, in parallel, collaborate in technical workgroups to combine technical requirements and interfaces with the goal of simplifying production of commercial implementations. Thus, GENIVI delivers a reusable, open source platform, providing the industry at large with a competitive environment for faster innovation and lower software development cost. Linux is the basis for the platform, and all software components defined and implemented by GENIVI members are hosted through the Linux Foundation in GENIVI repositories.

GENIVI members also engage directly in established open source projects to introduce the automotive perspective and needs. In excess of 150 software projects make up what is called the GENIVI baseline, to which Tier 1s and OEMs add additional open and closed source code to meet the OEMs' system requirements. Where no code exists, GENIVI will sponsor and launch a new open source project to develop the needed software. The GENIVI baselines serve as reusable platforms for organizations to use in product development and commercial activities.

Today, nine years after the alliance launch, automakers and their suppliers are reaping the benefits of GENIVI's open source approach, including adopting the open source middleware platform for IVI. As an example, Bosch Car Multimedia develops smart integration solutions for entertainment, navigation, telematics, and driver-assistance functions used in the automotive original equipment business. More specifically, Bosch's requirements for infotainment in the connected car included mandatory features of:

- Application frameworks
- Cloud access
- Fast updates of single features along with the related security and privacy requirements
- Smartphone integration

However, traditional requirements for quality, safety, cost, maintainability of variants, and time to market were still valid and desirable. Based on the above requirements, a new approach for delivering software was required to enable the connected car.

The IVI system developed by Bosch includes MirrorLink® and Apple CarPlay as well as an integrated Bluetooth hands-free kit. Audio streaming and digital audio broadcast in Europe brings music into the vehicle. Additional features include a 7-inch (0.1778 meter) touchscreen, steering wheel controls, and voice control.

5.7 Case Studies

The following section provides insight into some selected applications that automakers and telecommunication companies are working on with regard to V2X technologies, allowing vehicles to be connected, providing the capability of alerting or warning the driver of surrounding conditions or hazards, with the potential to reduce traffic jams, prevent accidents, and save lives. The case studies chosen illustrate how, in the not-too-distant future, vehicles will not only talk to us but communicate with each other and the roads.

5.7.1 BMW ConnectedDrive Store

BMW has developed and tested the ConnectedDrive Store, an application which allows users to buy all available services and vehicle IT functions for a BMW vehicle. The store uses a driver's data, contacts, and places, from settings stored by using cookies, to offer drivers and passengers the best possible services for driving with their BMW vehicles. Cookies are small files that are stored by a website on the user's computer or mobile device which contain information such as personal page settings and credentials.

BMW ConnectedDrive forms the center of an intelligent network of the vehicle, the driver, the passengers, and the outside world. Digital services, smart apps, and assistance systems ensure more comfort, more entertainment, and more security. This includes a variety of vehicle IT functions, such as access to the mobile office, access to social networks, or the feeding of routes from Google Maps from home via the Internet to the vehicle, to name a few of the many possibilities. In general, the digital services offered by the BMW ConnectedDrive Store connect the driver to everything that is important, such as:

- *Send to car:* Via smartphone apps or objectives found on the web, data are transferred seamlessly to the vehicle and the integrated navigation system. Even data in the smartphone calendar, such as stored meetings and desired arrival times, are automatically transferred to the BMW ConnectedDrive services as well as departure recommendations based on the current traffic situation.

- *Time to leave:* Via the iPhone or the Apple Watch®, BMW ConnectedDrive services inform the user about the ideal departure time to reach the next destination at the desired time. The system calculates the proposed departure time according to the whereabouts of the driver and based on real-time traffic data.
- *Last mile route:* On time and relaxed arrival at the appointment is made possible by the last mile route functions from BMW ConnectedDrive. After arriving at the destination, the driver is navigated, via iPhone or combined with Apple Watch, from the parked vehicle to the final meeting location.
- *Personal learned destinations:* The BMW ConnectedDrive service app learns from the driver's usage patterns and is able to automatically add frequently visited destinations into a personal mobility plan. Manual input is, therefore, now no longer necessary as everything can be delivered to the vehicle's integrated navigation system with one click.
- *Remote services:* With the remote functions of the BMW ConnectedDrive service app, different functions in the vehicle can be controlled from a distance, such as locking or unlocking the vehicle. This is a perfect aid in case of a key emergency. Assuming a driver has left his key on a journey abroad in the vehicle and went to a restaurant for lunch. Meanwhile the vehicle locked itself. After returning to his vehicle, the driver noticed the problem. With the help of his smartphone, he calls the BMW ConnectedDrive service in Munich and asks for help. The built-in SIM card in his BMW allows the service people to unblock the vehicle via ConnectedDrive from a distance. The driver can access the vehicle and continue the journey.
- The BMW ConnectedDrive service app also provides, through the customer portal, the ability to retrieve vehicle information, such as the fuel level and potential driving range or the status of windows and doors. In addition, the programmable climate control and charging timer ensure that the BMW is, for example, perfectly preconditioned and fully charged for each ride from Monday through Friday.
  The current location of the vehicle can easily be determined on the map in the BMW ConnectedDrive service app. In addition, if the driver is close, the vehicle can also be found by remotely activating the horn or flashing the headlamps. Thus, the driver is always informed, even from afar, of the vehicle location and can see all of the information by a glance at the smartphone or the smartwatch. To use the functions, a onetime activation of remote services in the BMW ConnectedDrive service customer portal at www.bmw-connecteddrive.com is necessary.

On top, the BMW ConnectedDrive Store also offers the following digital services:

- Connected home.
- Driving profiles.
- Mobile office; see above for more details.
- Music and entertainment.

- Nice travel, arrive relaxed.
- Park info.
- Search, find, discover.
- *Highly automated driving:* BMW Active Assist represents technologies that enable partial and highly automated driving for more safety, comfort, and efficiency. This means that the vehicle completely or partially, in certain situations, takes over the driving task. Therefore, BMW Active Assist has a total of four laser scanners that measure the exact distances to other objects and detect the size and speed as well as the whole environment of the vehicle. The laser scanners are located in front, back, left, and right of the vehicle. Thus, the vehicle gets a view of which areas are passable and free from obstructions. The next major goal of BMW Active Assist is to enable highly automated driving on European motorways with all challenges, such as driving over national borders or driving through construction sites. These highway pilots are expected to be available in serial vehicles by 2020.
- *Intelligent emergency call:* In the event of an airbag deployment, the Intelligent Emergency Call service will send data on an accident and will make an automatic immediate emergency call to the BMW Call Center via the car's installed telephone unit, regardless of the driver's mobile phone. This service functions both domestically and abroad. Specially trained staff will communicate with the caller, in his/her native language, if possible, and inform rescue workers.
- *Real-time traffic information:* Provides the driver with the current traffic situation in real-time. In addition, the system calculates the delays that are to be expected and displays rerouting recommendations. Hence, the driver is always accurately informed about the traffic situation on the planned route and potential alternative routes, and can react to congestion and blocked routes to avoid them.

Other services offered by the BMW ConnectedDrive Store are (Johanning and Mildner 2015):

- *Concierge services:* The BMW ConnectedDrive service offers the service Information Call with the "i" key, for information, the emergency call as Break Down Call with a tool symbol on its button, and an Emergency Call (eCall) function which automatically calls for assistance in case of an accident by providing the accident location. In addition to the call center-related functions, the search for a point of interest (POI), which is the search for an object of interest for different reasons, is part of the concierge services. With regard to the POI, the nearest restaurant, hotel, gas station, hospital, pharmacy, etc. can be found, and route guidance to a parking space close to the location can be given.
- *Online entertainment:* This service offers online downloads of music into the vehicle which can be ordered directly from BMW cooperation partners. The downloaded music can also be stored on the vehicle's hard disk.
- *Remote services:* This includes all vehicle-related IT functions which are all operated remotely by apps.

5.7.2 Mercedes COMAND Online

Mercedes Cockpit Management and Data System (COMAND or COMAND Online) is the brand name of Mercedes' communications and navigation system, which was the first fully integrated telematics system in the automotive industry. COMAND Online offers a solution for Internet connectivity, infotainment, multimedia, voice recognition, and telephony in the vehicle. The actual version is the New Telematics Generation (NTG) 4.5 representing a comprehensive basis for the connected car. In general, Mercedes COMAND Online combines audio (music streaming from the phone, radio, CD/DVD, optional TV reception), telephone, and navigation functions. It also provides an Internet browser and various Internet services, such as (URL15 2017, URL16 2017):

- *Facebook client:* Allows, for example, a quick glance at the pin wall or the news. Specific status messages can also be sent out by COMAND Online by using either preformulated text blocks or user formulated texts.
- *Google local search:* With access to Google live traffic information, Google Maps, and Google Street View™.
- *Parking information*.
- *Weather maps:* Germany and Europe.

The entire Internet connection runs via the Bluetooth-connected smartphone. Mercedes-Benz chose the option of a firmly built-in SIM card. But the user can, with the optional telephone module with Bluetooth (SAP Profile), insert a separate SIM card in the car and let it run the broadcast traffic.

Similar to other automakers, an emergency call function is part of the equipment. After triggering the airbags or belt tensioners the Mercedes emergency call center is notified by command COMAND Online mobile phone or telephone module which attempts to establish a voice connection to the occupants, and transmits the GPS location of the vehicle. The driver can also manually handle the emergency.

A USB port is fitted in the center armrest as a standard feature. With the optional special equipment, SPLITVIEW, the driver and front passenger can simultaneously use different media on the COMAND Online display. While the vehicle driver has the information on the control and display system in his/her view, the passenger can, for example, watch a movie on the same screen.

Mercedes COMAND Online also offers the following features:

- *Internet and apps:* Specific features such as:
  - *HRS hotel finder and cross-trade information:* Providing information on the current land traffic rules, maximum speeds, tolls/toll road, and more.
  - *News ticker:* Offers the usual selection by issues, such as economic or domestic topics. If the driver finds a message particularly interesting, he/she can also send a message by mail and can even have it read out loud.
  - *Stock market info*

- *Internet browser:* Web browser operates only when the vehicle is stationary for reasons of road safety, but the engine must be running. During the trip, only certain Mercedes apps, such as the weather display or the Google local search function, work. The exception: the passenger can surf the Internet through SPLITVIEW.
- *Web radio:* In order to receive radio over the Internet and become independent of the radio stations that can be received via the FM band, more music at the current location, sports, podcasts, and more can be searched while driving, as well as a search for the driver's favorite stations.
- *Navigation:* The user interface of the navigation system is functional; it reliably guides the driver. The driver can choose and switch between different map representations (2D, 3D, etc.) and specify what information to display on the screen, including the actual directions. Alternative routes can be determined at any time. Simple route information, such as the arrival time and the distance to the target, can be displayed and read aloud by voice command. For highway exits, there is a split screen wizard: left continues with the route; right, a separate window is displayed with a stylized representation of the exit. Route calculation and determination of traffic incidents are still provided on the basis of Navteq's TMC Pro information. Mercedes-Benz replaced the traffic calculation by embedding TomTom LIVE.
- *Voice control and telephony (hands-free):* With the voice control system, LINGUATRONIC, audio, telephone, and navigation functions can be controlled. On the radio or the CD, the station or the next track can be changed by voice. Targets for navigation can be entered by voice, and route information can be read out, such as travel time and arrival time. The traffic information, however, cannot be called by a voice command; it must be activated via the Mercedes COMAND Online controller.
- *Radio, CD, and audio streaming:* Audio streaming and playing songs that are on the driver's smartphone are possible via Mercedes COMAND Online. For this, the smartphone must be connected to Mercedes COMAND Online to play music again separately as a Bluetooth audio device.
- *Safety assistants:* Mercedes has always been a pioneer in passive and active safety. For example, DISTRONIC PLUS (Mercedes name for ACC), which automatically maintains a level of safety to vehicles ahead so that the vehicle brakes by itself, if necessary, and automatically follows the vehicle ahead without the driver having to touch the steering wheel.
- *Lane departure warning (LDW) and lane change assistant (LCA):* Also included.

In addition, the Mercedes Intelligent Drive system demonstrates the full range of advanced driver assistance functions and shows what is already possible in high automation, both on cross-country journeys and in city traffic; but extensive preparations are necessary before autonomous driving is available and widely deployed. This includes creating HD maps, as there is no existing material with the required precision (URL17 2017). HD mapping technology consolidates aerial imagery, aerial LiDAR data, and mobile (driven) LiDAR data to create standardized, high-precision 3D base maps focusing specifically on self-driving vehicles with an accuracy of less than 7 cm of the absolute range. Mercedes embedded a high-precision map together with a stereo camera scanning the roads along the route and gathering image data. High-precision GPS information is combined with positional data producing a highly detailed representation of the roads, which is more like a 3D model of the world instead of a traditional map. To improve the accuracy, the route will be driven several times in order to provide the necessary depth of data, however, the data recorded will not necessarily be as up-to-date as it needs to be because the vehicle might not be driven on the same roads again for some time. The actual development concept improving the accuracy of the maps was completed with the aid of self-learning algorithms. The initial aim was to have a vehicle create its own high-precision map. Test vehicles were fitted with the necessary sensors and computer equipment. Drive by drive, they gathered the data from which an ultraprecise representation of the road and its immediate surroundings was put together (URL15 2017).

5.7.3 HERE: Digital Maps for Fully Autonomous Driving

Self-driving must be able to determine their position exactly. Thus, high-precision maps that are updated and made available via the Internet have been created to help in doing so. Hence, fully autonomous driving can be introduced as an additional assistance function that, in many situations, will bring in high-level support on trips, in case of traffic jams, and other unforeseen situations. But to some extent, it is also the culmination of all of the previous safety innovations targeted at accident-free driving, a vision still in the future.

In autonomous, driving the vehicle follows the vehicle ahead, even around gentle bends in the road, detecting speed limits along the way and making sure they are not exceeded. But the as yet unsolved problem for autonomous driving is the transition period with mixed traffic, when autonomous and nonautonomous vehicles will simultaneously share the same road infrastructure.

A few years ago, some automakers supposed that autonomous vehicles might be able to find out their position themselves using today's low-definition maps available in turn-by-turn navigation devices and apps, assuming that sensors would do the rest. They hypothesized that with clear road markings, visual sensors could keep autonomous vehicles safely within their lanes and even spot the solid or dotted lines that indicate stop signs and exits. But the problem is that autonomous vehicles need to operate safely in all environments because road markings can wear away or disappear under snow.

Modern LiDARs may not be as accurate as needed in those conditions (see Sect. 4.9.2.2). LiDARs calculate distances by illuminating a target with a laser light and measuring the time it takes for the light to bounce back to the source. Radar is the same but based on radio waves (see Sect 4.9.2.1). In autonomous vehicles, LiDAR and radar have an effective range of around 50 m (164 ft) but that can shrink significantly in rain or when objects are obscured by vehicles ahead. Even the most advanced vehicle traveling at highway speeds can sense objects only about 1.5 s ahead.

Therefore, self-driving vehicles may use as many sensors as possible, but without an ultraprecise HD map, the vehicle does not have the ability to locate itself precisely (URL18 2016). When turning, for example, the autonomous vehicle cannot approximate the point at which the steering wheel should be turned, an area in which human drivers are experts at making adjustments. Digital driving instructions need to be ultraprecise. In addition to the map data, various sensors on the self-driving vehicle will also provide it with important information about its environment, which is essential for autonomous driving. Another example is an error of a couple of meters which could place an autonomous vehicle on the wrong side of a road. Commercial GPS systems are accurate only to around 5 m (16 ft) but can be wrong by 50 m (164 ft) in urban areas and fail completely in tunnels. However, HD maps include a so-called localization layer that works with a variety of sensors to position a vehicle within centimeters.

HERE, a company which provides mapping data and related services to individuals and companies, owned by a consortium of German automotive companies, namely, Audi, BMW, and Daimler, is experimenting with several such layers for their HD map. One involves extracting features such as bridges, road signs, and guard rails from images shot by the mapping vehicle and then comparing them to what the vehicle sees through its own cameras. Google, which has long been testing autonomous vehicles, builds its localization layer in a fashion similar to HERE. HERE is also trying out a system that uses artificial intelligence (AI) to identify features from cameras and LiDAR technology to collect billions of 3D points and model road surfaces down to the number of lanes and their width. It can now position an autonomous driving vehicle on the road to an accuracy of within 10–20 cm. HERE captures important details, such as the slope and curvature of the road, lane markings, and roadside objects, such as sign posts, including what that signage denotes. AI systems in HERE can identify road signs and traffic lights from photos. Humans then modify and optimize the results and check for errors. Assuming that current maps are not completely up-to-date, the next task will be to keep the map as accurate as possible. However, vehicle sensors must be robust enough to handle existing discrepancies. A partial solution is to use the digital traces of millions of people using smartphones and connected in-car systems for navigation.

HERE receives around two billion individual pieces of such data daily, comprised of a vehicle’s location, speed, and heading, for their ongoing development of HD maps. This data also serves as the foundation for real-time data about the road environment and modeling road surfaces down to the number of lanes and their widths. It captures important details such as the slope and curvature of the road, lane markings, and roadside objects such as sign posts, including what that signage denotes, a technology patented in 1999 by HERE and called Electronic Horizon. It enables a vehicle, for example, to adjust the cruise control or to be more fuel efficient based on road attributes included in a map, such as the slope and curvature of the road, traffic signs, and lane information.

Meanwhile, HERE's Electronic Horizon is an embedded software solution that processes and displays detailed road network information from the cloud to help the vehicle's ADAS make more intelligent and informed decisions without driver involvement. The software translates map information with detailed road characteristics into actionable data for the vehicle. This information is used to provide both the vehicle and the driver with relevant predictive information that can assist driving decisions and enhance vehicle functionality, thereby extending the vehicle's awareness beyond what its onboard sensors can see. HERE's Electronic Horizon enables the map to act as an additional sensor for in-vehicle ADAS and highly automated driving solutions (URL19 2017).

These real-time updates could be sent to the vehicle in advance if it was driving along a road where, e.g., new potholes had appeared. While sensors can inform the vehicle about its immediate surroundings, advance warnings from real-time map data allow the vehicle to react to changes in the road in a timely manner.

HERE also announced a significant step forward in efforts to establish a global standard for vehicle-to-cloud data with regard to the design of a universal data format called SENSORIS. It was initiated by HERE in June 2015 when the company published the first open specification for how vehicle sensor data gathered by connected cars could be sent to the cloud for processing and analysis. HERE has now submitted the design for a universal data format (SENSORIS) to ERTICO-ITS Europe, the European public-private partnership for intelligent transport systems. ERTICO-ITS Europe has agreed to continue using SENSORIS as an Innovation Platform to evolve it into a standardized interface specification for broad use across the automotive industry. Defining a standardized interface for exchanging information between the in-vehicle sensors and a dedicated cloud, as well as between clouds, will enable broad access, delivery, and processing of vehicle sensor data, enable easy exchange of vehicle sensor data between all players, and enable enriched location-based services, which are the key to mobility services as well as automated driving. To date, 11 major automakers and supplier companies have joined the SENSORIS Innovation Platform under the coordination of ERTICO. They are AISIN AW, Robert Bosch, Continental, Daimler, Elektrobit, HARMAN, HERE, LG Electronics, NavInfo, PIONEER, and TomTom. More organizations are expected to join the platform soon.

Furthermore, HERE outlined its Open Location Platform which intends to harness real-time data generated by the onboard sensors of connected vehicles to create a live depiction of the road environment. Drivers will be able to access this high-quality view of the road through four services that provide information on traffic conditions, potential road hazards, traffic signage, and on-street parking. The goal is to ensure that drivers have more accurate and timely information with which they can make better driving decisions. HERE plans to make the services commercially available to any customers both within and outside the automotive industry by the first half of 2017. The services are:

- *HERE real-time traffic:* The next generation of HERE's live traffic service, HERE real-time traffic, provides real-time traffic information enhanced with the new streams of data. The result is a high-quality, low latency feed showing hard braking alerts; jam tail warnings, with improved coverage and positional accuracy; and traffic flow, with more precise and granular data (also for lower-class arterial roads).

- *HERE hazard warnings:* Service that provides high-quality, near real-time information about potential hazards, including accidents and extreme weather events, such as slippery roads and reduced visibility. Because this service is fueled by real-time, rich sensor data, the validity of the hazards is of high quality and more trustworthy than competing services.
- *HERE road signs:* Service that provides near real-time traffic signage information, including permanent and temporary speed limits, which is useful for both the driver as well as for cars equipped with connected ADAS, such as adaptive cruise control.
- *HERE on-street parking:* Service that provides information to drivers showing roads where parking is or is not permitted for each side of the street, availability predictions and time-to-park estimations for each street and at a particular time of day based on historical driver data, and streets with paid, free, or lower-priced parking options.

HERE plans to license these four services to any automaker, municipality, road authority, smartphone maker, or app developer. As connectivity and vehicle sensor technologies become more pervasive across the industry, HERE also plans to enable other automakers to contribute their vehicle data.

The data HERE plans to use from Audi, BMW, and Mercedes-Benz vehicles in the provision of these services will be anonymized with no personal identifiers so as to ensure privacy of drivers (URL18 2016; URL20 2017).

5.8 Exercises

What is meant by the term *cyber-physical system*?
Describe the characteristics of a cyber-physical system.
What is meant by the term *cyber component*?
Describe the characteristics of a cyber component.
What is meant by the term *physical component*?
Describe the characteristics of a physical component.
What is meant by the term *wireless sensor network*?
Describe the characteristics of a wireless sensor network.
What is meant by the term *flat network architecture*?
Describe the characteristics of a flat network architecture.
What is meant by the term *Bellman-Ford algorithm*?
Describe the characteristics of the Bellman-Ford algorithm.
What is meant by the term *Dijkstra Algorithm*?
Describe the characteristics of the Dijkstra algorithm.
What is meant by the term *shared sensor network*?

Describe the characteristics of a shared sensor network.
What is meant by the term *human-machine interface*?
Describe the characteristics of a human-machine interface.
What is meant by the term *cyber-physical systems roadmap*?
Describe the characteristics of a cyber-physical systems roadmap.
What is meant by the term *cyber-physical systems design recommendations*?
Describe the characteristics of cyber-physical systems design recommendations.
What is meant by the term *requirements characteristics*?
Describe the characteristics of requirements characteristics.
What is meant by the term *requirements engineering*?
Describe the characteristics of requirements engineering.
What is meant by the term *interoperability requirement*?
Describe the characteristics of an interoperability requirement.
What is meant by the term *real-time requirements*?
Describe the characteristics of real-time requirements.
What is meant by the term *control system*?
Describe the characteristics of a control system.
What is meant by the term *proportional control*?
Describe the characteristics of proportional control.
What is meant by the term *integral control*?
Describe the characteristics of integral control.
What is meant by the term *derivative control*?
Describe the characteristics of derivative control.
What is meant by the term *proportional, integral, and derivative control*?
Describe the characteristics of proportional, integral, and derivative control.
What is meant by the term *vehicle tracking*?
Describe the characteristics of vehicle tracking.
What is meant by the term *fleet management*?
Describe the characteristics of fleet management.
What is meant by the term *Internet of Things*?
Describe the characteristics of the Internet of Things.
What is meant by the term *Internet Protocol version 6*?
Describe the opportunities of this manifold of addresses.
What is meant by the term *RFID*?
Describe the characteristics of RFIDs.
What is meant by the term *telematics*?
Describe the characteristics of telematics.
What is meant by the term *carsharing*?
Describe the characteristics of carsharing.
What is meant by the term *vehicle insurance*?
Describe the characteristics of vehicle insurance.
What is meant by the term *smart ticketing*?
Describe the characteristics of smart ticketing.
What is meant by the term *machine-to-machine telematics*?
Describe the characteristics of machine-to-machine telematics.

What is meant by the term *infotainment*?
Describe the characteristics of infotainment.
What is meant by the term *connected car?*
Describe the characteristics of connected cars.
What is meant by the term *Automotive Cloud Service System?*
Describe the characteristics of an Automotive Cloud Service System.
What is meant by the term *HTML5?*
Describe the characteristics of HTML5.
What is meant by the term *business models in connected cars?*
Describe the characteristics of business models in connected cars.
What is meant by the term *connected car platform?*
Describe the characteristics of connected cars platforms.
What is meant by the term *connected car architecture?*
Describe the characteristics of connected cars architectures.
What is meant by the term *connected car gateway?*
Describe the characteristics of connected cars cloud-based services.
What is meant by the term *Connected Car Reference Platform?*
Describe the characteristics of the Connected Cars Reference Platform.
What is meant by the term *OEM*?
Describe the characteristics of an OEM.
What is meant by the term *Tier 1*?
Describe the characteristics of a Tier 1.
What is meant by the term *connected car in the cloud?*
Describe the characteristics of connected cars in the cloud.
What is meant by the term *BPaaS*?
Describe the characteristics of BPaaS.
What is meant by the term *IaaS*?
Describe the characteristics of IaaS.
What is meant by the term *PaaS*?
Describe the characteristics of PaaS.
What is meant by the term *SaaS*?
Describe the characteristics of SaaS.
What is meant by the term *autonomous vehicle*?
Describe the characteristics of an autonomous vehicle.
What is meant by the term *highly automated driving?*
Describe the characteristics of highly automated driving.
What is meant by the term *eCall?*
Describe the characteristics of eCall.
What is meant by the term *intelligent drive?*
Describe the characteristics of intelligent drive.
What is meant by the term *LiDAR sensor*?
Describe the characteristics of a LiDAR sensor.
What is meant by the term *laser sensor*?
Describe the characteristics of a laser sensor.
What is meant by the term *radar sensor*?

Describe the characteristics of radar sensor.
What is meant by the term *camera sensor*?
Describe the characteristics of Camera Sensors.
What is meant by the term *GENIVI Alliance*?
Describe the characteristics of the GENIVI Alliance.
What is meant by the term *BMW ConnectedDrive Store*?
Describe the characteristics of BMWs ConnectedDrive Store.
What is meant by the term *Mercedes COMAND Online*?
Describe the characteristics of Mercedes COMAND Online.
What is meant by the term *HERE*?
Describe the characteristics of HERE.
What is meant by the term *digital map*?
Describe the characteristics of a digital map.

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